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WELD OVERLAYING FOR CORROSION RESISTANCE IN COAL GASIFICATION ATMOSPHERES

Final Report for Period August 15, 1977—August 15, 1979

By
Edward P. Sadowski

Work Performed Under Contract No. AC01-77ET10496

Inco Research & Development Center, Inc.
Suffern, New York

U. S. DEPARTMENT OF ENERGY

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INCO

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FINAL REPORT

For Period August 15, 1977 - August 15, 1979

- by -

Edward P. Sadowski

INCO RESEARCH & DEVELOPMENT CENTER, INC.
A UNIT OF INCO CORPORATE R & D
STERLING FOREST
SUFFERN, NY 10901

PREPARED FOR DEPARTMENT OF ENERGY
MER/MATERIALS BRANCH
UNDER CONTRACT NO. EF-77-C-01-2621

FOREWARD

This is a final report on the work performed under Contract No. EF-77-C-01-2621 during the period August 15, 1977 through August 15, 1979. The work was administered by the Fossil Energy Division of the DOE with Mr. S. J. Dapkunas as Project Manager. The report was prepared by E. P. Sadowski, Project Manager.

The work was performed under the direction of E. P. Sadowski as principal investigator. The various functions were carried out by the following personnel:

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The exposures in the coal gasification atmosphere were made at Martin-Marietta, Denver, CO, under sub-contract. The Project Manager at Martin-Marietta was Mr. M. E. Wakefield.

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ABSTRACT

Tests by others have indicated that at least 25% chromium is required to obtain long time protection in coal gasification atmospheres at 982°C (1800°F). High aluminum content may also be beneficial for this service.

Two nickel-base filler metals which were designed to deposit high Cr and Cr-Al contents were used to surface Types 304L and 310 stainless steel (SS) and INCOLOY* alloy 800H. These weld overlays were compared to AWS-ER309 deposited on 304L. The filler metals were INCONEL* Filler Metal 72 (44%Cr-0.7%Ti-Bal Ni) and an experimental filler metal, R139 (31%Cr-15%Fe-3.25%Al-Bal Ni). Single and double layers were desposited successfully using three weld processes: submerged-arc, gas metal-arc and gas tungsten-arc with a hot wire addition.

Cr contents of 39-41.5% were obtained in the INCONEL Filler Metal 72 (FM72) double layer overlays and the single layer overlays contained 34-38% Cr. A combination of 30-34% Cr and 2.8-3.2% Al was obtained in the R139 double layer overlays deposited by inert gas processes. The compositions of the deposited overlays were affected by the compositions of the filler metal and substrate, the percentage dilution, the percentage recovery of elements across the arc, and the composition of the flux used with the submerged arc welding process.

All surfaced substrates had better corrosion resistance than the unprotected substrates when exposed for 1000 hours in a coal gasification atmosphere (CGA) at 982°C (1800°F). The CGA consisted of 12% CO_2, 18% CO, 24% H_2, 5% CH_4, 1% NH_3, 1% H_2S and balance H_2O. The INCONEL Filler Metal 72 overlays provided somewhat better corrosion resistance than the R139 overlays, although both had corrosion resistance better than the most corrosion resistant of the unwelded specimens in this test, 310SS. A protective layer of Cr_2O_3 was formed on the INCONEL Filler Metal 72 and R139 overlays when exposed to the CGA. Also, the R139 overlays deposited by the inert gas processes formed an incomplete layer of Al_2O_3. The extent of corrosion attack observed on the unprotected substrates indicated that the test conditions were very severe.

The different filler metals, substrates or welding processes evaluated did not affect the "as-welded" room temperature tensile properties of composite specimens of overlay and substrate. The 1000-hour stress rupture strength at 982°C was, however, affected by substrate and weld process. The highest stress rupture strength was obtained with the INCOLOY alloy 800 H weldments.

*Trademark of the Inco family of companies.

The room temperature yield and tensile strengths of all weldments decreased after exposure to the CGA. Tensile ductility of most weldments also decreased. The 310SS weldments had the largest decrease in tensile elongation.

The INCONEL Filler Metal 72 and R139 overlays increased in hardness and the AWS-ER309 overlays decreased in hardness after exposure to the CGA. The hardness response of the INCONEL Filler Metal 72 overlays was not affected by the weld process used for deposition.

The greatest change in the distribution of Cr and Ni after exposure was obtained in the INCONEL Filler Metal 72 and R139 overlays. The changes in distribution are probably associated with the precipitation of the alpha chromium phase.

1.0 OBJECTIVE

The objective of this program was the development and evaluation of weld deposited overlays to provide resistance to corrosion in coal gasification atmospheres at 982°C (1800°F).

A 44% Cr and a 31% Cr-15%Fe-3.25%Al nickel-base alloy were overlaid onto lower alloyed substrates in order to provide protection from the corrosive atmosphere. These materials were compared to a conventional stainless overlay material, AWS-ER309.

After the welding procedures were established, the effects of a 1000-hour exposure of weldments in a CGA at 982°C (1800°F) on corrosion, metallurgical stability, mechanical properties and the diffusion of major alloying elements were determined.

2.0 SCOPE

The program was divided into four tasks as follows:

2.1 Task I - Development of Weld Deposition Procedures and Welding of Overlays

Weld deposition procedures were developed for overlaying with two high chromium-nickel base filler metals. The 44% Cr and 31%Cr-15%Fe-3.25%Al filler metals were overlaid on three lower alloyed substrates with three welding processes. AWS-ER309 was overlaid on 304L stainless steel and used as a standard.

2.2 Task II - Exposure to a Coal Gasification Atmosphere

A test cell was constructed at Martin-Marietta, Denver and weldments were exposed to a coal gasification atmosphere for 1000 hours at 982°C (1800°F). The composition of the inlet gas was CO_2-12%, CO-18%, H_2-24%, CH_4-5%, NH_3-1%, H_2S-1% and H_2O balance. The weldments exposed were 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 were tested. Data was obtained on the extent of corrosion, change in elemental distribution, and mechanical properties as a result of exposure to a CGA.

Stress-rupture properties were determined in air at 1800°F for time periods up to 1000 hours on "as welded" composite specimens.

2.4 Task IV - Collate and Analyze Data and Final Report

3.0 RESULTS AND DISCUSSION

3.1 Task I - Development of Weld Deposition Procedures and Welding of Overlays

Weld deposition techniques and procedures were established for three welding processes. The processes were gas metal-arc (GMAW), submerged-arc (SAW) and gas tungsten-arc with a hot wire addition (GTAW-HW). Three substrates were overlaid with INCONEL Filler Metal 72 (44%Cr-0.7%Ti-bal Ni) and an experimental filler metal designated R139 (31%Cr-15%Fe-3.25%Al-bal Ni). The substrates were AISI 304L and 310 stainless steels and INCOLOY alloy 800H. The AWS-ER309 (24%Cr-13%Ni) was overlaid on 304L to serve as a standard. Single and double layers were deposited on both sides of the substrate. High integrity weldments were obtained with all filler metals, although some of the R139 weldments showed some minor fissuring. The materials for welding, welding procedures, results of examination for integrity, measurement of percentage dilution of the filler metal by the substrate, and percentage recovery of the alloying elements in the deposit composition are discussed below.

3.1.1 Materials

The compositions of the substrates and filler metals are given in Table 1. The 25.4 mm (1 inch) thick plates were received in the hot rolled annealed and pickled condition.

The R139 and some of the INCONEL Filler Metal 72 were melted as 45 kg (100 lb) vacuum melts. The 12.7 x 12.7 x 40.6 cm (5 x 5 x 16 inch) ingots were reduced to 1.55 mm (.062 inch) and 2.36 mm (.093 inch) diameter wire at either IRDC or Huntington Alloys, Inc. (HAI). The remainder of the filler metal was obtained from a commercially melted heat from HAI.

3.1.2 Welding Processes

A description of the welding processes used and the advantages of each process are given below.

3.1.2.1 Submerged-Arc. In this process, which uses a continuous wire, the arc and molten metal are shielded by an envelope of molten flux and a layer of unfused granular flux particles. In our work, we used ARCOS S-4 flux for the AWS-ER309 filler wire and INCOFLUX* 6 for the nickel-base filler metals. These fluxes were chosen based upon previous experience with stainless steels and nickel-base alloys as well as trial runs with other fluxes.

*Trademark of the Inco family of companies.

The SAW process has many advantages and is the most widely used process for surfacing. It has high deposition rates and deposits are generally of high quality. There is no spatter that requires cleaning and the absence of ultra-violet radiation of an exposed arc is advantageous in the shop.

The power supply and equipment used for making the SAW process weldments is shown in Figure 1. The AWS-ER309-304L weldments are shown in Figure 2 (single layer) and Figure 3 (double layer). A cross section of the double layer overlay is shown in Figure 4.

3.1.2.2 Gas Tungsten-Arc With Hot Wire. The gas tungsten-arc process is an arc welding process wherein coalescence is produced by heating with an arc between a non-consumable tungsten electrode and the workpiece. Shielding is obtained from a gas or gas mixture. In the present work argon was used. In the hot wire process, the filler metal protruding from the contact tube is preheated by resistance heating for easier melting. The arc melts the desired amount of base plate material, and filler metal is added to the rear of the arc in the resulting molten pool. The hot wire entry point is slightly over half way toward the rear of the puddle(1,2). The use of hot wire permits higher deposition rates with automatic processes and maintains all the advantages of conventional gas tungsten-arc welding. An advantage in our work is that the inert gas process results in a higher transfer of volatile elements such as Al across the arc.

The power supply and equipment used to deposit the overlays with this process are shown in Figure 5. A close-up of the position of the filler metal wire in relation to the tungsten electrode is shown in Figure 6. The completed AWS-ER309-304L double layer weldment is shown in Figure 7. A cross section of the overlay is shown in Figure 8.

3.1.2.3 Gas Metal-Arc. This process is an arc welding process wherein coalescence is produced by heating with an arc between a continuous filler (consumable) electrode and the workpiece. Shielding is obtained entirely from an externally supplied gas or mixture of gases. The shielding gas protects the fluid metal from oxidation or contamination by the surrounding atmosphere. In our work we also used a trailing shield to prevent oxidation. The advantages of this process are low cost and high deposition rates. The gas metal-arc welds were made with the same power supply and equipment (Figure 1) as was used for the submerged-arc welds, except that a gas metal-arc torch was used. The double layer overlay made with the AWS-ER309 filler metal on Type 304LSS using the GMAW process is shown in Figure 9. A macro view of the overlay is shown in Figure 10.

Examples of the surface appearance of overlays deposited with INCONEL Filler Metal 72 and R139 are given in Figures 11 and 12.

3.1.3 Welding Parameters

The welding parameters established for each process are given in Table 2. The parameters were chosen to deposit an overlay with good bead contour and appearance having a level surface about 4.8 mm (3/16 inch) thick per layer. A straight line oscillation cycle was used in making the overlays(3). The wire speed and amperage were adjusted on the R139 SAW process weldments for the two different diameter wires in order to obtain the same thickness of deposits for both diameter wires.

The 360 x 360 x 25.4 mm (14 x 14 x 1 inch) base plates for all welds except W6180 and W6181 were welded to a 79 mm (3-1/8 inch) thick strongback before depositing the overlay to prevent distortion. This was done after some distortion was observed on welds 6180 and 6181 which were restrained with bolts and stainless steel plates. INCO Weld A* welding electrode was used to weld the substrates and strongbacks together.

The identification of all weldments in relation to process, substrate and filler metal are given in Table 3. The thicknesses of the overlays are given in Table 4.

3.1.4 Inspection

The integrity of the weldments was established by Dy-chek, visual examination at 10X of etched cross-sections of bend specimens before bending and by 180° guided bend tests.

Duplicate side bend tests were made on specimens (Figure 13) which were machined longitudinal and transverse to the welding direction. Cross-head speed was 12.7 mm (0.5 inches) per minute. The bend ductility was limited to approximately 20% in 25.4 mm (1 inch) by the specimen design. The criterion for passing the bend test was a 180° bend without the formation of a 3.2 mm (1/8 inch) defect in the overlay.

3.1.4.1 Integrity of AWS-ER309 and INCONEL Filler Metal 72 Overlays. All AWS-ER309 and INCONEL FM-72 weldments were free from visual defects and passed the bend test successfully. Examples of the appearance of the bend specimens are given in Figures 14 through 16. The samples shown were from the specimens machined transverse to the direction of welding which is considered to be the more severe test.

*Trademark of the Inco family of companies.

Some Dy-chek indications were observed on the GMAW overlays of INCONEL Filler Metal 72 on 304L stainless steel. The indications were observed at overlaps of some passes and were very fine and shallow. As discussed above, the overlays were free from fissuring after the 180° bend tests and no problem is anticipated from these minor defects.

Further evidence of the integrity of the INCONEL Filler Metal 72 overlays are shown in Figure 17. Very little fissuring was observed after room temperature tensile testing.

3.1.4.2 Integrity of R139 Overlays. Surface defects were observed by Dy-chek on three SAW process overlays: welds 6206, 6207 and 6218. Fissuring was observed by visual examination at 10X of the cross sections of specimens before bending in seven of the R139 weldments.

The surface defects on W6206 and 6207 were cosmetic, whereas two cracks about 9.5 mm (3/8 inch) long and a tunneling defect were observed on W6218. The tunneling defect was attributed to moisture in the flux. The defects were repaired using the GTAW process and subsequently shown to be clear after Dy-checking.

The fissuring observed before bending in specimens from welds 6209, 6210, 6211, 6220 and 6321 was minor. The defects ranged from 0.5 to 1.8 mm (.02-.07 inch). Specimens from these weldments passed the 180° bend test successfully. Examples of some of the bend test specimens are given in Figures 18 through 20.

Mixed results were obtained on bend tests from welds 6206, 6208 and 6218 (Figures 18 and 20, Table 5). The defects observed after bending in W6206 were associated with the repairs made with the GTAW process for cosmetic reasons. An example of a defect observed below the surface in the fusion area of the GTAW process bead and the original SAW process deposited overlay (before bending) is shown in Figure 21.

Fissuring was also observed in welds 6208 and 6218 before testing. The defects in W6208 appeared to be associated with an oxide which had formed on the first layer of the double layer overlays. Three of the four specimens from this GTAW-HW weldment passed the bend test successfully.

The fissuring that was observed in W6218 before bending was confined to one of the two overlays on each specimen and was predominantly in the upper layer. Eight fissures in the range of 0.50 to 3.8 mm (.02-.15 inch) were observed in a 152 mm (6 inch) length of each of the transverse specimens before bending. As stated earlier, the

surface of this weldment was repaired after dye penetrant inspection. The longitudinal specimens had excellent bend test results, whereas the transverse specimens had 3.2 mm (1/8 inch) cracks at bend angles of 54 and 109 degrees in the defective layer of the overlay. The sound overlay remained defect free. The defects appeared to be associated with slag inclusions.

3.1.5 Dilution

When dissimilar alloys mix in a weld pool problems can occur that originate from change in composition and changes in metallurgical structures. The American Welding Society defines dilution as a change in chemical composition of a welding filler metal by the admixture of the base metals (as in a single layer overlay) or previously deposited weld metals (as in a multilayer overlay). It is normally measured by the percentage of the base metal or previously deposited weld metal in the weld bead(4,5). For example, a 30% dilution factor for a 50% Cr filler metal and a 25% Cr base metal with 100% recovery would result in 42.5% Cr in the deposit (0.7 x 50 + 0.3 x 25). Since our objective was to deposit high alloy overlays, low dilution values were preferred.

The control of dilution is affected by the apparatus selected for welding and by welding techniques. Penetration and width of the weld can be changed by changes in welding parameters (travel speed, current and voltage) and by oscillation of the electrode holder.

The method of calculating the % dilution of the overlays on the present work is given in Figure 22(5). The effects of weld process on % dilution for each filler metal and substrate are given in Table 6. The values for the double layers are for overall dilution even though the dilution of each layer would be the same as for the single layer. The second layer would be diluted by the first layer deposited rather than the base plate. The lowest dilution was obtained with the R139 filler metal. This was attributed to the transfer characteristics of the R139 filler metal which had a more globular spray than the AWS-ER309 and INCONEL Filler Metal 72 when deposited under the same welding conditions. The SAW process gave the least dilution with AWS-ER309 and INCONEL Filler Metal 72. The least dilution for R139 was obtained with the GMAW process.

3.1.6 Composition of Overlays

The compositions of the deposited overlays (Table 7) were affected by the composition of the filler metal and substrate, the % dilution, the % recovery of elements across the arc and the flux composition used with the SAW process.

The chemical compositions of the overlays were obtained by x-ray fluorescence, wet analyses and combustion. Cr, Ni, Mn, Si, Al, Ti and Fe were determined by x-ray fluorescence, P by wet analysis and C and S by combustion. The x-ray fluorescence analyses were obtained on the top surface of the overlay after suitable preparation.

3.1.7 Recovery

The % recovery of elements (Table 8) was established by calculating the theoretical composition of the overlays (Table 9) from the dilution measurements and comparing the theoretical value to the analyzed value. The method of calculation of the theoretical values is given in Table 10.

The % recovery of the major elements, as related to welding process, substrate and filler metal are given in Tables 11 through 17. Analysis of these data led to the observations listed below. (1) Virtually all Cr and Ni and higher Fe than was calculated theoretically were recovered regardless of welding process. (2) The recovery of Si was affected by weld process. With the SAW process, an increase of 2-10 times was obtained and the greatest increase was obtained with R139. The increase was probably associated with the flux used with this process. The GMAW process generally resulted in higher Si contents than expected but to a lesser degree than with the SAW process. The results obtained with the GTAW-HW process were inconsistent. (3) Essentially all Mn was recovered or there was an increase in Mn with all processes except for the AWS-ER309 overlays. In general, the SAW process double layers and INCONEL Filler Metal 72 showed the highest recoveries. A different flux was used for AWS-ER309 which probably accounts for the differences observed. (4) The recovery of Ti was inconsistent. In most cases, Ti was not fully recovered; the exceptions were R139 on 304L with the SAW and GMAW processes. The greatest loss was with INCONEL Filler Metal 72 and the SAW process. (5) No consistent effect was observed with the recovery of C, although in most instances, a higher carbon content was obtained than was expected. The most consistent carbon recoveries were obtained with R139 and the SAW process. It should be noted that the carbon levels we are working with are very low and any small differences in analyses could result in a large difference in % recovery. (6) The recovery of Al from the R139 filler metal, which was believed to be necessary for corrosion resistance, was affected by the welding process. The inert gas processes gave relatively high recoveries, whereas the SAW process gave low recoveries (Table 18). The double layers were effective in obtaining recoveries between 88 and 94%. An aluminum-like coloration was observed after welding on the SAW process slag which was in contact with the weld metal. The Al probably reacted with the flux and remained in the slag.

The importance of welding process on the recovery of aluminum is shown in Table 18. Although the GTAW-HW process had much higher dilution than the SAW process, the Al contents of the deposits were much higher due to the higher recovery with this inert gas process.

3.1.8 Distribution of Elements

The distribution of selected elements was determined on the cross-sections of weldments using an Applied Research Laboratory electron probe microanalyzer in conjunction with a MAGIC program on a Data General Computer, Model Eclipse S-200. Generally, the concentrations were measured from a point about 0.025 mm (0.001 inch) below the surface in one mm (.04 inches) intervals to a point just before the apparent fusion line, then in 0.1 mm (0.004 inch) intervals to an arbitrary distance just beyond the fusion line and finally in the substrate about 5 mm (.20 inches) from the fusion line. A point counting technique was used.

The elements which were determined were Ni, Cr,. Mn, Si, Fe, Al and Ti. Initially, S was determined on several weldments but was discontinued when it was found that differences were small between points. The determination of Al and Ti profiles was limited to R139 and INCONEL Filler Metal 72 weldments. The results are given in Tables 19 through 39 and Figures 23-45.

A feature observed in most composition profiles is that the difference in composition on either side of the interface (fusion line) was a very drastic one from overlay composition to substrate composition. Also, there was, in general, considerable fluctuation in composition in the overlay in the area immediately adjacent to the fusion line with a relatively high value in alloy content being obtained about 0.1-0.2 mm (.004-.008 inch) from the interface (fusion line).

3.1.8.1 Effect of Filler Metal. The distribution of Cr for each filler metal, welding process and substrate is shown in Figures 23-25. As expected, the Cr level of the overlays was directly related to the Cr content of the filler metal. That is, the highest Cr content was obtained with INCONEL Filler Metal 72 and the lowest with AWS-ER309.

The most uniform distribution on 304L was obtained with the AWS-ER309 and R139 filler metals (Figure 23). Reasonably uniform distribution of Cr was obtained with both INCONEL Filler Metal 72 and R139 when deposited on 310 stainless steel (Figure 24) and INCOLOY alloy 800H (Figure 25) with all processes. Exceptions were in the first layer of R139 deposited on 310SS by the GMAW process (Figure 24) and on INCOLOY alloy 800H when deposited by the GTAW-HW process (Figure 25).

The effects of weld process and substrate composition on the distribution of the elements in the overlays deposited with each category of filler metal are discussed below. Emphasis will generally be on the second layer deposited in the double layers, that is, the layer closest to the surface since this layer will be in contact with the corrosive environment.

3.1.8.2 AWS-ER309 Overlays.

3.1.8.2.1. Chromium Distribution. The highest Cr contents were obtained and maintained for a greater depth in both the single and double layer overlays deposited by the SAW process (Tables 19 and 20 and Figure 26). A minimum value of 25% Cr was obtained for a depth of 4 mm (0.16 inches) in the double layer overlay deposited by the SAW process. [NOTE: Generally, the Cr content obtained by microprobe analysis was higher just below the surface than was obtained by bulk analyses. Also, the surface values obtained by microprobe analysis could have been affected by roundness of the edge surface, since they were obtained on cross sections approximately 0.025 mm (0.001 inches) below the surface edge.] The higher Cr content obtained with the SAW process was due to the lower dilution obtained with this process and Cr in the flux. Of the two inert gas processes, higher Cr was deposited with the GTAW-HW process. The Cr content dropped very rapidly in the first layer with the GTAW-HW process in contrast to the SAW and GMAW processes which gave two distinct layers of Cr.

3.1.8.2.2. Nickel Distribution. The distribution of Ni was similar in overlays deposited by the SAW and GTAW-HW processes (Tables 19, 20 and Figure 27). The GMAW process gave lower values particularly near the surface in the double layer overlay.

3.1.8.3 INCONEL Filler Metal 72.

3.1.8.3.1. Chromium Distribution. All overlays had Cr contents of 35% or higher for the entire depth of overlay or to within 0.1 to 0.4 mm (0.004-0.016 inches) of the apparent fusion line with one exception. The exception was a double layer overlay deposited on INCOLOY alloy 800H by the GMAW process. However,even in this overlay,the depth of 35% Cr was maintained for a depth of 5.9 mm (0.23 in). The depth of 35% Cr was maintained for a depth of 3.5-6.6 mm (0.14-0.26 inches) in the single layer overlays and 5.9-10.3 mm (0.23-0.41 inches) in the double layer overlays (Table 21). The data for the INCONEL Filler Metal 72 overlays are presented in Tables 21-30 and Figures 28-33.

Cr contents of up to 40% and higher were obtained on all double layers and two single layer overlays (SAW process, 304L and 310SS substrates) (Table 21). The 40% Cr level in the single layer deposited on 310SS was maintained

for a depth of 5.3 mm (0.021 in) except for one lower reading at 3.0 mm (0.12 in) (Weld 6195, Table 26), while the overlay deposited on 304L had 40% Cr near the surface only (W6189, Table 23). Since the highest Cr content attainable for the greatest depth was desired for long time corrosion resistance, the discussion which follows will be concentrated on the double layer overlays.

The Cr content in the upper area, that is, in the area up to 4 mm (0.16 inch or 160 mils) from the surface, was not affected by the Cr content of the substrate. There were small differences obtained in the level of Cr due to the welding process. The highest Cr content was obtained with the lowest dilution process, SAW. In general, the SAW process also gave the greatest depth of 40% Cr for each substrate. The Cr content of the substrate had an effect on the depth of the 40% Cr level. The overlays deposited on the highest Cr substrates, 310 SS, had the greatest depth of 40% Cr for each weld process. The overlays deposited on the substrate with the lowest Cr content, 304L, had the shortest depth of 40% Cr when deposited with the inert gas processes.

3.1.8.3.2. Iron Distribution. The Fe content in the first 4 mm (0.16 inch) from the surface was related to the welding process used for deposition (Figures 28-33). The lowest dilution process, SAW, produced the lowest Fe content, and the substrate composition had little effect on the near surface Fe content of the SAW deposited overlays (Figure 29). With the inert gas processes, the lowest Fe contents were obtained in the overlays deposited on INCOLOY alloy 800H which was also the substrate that contained the lowest Fe content. The distribution of Fe in the upper 4 mm (0.16 inch) was very uniform regardless of weld process or substrate composition.

As will be described later the nature of the scale which formed during exposure to the CGA appeared to be related to the Fe content of the overlay.

3.1.8.4 R139 Overlays

3.1.8.4.1. Chromium Distribution. There was an interdependence of weld process and substrate on both the Cr level that was attained in the near surface area of the R139 overlays and the depth to which the Cr level was maintained (Tables 31-40 and Figures 34-39). The highest Cr obtained in the double layer overlays on 304L (Figure 34) and INCOLOY alloy 800H (Figure 35) were obtained with the GMAW process, whereas the SAW process deposited the highest Cr content on the 310SS substrate (Figure 36). When the substrate was considered as a variable the highest Cr contents obtained with the SAW and GTAW-HW processes were obtained in the overlays deposited on 310SS (Figures 37 and 38), and the highest Cr content obtained with the GMAW process was obtained with the 304L and INCOLOY alloy 800H substrates (Figure 39).

All overlays contained 25% or higher (Table 40), and some single layers had 30% or more Cr. All double layers had 30% or more Cr with the exception of the overlay deposited on 304L by the GTAW-HW process, which was slightly below 30% Cr near the surface. Thirty percent Cr or higher was obtained for the complete depth of overlay on all substrates when deposited by the GMAW process and all overlays deposited on 310SS with all weld processes.

Fluctuations of Cr content were observed near the apparent fusion line of the overlays deposited by the inert gas processes on 310SS (Figure 36) suggesting the formation of a second phase which may have affected the stability of the weldments when exposed to elevated temperature. The largest differences in Cr between the first and second layers were obtained with the GTAW-HW process and 304L and INCOLOY alloy 800H substrates which appeared to give two distinct levels of Cr in each layer (Figure 38).

3.1.8.4.2. Nickel Distribution. The distribution of Ni in the R139 overlays and the Ni content at or near the surface was affected by the weld process and the substrate composition. The data are presented in Tables 31-39 and 41 and Figures 34-39.

Two distinct levels of Ni content were observed in the double layer overlays deposited on 304L and 310SS with all three welding processes and on INCOLOY alloy 800H when deposited by the GTAW-HW process (Figures 34-36). The Ni level of the first layer, that is, the one nearest the substrate, was related as one might expect to the Ni content of the substrate. A higher level of Ni was deposited on 304L with the SAW process (Figure 34). Lower values of Ni were obtained in the upper layer just below the surface than in the first layer of the overlay deposited on INCOLOY alloy 800H by the SAW process (Figure 35). This was not duplicated in the samples examined after exposure to the coal gasification atmosphere and the reason for the lower values in the "as welded" specimen is not known.

The Ni content at the surface and 1 mm (0.04 inches) below the surface obtained for the different substrates and welding processes are given in Table 41. The Ni content of the filler metal used for each deposit are also given in Table 41. The differences in the original Ni content were taken into consideration in analyzing the data. The data show that the SAW process gave the highest Ni values for the overlays deposited on 304L and 310SS and the GMAW process for the overlays on INCOLOY alloy 800H. The lowest values were obtained with the GTAW-HW process for all substrates.

3.1.8.4.3. Aluminum Distribution. The distribution of Al in the R139 overlays was affected by the weld process (Figures 40-42) and substrate composition (Figures 43-45). The most uniform distribution of Al throughout the overlay was obtained with the SAW process; however, this process also gave the lowest level of Al. The highest level of Al was obtained with the GMAW process in overlays deposited on INCOLOY alloy 800H. In general, the Al content was very erratic (severely segregated) throughout the complete depth of overlay and, in particular, near the interface when deposited by the inert gas processes. The overlays made with the 310SS substrate had the most erratic distribution of Al for all three weld processes. An anomaly was observed in the overlay deposited on 304L by the GMAW process. In this overlay, the Al content increased steadily with increasing depth of overlay up to 6 mm (0.24 inches) and then decreased rapidly in the first layer (Figure 40).

3.1.8.4.4. Iron Distribution. The distribution of Fe in the R139 double layer overlays is shown in Figures 40-45. There appeared to be an interdependence of welding process and substrate on the uniformity of the distribution of Fe in the second or upper layer. The most uniform distribution, that is, the least fluctuation, in the R139 overlays on 304L was obtained with the GTAW-HW process (Figure 40). On the 310SS substrate the most uniform distribution was obtained with the SAW process (Figure 41) and on INCOLOY alloy 800H the most uniform distribution was obtained with the SAW and GMAW processes (Figure 42).

The level of the Fe content near the surface of the overlays was affected by welding process and substrate; however, the welding process had the greater effect (Table 42). The highest Fe content obtained in the R139 overlays for all three substrates was obtained with the GTAW-HW process. The lowest Fe levels in the overlays on 304L and 310SS were obtained with the SAW process and on INCOLOY alloy 800H with the GMAW process. The Fe content of the overlay surface was not directly related to the Fe content of the substrates for all weld processes, for example, the Fe content obtained in the overlay deposited on 304L by the SAW process was lower than the Fe content obtained in the overlays deposited by the same process on 310 and INCOLOY alloy 800H substrates (Table 42).

3.2. Task II - Exposure of Samples in a Coal Gasification Atmosphere

The size and the number of specimens to be exposed in the coal gasification atmosphere (CGA) in a single run required the construction of a test cell. The construction of the test cell and the exposure of the samples was done by Martin-Marietta, Denver, under subcontract. A detailed

description by M. E. Wakefield, Project Manager of the test and test equipment, is given in the Appendix. A brief description of the test follows.

Four unwelded coupons from each substrate and one sample from each of the weldments were exposed to the CGA. The size of the coupons were 25.4 x 19.0 x 9.5 mm (1 x 3/4 x 3/8 inches) and each weldment was approximately 279 x 168 x 32-44 mm (11 x 6-5/8 x 1-1/4-1-3/4 inches). The weldments were sufficiently large to permit mechanical testing after exposure.

The samples were exposed for 1000 hours in a CGA at 982°C (1800°F) similar to the gas at the high H_2S level used at the Illinois Institute of Technology Research Institute (ITTRI) for the Materials Properties Council tests. The gas composition upon entry was: 12% CO_2, 18% CO, 24% H_2, 5% CH_4, 1% NH_3, 1% H_2S and 39% H_2O. A fresh supply of gas equivalent to 130% of the test cell volume was injected periodically. Initially, the gas injection was made on an hourly basis but after 16 hours of testing the injection cycle was changed to inject 1/4 of the amount which was required hourly at 15-minute intervals. The exposure was interrupted after 700 hours of test time when the temperature dropped 149°C (300°F) because of a power outage. The test cell was purged with argon, the system temperature increased to 982°C and the exposure time started after the injection of the CGA.

3.3. Task III - Testing

Stress rupture properties, hardness, tensile properties, corrosion resistance, and the distribution of major elements were determined. The stress rupture properties were determined on "as welded" specimens, whereas the remaining properties were determined on "as welded" and "exposed" specimens. The effects of exposure, welding process, filler metal and substrate on properties were established.

All tests were made on composite specimens without machining of the "as deposited" overlay surface before or after exposure in order to include any notch effects which may have been present. Also by testing in this condition, the total effects of corrosion and temperature on the overlay and the effects of temperature on the substrate were measured. In service, the overlay is subjected to corrosive as well as temperature effects, since its outer surface is in intimate contact with the corrosive media. On the other hand, the substrate, although subject to the effects of temperature (microstructural, diffusional, etc.), is protected from corrosion by the overlay. The locations of the test specimens in the original weldments are shown in Figure 46. The results are discussed below.

3.3.1 Stress-Rupture

Stress rupture tests were run in an air atmosphere at 982°C (1800°F) on all weldments. Sufficient tests were made (usually four but in a few cases three) on each weldment to establish the stress required for rupture in 100 and 1000 hours. The dimensions of the specimens are given in Figure 47.

The results of the stress-rupture tests are given in Table 43. The stresses in the stress rupture tests were computed using the full width of the specimen, that is, base metal plus overlay. [Normally, for design purposes the overlay would be considered sacrificial and not enter into the calculation of the stress.] The stresses required to produce rupture in 100 and 1000 hours are given in Tables 44 and 45. The effects of substrate composition, welding process and filler metal composition on the 1000-hour rupture strength are shown in Figures 48-51. The data indicate: (1) the substrate had most effect on the stress rupture strength and the highest stress rupture strength was obtained with INCOLOY alloy 800H as the substrate material (Figure 48); (2) generally, the inert gas welding processes gave higher stress rupture strength than the submerged-arc welding process (Figure 49); (3) R139 and INCONEL Filler Metal 72 overlays had higher stress rupture strength than AWS-ER309 on 304L except with the SAW process (Figure 50) and, (4) R139 gave slightly higher stress rupture strength than INCONEL Filler Metal 72 in most cases (Figure 51).

3.3.2 Hardness

Vickers hardness numbers (VHN) were obtained before and after exposure in the overlay, heat affected zone and substrate. The hardnesses were determined on cross sections of samples which were surface ground and etched before testing. A 10 kilogram load was used. A minimum of five readings were made in each area. Hardness was determined in each layer of the double layer overlays. The results are given in Tables 46-49 and plotted in Figures 52-56. The hardness data plotted in Figures 52-56 for the double layer overlays were from the upper layer. The observations made on "as welded" and "exposed" samples are discussed separately.

3.3.2.1. As Welded. Some general observations on hardness in the "as welded" condition were: (1) the difference in hardness between the "hardest" and "softest" overlays was 44 VHN or approximately 12 Rockwell C (R_C) points. The range for the upper layer in the double layer overlays was 180-218 VHN, and for the single layer overlays 170-210 VHN which is a range of approximately 8 R_C points; (2) the second layer of the double layer overlay had higher

hardness than the single layer overlay; (3) the R139 overlays were harder than the INCONEL Filler Metal 72 overlay when deposited by the SAW process, but not when deposited with the inert gas processes.

3.3.2.2. After Exposure. The significance of a change in hardness after the exposure in the CGA is that it may be an indication of metallurgical instability. The change in hardness as a function of weld process, filler metal and substrate are given in Table 49 and plotted in Figures 55 and 56. The results show that the effects of exposure in the CGA for 1000 hours at 982°C (1800°F) were: (1) All AWS-ER309 overlays decreased in hardness; (2) the R139 and INCONEL Filler Metal 72 overlays increased in hardness, which was probably due to the precipitation of alpha chromium; (3) the INCONEL Filler Metal 72 overlays had a smaller increase in hardness than the R139 overlays; (4) the increase in hardness in INCONEL Filler Metal 72 and R139 overlays was greater in the upper layer than in the lower layer of double layer overlays; (5) the smallest increase in hardness of the INCONEL Filler Metal 72 and R139 overlays was obtained with INCONEL Filler Metal 72 and INCOLOY alloy 800H in the single layer overlays and in the lower layer of double layer overlays, which are areas where dilution from the substrate would be expected to have most effect; (6) welding process had very little effect on the increase in hardness of the INCONEL Filler Metal 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); (7) generally, hardness decreased in the heat affected zone and base metal.

3.3.3. Tensile Tests

Room temperature tensile tests were run in duplicate before and after exposure in the CGA. The change in tensile properties with emphasis on tensile ductility may be considered as a measure of metallurgical stability.

The tests were run in conformance with ASTM Specification E-8. The crosshead speed was approximately 0.5 mm (.02 inches) per minute up to the yield strength (0.2% offset and 25.4 mm (1 inch) per minute after the yield strength was obtained. The yield strength was measured with the extensometer attached to the substrate. The dimensions of the tensile specimens are given in Figure 57.

The results of the tests are given in Tables 50 and 51 and discussed below.

3.3.3.1. As Welded. There were no significant differences in "as welded" tensile properties due to filler metal, substrate or welding process.

3.3.3.2. After Exposure. The effects of the exposure on tensile properties were as follows:

3.3.3.2.1. Tensile Strength. The tensile strength of all weldments (Figure 58) decreased after exposure, with the weldments consisting of AWS-ER309 on 304L retaining the highest strength. No clear distinction was observed between the R139 and INCONEL Filler Metal 72 weldments. Generally, the R139 on 304L weldments were slightly stronger than the INCONEL Filler Metal 72 on 304L weldments. The INCONEL Filler Metal 72 on 310SS weldments were stronger after exposure than the INCONEL Filler Metal 72 on INCOLOY alloy 800H, whereas R139 on INCOLOY alloy 800H had higher retained strength than R139 on 310SS. The percentage decrease in the original tensile strength is given in Table 52. The AWS-ER309 on 304L weldments had the smallest percentage decrease (were more stable) with all weld processes. The results obtained with INCONEL Filler Metal 72 and R139 were mixed. Generally, the INCONEL Filler Metal 72 GMAW weldments had a lower percentage decrease than the R139 GMAW weldments, whereas the R139 had a smaller decrease with the GTAW-HW and SAW processes (except for the double layer on 310SS).

3.3.3.2.2. Yield Strength. Yield strength of all weldments decreased after exposure. The AWS-ER309-304L weldments had the lowest yield strength after exposure and the R139 weldments had the highest yield strength after exposure for all welding processes and substrates (Table 53). The largest percentage decrease in yield strength was obtained with the AWS-ER309-304L weldments and the R139 weldments had the smallest percentage decrease (Figure 59a). In general, the INCOLOY alloy 800H weldments had a smaller percentage decrease in yield strength than the 310SS weldments. The effect of the difference in welding process was not defined clearly (Figure 59b).

3.3.3.2.3. Tensile Elongation. The tensile elongation and, in particular, the change in tensile elongation after exposure is considered as a good measure of stability or embrittlement. Most weldments had a lower tensile elongation after exposure, with the exception of several 304L weldments (Figure 60). Both the substrate and filler metal compositions affected the tensile elongation (Table 54). The 304L weldments had the highest tensile elongation and the 310SS weldments had the lowest tensile elongation after exposure. In general, the filler metal composition affected the tensile ductility as follows: (1) the AWS-ER309 weldments had the highest tensile elongation and, (2) the INCONEL Filler Metal 72 weldments had higher tensile ductility than the R139 weldments when 310SS and INCOLOY alloy 800H were used as substrates. The lowest value obtained on the double layers was 9.5% (R139 on 310SS, SAW

process) and the highest value was 51.5% (R139 on 304L, GMAW process). The percentage change of the original tensile elongation after exposure is probably more important as a measure of stability, since it shows the degree of change. The percentage change in ductility was affected in the same manner as decribed above for the actual tensile elongation, that is, the 310SS weldments had the largest percentage decrease in ductility and the 304L weldments had the smallest decrease (an increase in some cases). The INCONEL Filler Metal 72 weldments had a lower percentage decrease in tensile elongation than the R139 weldments except on 304L.

The appearance of the fracture is another factor that is related to tensile ductility. The effect of the substrate on the fracture appearance of all double layer overlays after exposure is shown in Figures 61-67. The difference in fracture appearance of some of the INCONEL Filler Metal 72 weldments before and after exposure can be obtained by comparison with the as welded tensile specimens shown in Figure 17. The high post exposure ductility obtained with the AWS-ER309-304L weldments is reflected in the ductile type fracture shown in Figure 61. Portions of three of the six 310SS weldments were more shear-like (Figures 63, 66 and 67). Some peculiar appearing fractures were obtained on three of the 304L weldments which were overlayed with INCONEL Filler Metal 72 or R139 (Figures 64, 65 and 66). None of the pieces were missing after fracture in these tests. The much more ductile substrate elongated more than the less ductile overlay. Why this occurred in only half of the 304L weldments is not known.

3.3.4. Corrosion Tests

3.3.4.1. Alloy Design for Corrosion-Erosion Resistance. The gasifier internals in coal gasification systems will be simultaneously subjected to a variety of high temperature corrosion conditions. In addition, the resulting corrosion scales will be eroded by char, ash and unburned coal. Heat resistant alloys and coatings rely solely on continuous dense protective oxide coatings for resistance to high temperature corrosive attack. Without these oxide scales, corrosion reaction rates are so high as to preclude long-time section thickness integrity. Of the available oxides which may be formed, only Al_2O_3, Cr_2O_3 and $(Ni,Co,Fe)Cr_2O_4$ provide realistic protection above 600 or 700°C (1110 or 1290°F). Of these, Al_2O_3 is the most protective but exhibits the poorest ability to reform on conventional alloys, while Cr_2O_3 provides an excellent combination of protection and repairability. The growth rates of $(Ni,Co,Fe)Cr_2O_4$ become excessive above about 900 to 1000°C (1650 to 1830°F). For successful use in a corrosion-erosion environment, metallic materials must exhibit the ability to initially form and maintain these oxides.

The corrosion problems in coal conversion systems could consist of a combination of the following phenomena: oxidation, sulfidation, carburization, nitridation and possibly fused alkali salt hot corrosion. A brief discussion of each phenomenon follows:

3.3.4.1.1. Oxidation. The most familiar and best understood form of high temperature corrosion is oxidation. The natural high temperature oxides that form on pure Fe, Ni and Co (FeO + Fe_3O_4, NiO and CoO + Co_3O_4 respectively), offer only limited protection. Cr is most commonly utilized for improving oxidation resistance, but a sufficient amount, about 15 to 20% in Fe and Ni-base alloys(6) and 30% in Co base alloys, must be provided so that the alloy will form a continuous Cr_2O_3 scale. At lower levels of Cr, less protective spinels $(Fe,Ni,Co)Cr_2O_4$ will form and internal oxidation may occur. Internal oxidation may lower mechanical properties.

Water vapor is an important factor in oxidation testing. It has been shown(7) at the Inco Research & Development Center (IRDC) that the presence of water vapor markedly reduces the oxidation resistance of austenitic stainless steels, but has a smaller effect on Ni-base alloys.

At temperatures above 1093°C (2000°F), the Cr_2O_3 scale transforms to a volatile specie, CrO_3(8,9). Under these conditions an Al_2O_3 oxide may be more desirable. As in the case of Cr, small amounts of Al lead to internal oxidation in both Ni and Co. Similarly, larger amounts favor the formation of $(Fe,Ni,Co)Al_2O_4$ spinels, while an even larger amount will induce a highly protective Al_2O_3 scale to form. Unfortunately, Al_2O_3 cannot easily repair itself on alloys forming the voluminous pure Fe, Ni and Co oxides. It is therefore usually present in combination with Cr, which does two things: It stabilizes Al_2O_3 at lower Al contents than possible in a Cr-free alloy and also induces protective Cr_2O_3 or spinels to form if the Al_2O_3 is disrupted. Conversely, small amounts of Al stabilize Cr_2O_3 at lower Cr contents than in an Al-free alloy and also form Al_2O_3 subscales under Cr_2O_3 for added protection. This effect has been reported by Michels(10) in the case of INCONEL alloy 601, which formed an outer scale of Cr_2O_3 and an inner one of Al_2O_3.

There are very few commercial alloys that make use of the highly protective capabilities of the Al_2O_3/Cr_2O_3 continuous scale combination because of the adverse effects of Al on other properties such as hot workability. Instead, the conventional approach has been to aluminize the surfaces of Cr_2O_3-forming alloys, as in the case of pack cementation techniques for gas turbine alloys and vapor deposition (aluminizing) for petrochemical components. IITRI tests on aluminized 310 stainless steel and INCOLOY alloy 800H

indicated a protective life of the Al_2O_3 rich scale of about 3000 hours at 982°C (1800°F). One of the filler metals in our work, R139, is an experimental alloy which was designed to form the Al_2O_3/Cr_2O_3 protective scale.

3.3.4.1.2. Sulfidation. Sulfidation is the term used to describe the reaction of mixtures of gases such as SO_2, SO_3, H_2S, CS and S with engineering alloys, which disrupt the protective oxides and form sulfides. This type of attack can be catastrophic because many of the sulfides, e.g., NiS, have low melting points and form at very high rates. The only sulfide that provides any protection is CrS, but its growth rate is orders of magnitude higher than Cr_2O_3.

Sulfidation occurs quite readily at low sulfur contents in reducing gases because protective oxide stability is lower. The gas compositions in coal conversion systems make this form of attack inevitable for conventional alloys at higher temperatures. The normal engineering approach to prevent sulfidation attack is to use alloys or coatings high in Cr and Al, to provide a protective Cr_2O_3/Al_2O_3 barrier.

Unpublished research at IRDC has shown that Cr contents of 20 to 50% and Al above 1% are needed in Fe, Ni and Co base alloys to achieve good sulfidation resistance. The IRDC filler metal described in the previous section meets these requirements. The most recent IITRI results indicate that a minimum of 25-30% Cr is needed for long time protection in 0.5 v/o H_2S coal gasification environments at 982°C (1800°F)(11).

3.3.4.1.3. Carburization and Nitridation. Since carburization and nitridation are similar forms of high temperature attack that have the same net effect on alloys, they will be discussed together. All comments on carburization apply equally to nitridation.

Carburization is the term describing the reaction between carbon in the environment and alloy constituents to form metal carbides. In the context used here it is an undesirable reaction because the carbon from the atmosphere reacts with crucial alloying elements and markedly alters microstructures, changing mechanical properties and possibly disrupting protective oxide scales. Of greatest concern is carburization at high temperatures where diffusion rates of carbon in metals are high and microstructural alterations can be sufficient to subvert the engineering integrity of a material. Deleterious effects on protective oxides are less likely, but cyclic reducing/oxidizing carbonaceous environments have been known to cause catastrophic oxidation, called "green rot".

It is expected that coal gasification atmospheres, which contain high hydrogen and methane contents, will readily carburize many heat resistant alloys. Carburization attack will be typified first by intergranular and then by intragranular Cr_7C_3 formation, causing the alloys to be weakened at high temperatures and embrittled at low temperatures. Protection against this phenomenon at high temperatures requires dense protective oxide scales.

3.3.4.1.4. Fused Salt Corrosion. Catastrophic oxidation due to liquid alkali metal salt condenstation has been recognized for many years as a severe problem in gas turbines (Na_2SO_4-NaCl), oil fired boilers (V_2O_5-Na_2SO_4) and coal-fired boilers (complex sulfates of Na, K and Fe_2O_3). If these salts are present as contaminants in coal in significant quantities, coal conversion systems will also be subjected to this corrosion problem.

The attack can be viewed simply as the disruption of normally protective oxide scales by fused salts, causing extremely rapid formation of non-protective porous oxides. Corrosion rates can increase by orders of magnitude. The mechanistic details of the fused salt attack are still not understood.

The Na_2SO_4-NaCl attack in gas turbines occurs between 800 and 1100°C (1470 and 2012°F), while the Na_2SO_4-V_2O_5 oil ash corrosion starts at 800°C (1470°F) and seems to have no upper temperature limit. Coal ash corrosion caused by the complex sulfates of Na, K and Fe_2O_3 occurs between 550 and 700°C (1020 and 1290°F). These temperature regimes are dictated by the fact that they define the temperature range in which the liquid salt is stable or can be condensed on the components. It is not clear which combination will exist in coal conversion systems, but the alloy solutions are similar.

The alloying elements that classically provide fused salt corrosion resistance in heat resistant alloys again are Cr and Al. In this situation, the alloy composition must provide a stable Cr_2O_3 or $(Ni,Fe,Co)Cr_2O_4$ oxide as a barrier to the salt. Al is useful only if there is a very large amount coupled with a high Cr content. The best alloys available to resist this attack contain 25 to 60% Cr.

Our experience with oil and coal ash indicates Ni-50%Cr to be the most resistant state-of-the-art alloy. However, Ni-50%Cr alloy is extremely difficult to reduce to wire. INCONEL Filler Metal 72 contains 44% Cr and is more readily hot and cold worked than the 50% Cr alloy(13); therefore, it was chosen for this investigation.

3.3.4.2. Corrosion Evaluation. The exposure conditions were judged to be very severe based upon the evaluation of unclad base plate after exposure. The INCONEL Filler Metal 72 and R139 overlays provided particularly good corrosion resistance considering the severity of attack upon the unclad base plate specimens. A description of the examination procedure and the results follow.

3.3.4.2.1. Unclad Base Plate. All samples of 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. INCOLOY alloy 800H was severely attacked with the formation of liquid sulfide scales and extensive oxidation. Type 310 stainless steel had the best resistance to the environment. The unclad base plate evaluations are 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. The masked portion was used for metallographic and microprobe examination. Weight change and penetration data are given in Table 55. 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 68 after removal from the test cell. They are grouped in a similar, but not identical, manner to the way in which they were exposed.

3.3.4.2.1.1. Type 310 Stainless Steel. Only one of the type 310 stainless steel samples (shown in Figure 69) was noticeably attacked and there was no evidence of liquid sulfide formation. The total affected metal was on average 0.19 mm (0.0074 inches) with one sample giving a value of 0.13 mm (0.0052 inches) and another sample giving a value of 0.33 mm (0.0132 inches) (Table 55). These values extrapolate on a straight line basis to 1.65 mm, 1.14 mm and 2.44 mm/yr (0.065, 0.045 and 0.116 inches/yr). Samples 6 through 8 showed similar penetration depths (Table 55). This was true on average, but mean depths of attack from area to area in a given sample varied by as much as 50%, depending upon the local characteristics. Figure 70 (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 the 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. Sample 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 shown in Figure 71, were more heavily attacked. The mixed oxide-sulfide, 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 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 having the appearance of $MnO \cdot Cr_2O_3$ was found in the alloy. These were more numerous just below the scale and were often associated with intragranular sulfides. They can be differentiated by their cubic section outline and slight relief due to their hardness. Their behavior is judged to be of little consequence to the alloy's behavior.

3.3.4.2.1.2. INCOLOY Alloy 800H. Alloy 800H was found to be more severely attacked (Figure 72) than type 310 stainless steel. Liquid sulfide slagging was observed on the samples. Much of this outer scale was loose and could not be 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, peaks related to phases of the type $(Cr,M)_2S_4$ were present but these could not be unambiguously identified.

Table 55 shows the degree of surface loss and measured weight changes. All samples of alloy 800H contained 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 areas was limited. Elsewhere, as shown in Figure 73 for Sample 800-10, non-protective iron-rich oxide scales were produced which were 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 an iron-nickel alloy almost totally depleted of chromium. In addition to the massive sulfides above this zone, finely divided sulfides, predominantly 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 phase did not form as a result of exposure to the gasifier atmosphere.

3.3.4.2.1.3. Type 304L Stainless Steel. All 304L samples were practically destroyed (Figure 74). X-ray diffraction of the residue revealed primarily Fe_3O_4 with 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 75. No sound alloy remained.

3.3.4.2.2. Surfaced Substrates.

3.3.4.2.2.1. Scaling Behavior. The appearances of the weldments after exposure in the CGA are shown in Figures 76-85. The filler metal substrate, and weld process used in making each weldment is given in Table 3. Each figure consists of six weldments for a particular filler metal deposited on the same substrate using three different weld processes. For example, Figure 76 shows the appearance of the AWS-ER309 overlays on a 304L substrate. The overlays with the lowest two code numbers in each series were deposited by the GMAW process, the next two higher code numbers by the SAW process and the highest two code numbers by the GTAW-HW process. The odd numbered codes are single layer overlays and the even numbered codes are double layer overlays. The welds coded 00 through 21 correspond to codes 6200 through 6220 and 6321 in Table 3. Figures 77, 79 and 83 are edge views of the weldments in Figures 76, 78 and 82 which clearly show the difference in degree of attack of the overlay and 304L stainless steel substrates. As shown in Figure 76 all AWS-ER309 overlays had a spalling type scale with the exception of the double layer overlay deposited by the SAW process (W6182). This is in contrast to the scales formed on the R139 overlays in which the inert gas deposited overlays formed scales after exposure which were more adherent than the scales that were obtained with the SAW deposited overlays. The difference in scale appearance after exposure obtained on the inert gas and submerged-arc deposited overlays appears to be related to the higher recovery of Al which was obtained with the inert gas processes. All the INCONEL Filler Metal 72 overlays formed thin adherent scales after exposure.

3.3.4.2.2.2. Corrosion Behavior. Metallographic sections of each weldment were evaluated for scale thickness and constitution, the extent of internal oxidation and/or sulfidation, uniformity of attack and maximum depth of affected metal (discontinuous penetration). Overlay behavior was related to compositional variations, welding process and choice of substrate for each type of filler metal.

An effort to quantify the results was made as follows: measurements were made of the 279 x 168 mm (11 x 6-5/8 inch) specimens at eight referenced locations before and after exposure to establish changes in thickness due to exposure (Table 56); after sectioning and polishing, measurements were made for scale thickness, internal oxidation and sulfidation and subscale porosity from the outer scale surface at a single location corresponding as closely as possible to a single referenced point. Due to the undulating weld surface there was some uncertainty about the location of some of the reference points with respect to the plane of polish that was frequently greater than the depth of attack. These values must be considered as approximate. Subsequently, a second investigator also made measurements for maximum corrosion in the one inch metallographic specimen without regard to the original reference point. This investigator did not account for subscale Kirkendall porosity but considered all indications as affected metal. These values were generally higher than were obtained by the first investigator (Investigator A in Table 57) and must be considered as conservative estimates.

The penetration data are given in Table 57. The data are compared in Figures 86 and 87 to the results obtained on the unwelded 310 stainless steel. The 310 stainless steel was chosen for comparison because it had the best corrosion resistance of the bare substrates (Table 55). The stainless steel data are plotted as the average, highest and lowest maximum penetration obtained in the four test samples. The corrosion resistance was affected by weld process, substrate and filler metal composition. In general, the INCONEL Filler Metal 72 and R139 overlays had better corrosion resistance than the unwelded 310 stainless steel, whereas the 309 overlays showed improvement in only one case.

Except for the 309 overlays, the corrosion was not severe and metallographic examination supplemented with microprobe, scanning electron microscope and x-ray studies provided all necessary information. The results obtained by x-ray scanning of the scale of specific samples are given in Table 58 and the Kα x-ray images are shown in Figures 88-94. A discussion of the exposure on corrosion resistance for each category of overlay follows.

3.3.4.2.2.2.1. AWS-ER309 (24.6% Cr). Heavy scaling was observed in five of the six 309 overlays on Type 304L stainless steel. Sulfidation was observed in all overlays. Double layer overlays deposited by the submerged arc process (SAW) provided the best resistance to the test environment and overlays deposited by the gas-tungsten arc process with a hot wire addition (GTAW-HW) provided the least resistance. Micrographs of double and single layer overlays deposited with each process are shown in Figure 95. W6182

(SAW, double layer) formed a protective chromia subscale with essentially no internal sulfidation apart from a very shallow zone of solid MnS below the subscale. The structure shown in Figure 95 is typical of the entire sample. The double layer GTAW-HW sample was severely corroded with general attack greater than in the single layer SAW deposit. Grain boundary oxidation and sulfidation were observed throughout the GTAW-HW overlays.

The results may be explained to some extent in terms of dilution of the filler metal by the Type 304L substrate. The least dilution was obtained with the SAW process for deposition of the overlays. The compositional differences obtained with the bulk analyses of the overlays (Table 7) show higher Cr and Si were obtained with the SAW process (**NOTE**: The Si and some Cr was picked up from the flux.) This was, in general, borne out in compositional profiles obtained by microprobe analyses (Table 20). Approximately 25% Cr was measured in the near surface layer of W6182 which is now considered necessary for corrosion resistance in 1% H_2S coal gasification environments at 982°C (1800°F). After exposure higher Cr and Si and lower Mn were obtained in the compositional profiles of the double layer SAW process overlay than were observed in the GTAW-HW overlay (Tables 60 and 61). Local variations of composition in weldments may be marked, however, and there is some question that this might be used as a ranking tool.

In summary, the double layer overlay of 309 on 304L deposited by the SAW process provided reasonable protection in the present test. An increase in the Cr content may provide acceptable corrosion resistance in coal gasifiers. Much better corrosion resistance was obtained with the other filler metals, however, as will be shown below.

3.3.4.2.2.2.2. <u>INCONEL Filler Metal 72 (44% Cr)</u>. In contrast to the performance of the AWS-ER309 overlays, the FM72 overlays had good corrosion resistance. Internal sulfidation was observed in only one (W6198) of the eighteen overlays and this was localized and judged to be of minor consequence. The location of the test sample, which was directly below the gas intake in the test cell, probably affected this result.

Features of the examinations are shown in Figures 96-98. In general, the best corrosion resistance in terms of scale uniformity was found in the SAW process deposited overlays, followed by the GMAW process overlays and then the GTAW-HW process overlays. These results follow dilution trends, with the least diluted overlay (SAW) providing the most uniform scale. Note from the representative microsections (Figures 96-98) that differences were small and that any of the three processes can provide an acceptable overlay.

The lower the iron content of the base plate, the lower the iron pick-up and the better the scale appearance, but differences may be of minor consequence in more extensive testing. The scales that formed on the INCONEL Filler Metal 72 overlays were chromia with subscale Kirkendall porosity which was enlarged by mechanical polishing. Ti was identified in the chromia scales which formed on the overlays deposited by inert gas welding processes but not in the SAW deposited overlays (Table 58).

It is recognized that minor elements can affect the corrosion resistance of high chromium overlays in gasifier atmospheres. The choice of substrate composition and selection of welding process to maximize Cr and Ti(12) and minimize Mn(13) may improve performance still further. Since this work was completed, a dilution level of 5% was obtained in surfacing a marine diesel valve with INCONEL Filler Metal 72 using the pulsed gas metal arc process with a cold wire addition(14).

3.3.4.2.2.2.3. R139 (31%Cr-3.25%Al-15%Fe-Bal Ni). Most of the R139 overlays formed compact chromia scales which provided most of the resistance to attack by the environment, and alumina which formed as an internal oxide. At low Al recoveries in the deposits, there were fingers of alumina below the scale. With increasing Al recovery these became thicker and semicontinuous subscales of Al_2O_3 were observed to form. These features are shown in Figures 99-107.

All overlays on type 304L substrates had inferior corrosion resistance in this group. As Table 57 shows, these were the only R139 deposits that showed any significant sulfidation. Weld 6204, the double layer GMAW overlay, gave the best performance. Overlays with substrate alloy types 310 and INCOLOY alloy 800H were better with all welding processes.

In contrast to the results obtained on the INCONEL Filler Metal 72 overlay, dilution alone was not the most important factor in the corrosion resistance; recovery of Al plays an important role as well. Poorest performance was shown by those welds which had the lowest Al content (although in the same deposits Cr was also lower in many cases). While dilution was highest in the GTAW-HW overlays these samples showed corrosion resistance equivalent to the GMAW welds, chiefly, it appears, because of the high recovery of aluminum (Table 18). The SAW process overlays on 310 and INCOLOY alloy 800H, while not heavily attacked (Figures 106-107), produced thin, discontinuous chromia scales that may be less protective in longer or more severe exposures. Al recoveries, even in the double layer overlays, were very low compared with those from the inert gas process overlays.

The general attack of the R139 weldments by scaling and internal oxidation is in our experience normal behavior for this type of alloy in low oxygen environments. While the indicated depth of attack in Table 57 is seen to be somewhat greater than for the INCONEL Filler Metal 72 specimens, it is expected that performance of the two overlay materials on Type 310 stainless steel and INCOLOY alloy 800H can be judged nearly equivalent provided dilution is minimized, and that for R139 aluminum recovery is maximized.

In coal gasification atmospheres, it is generally found that 50%Ni-50%Cr alloys have good resistance to attack. In similar tests at IRDC, involving cyclic exposures to atmospheres close to the Materials Properties Council average gasifier environment, no attack was obtained on INCONEL Alloy 671, IN-657 or 50%Cr-50%Ni at the 0.4 and 1.0% H_2S levels. Alloys of the R139 type have been found to be somewhat inferior to the high Cr types in these tests with performance dependent upon Cr and Al contents. With supplementary data of this kind, INCONEL Filler Metal 72 is suggested to be most desirable for CGA applications. The alloy provides good corrosion resistance over the widest range of welding processes and substrates. From these tests, best corrosion properties are achieved with INCONEL Filler Metal 72 deposited on INCOLOY alloy 800H by the SAW process.

3.3.5 Distribution of Elements After Exposure in a CGA

The distribution of selected elements was established on all weldments after exposure to the CGA for 1000 hours at 982°C (1800°F). Two factors acting independently or together which could affect the elemental distribution are diffusion and atmosphere-metal reactions occurring at the surface. The diffusion of an atom through an alloy is a function of the size of the diffusing atom, the crystal structure of the alloy, the concentration gradient and the temperature(15). Diffusion is an important consideration when alloys are exposed at elevated temperatures because it can result in the precipitation of new phases which are detrimental to structural properties. The formation of the brittle sigma phase in stainless steels is an often quoted example. Kirkendall porosity which was observed in some of our samples is a result of the atoms of one element diffusing faster in one direction than other atoms are diffusing in the opposite direction.

In the overlays made in this program a compositional gradient existed through the overlays and substrate. Since the diffusion rate (the rate of flow of atoms) is proportional to the concentration gradient and directed down it, it was anticipated that Cr and Al would tend to diffuse inward to the substrate and Fe outward from the substrate to the surface. The trend, therefore, would be to lower the Cr

and Al levels at the surface. Concurrently, atmosphere-metal reactions at the surface such as the formation of scales (Cr_2O_3, Al_2O_3, etc.) would cause localized concentration gradients at the scale-metal interface and diffusion toward the surface. Also, grain boundary and surface diffusion rates are much faster than the volume diffusion rate which complicates further the final distribution of elements.

The results obtained are given in Tables 59-79 and Figures 108-135. The cross-section on which the composition profiles were established on each overlay was immediately adjacent to the face of the specimen examined for corrosion (Figure 46). The differences observed in the location of the interface of overlay and substrate before and after exposure should not be attributed to the exposure since measurements were not made on the same specimen. Also, measurements after exposure were made with the scale-metal interface used as the reference point, which could be considerably different from the original "as welded" surface depending upon the degree of scaling and metal loss. In comparing the "before" and "after exposure" composition profiles, emphasis was made on major changes rather than subtle differences. The effect of the exposure on the composition profiles are discussed for each filler metal below.

3.3.5.1. AWS-ER309 Weldments. The post exposure data are given in Tables 59-61. The composition profiles for selected elements "before" and "after exposure" are given in Figures 108-111. The interface of the first and second layers in the inert gas deposited double layer overlays was inadvertently taken for the interface between the overlay and substrate and the composition profiles for that area are incomplete. However, despite this deficiency certain observations were made. These were as follows.

3.3.5.1.1. Chromium Distribution. A more uniform distribution of Cr was observed in the SAW deposited overlay after exposure than was observed before exposure, except at the interface of the overlay and substrate in both the single and double overlays (Figures 26, 108 and 109). In the overlays deposited with the inert gas processes, there was a large fluctuation in Cr content after exposure at the interface between layers in the double layer overlays (Figures 110 and 111) and at the interface of the overlay and substrate in the GTAW-HW single layer overlay (compare Figures 26 and 108). The Cr fluctuations are probably related to phase changes occurring at the interfaces.

3.3.5.1.2. Nickel Distribution. The distribution of Ni after exposure followed trends similar to those described for Cr above (Figures 109-111), although the fluctuation in Ni content at the interface between layers

obtained with the GTAW-HW deposited overlay was not as drastic as was obtained with Cr (Figure 111). The most uniform distribution of Ni before and after exposure was obtained with the SAW deposited overlay (Figure 109).

3.3.5.1.3. Manganese Distribution. This element also showed some fluctuation after exposure at the interfaces as described for the Cr and Ni. All profiles had lower Mn at the surface. Except for the surface values, all overlays had relatively uniform distribution.

3.3.5.2. INCONEL Filler Metal 72 Weldments. The data for the elemental distribution after exposure are given in Tables 62-70 and plotted in Figures 112-123. There appeared to be an inter-relationship between substrate and welding process on the distribution of Cr and Ni. No single weld process gave the most uniform distribution of Cr and Ni for the overlays deposited on all three substrates. The effects of exposure on Cr and Ni distribution will be discussed together, since these two elements acted in harmony, that is, in most cases when the Cr content was high the Ni content was low and vice versa. Some of the effects of exposure are discussed below.

3.3.5.2.1. Chromium and Nickel Distribution. The overlays deposited on 304L all showed a large fluctuation in Cr and Ni content after exposure (compare Figures 31, 112 and 113). The least fluctuation was obtained in the overlay deposited by the GTAW-HW process. The composition profiles for Cr and Ni for the overlays deposited by the submerged arc and gas metal arc processes had a saw tooth appearance and the Cr was at a higher level below the surface than was obtained with the GTAW-HW process (Figure 112).

The overlay deposited on 310SS by the SAW process was least affected by exposure in the CGA (Figures 32, 114, 115). The distribution of Cr and Ni in the SAW deposited overlay was very uniform after exposure with only a small difference in Cr and Ni content between layers. Conversely, large fluctuations in Cr and Ni were noted after exposure in the overlays deposited by the inert gas processes. The reason for the difference in response to the CGA exposure for the different welding processes is not known, although the fluctuation in Cr and Ni is probably associated with the precipitation of a second phase (alpha chromium).

The least change in the distribution of Cr and Ni after exposure in overlays deposited on any one substrate with all weld processes was obtained with the overlays deposited on INCOLOY Alloy 800H (Figures 28-30, 33, 116-120). The GMAW deposited overlay had the most uniform distribution after exposure. The overlay deposited by the SAW process

also had uniform distribution of Cr and Ni after some fluctuation near the scale-metal interface. The SAW deposited overlay had higher Cr and lower Ni content than the GMAW deposited overlay. After exposure the inert gas deposited overlays had large localized fluctuations in Cr and Ni near the interface of the overlay and substrate.

3.3.5.2.2. Iron Distribution. The changes in Fe distribution in the INCONEL Filler Metal 72 overlays due to exposure in the CGA at 982°C (1800°F) for 1000 hours were small regardless of welding process or the substrate upon which the overlays were deposited. The effects which were observed due to welding process or substrate are given below.

Very little change was observed with all welding processes in the overlays deposited on 304L (Figures 31 and 112). The distribution was more uniform at the interface of overlay and substrate after exposure. The most change occurred in the overlay deposited by the SAW process (Figures 29 and 119). In the overlays deposited on Type 310, the SAW deposited overlay was least affected by the exposure (Figures 32 and 114). Slight fluctuations were observed in the inert gas deposit overlays after exposure. All overlays on 310SS had a lower Fe content than the substrate in the area immediately adjacent to the interface. No change in Fe distribution was observed in the overlays deposited on INCOLOY Alloy 800H except in the lower layer in the overlay deposited by the GTAW-HW process (Figures 30 and 120). The overlay had a very uniform distribution in both layers in the "as welded" condition and after exposure higher Fe contents were observed in the layer nearest the substrate. The composition profile obtained in the exposed condition is more in agreement with expected results than was obtained in the "as welded" condition.

3.3.5.2.3. Titanium Distribution. Since Ti was identified in the scale of several overlays which formed protective scales upon exposure to the CGA (Table 58), it was thought that the composition profiles obtained after exposure would show a migration of Ti towards the overlay surface. This was not the general trend, although several overlay surfaces did have high Ti at or near the surface. The most general effect of exposure was a lessening of the fluctuation in the saw tooth type curves obtained in the "as welded" condition (Figures 121-123). After exposure very drastic changes occurred near the interfaces of overlays and substrates.

3.3.5.3 R139 Weldments. The data for the distribution of elements after exposure are given in Tables 71-79 and Figures 124-135. The effects of exposure on the distribution of the various elements are given below.

3.3.5.3.1. Chromium and Nickel Distribution. The distribution of Cr and Ni after exposure to the CGA was affected by the welding process and substrate (Figures 34-39 and 124-129). The relationship of Cr and Ni in the R139 overlays after exposure appeared to be more complex than was obtained with the INCONEL Filler Metal 72 overlays. In the latter the Cr and Ni distribution appeared to be related, that is, when the Cr increased there was a decrease in Ni at the same point and vice versa. This was not the case with all R139 overlays. The changes in Ni and Cr content were related as described above in all upper layers of the double layer overlays; however, there were some welds in which the Cr and Ni did not change in concert in the second layer or near the interface of the overlay and substrate.

The exposure had very little effect on Cr distribution of the overlays deposited on 304L by the SAW and GTAW-HW processes. The greatest changes in the composition profile were obtained with the GMAW process (Figures 34 and 124). Cr was more evenly distributed in the SAW and GTAW-HW deposits and Cr was at a higher level in the SAW deposited overlay. Ni was not as evenly distributed as Cr in these overlays but this was a carryover from the "as welded" condition. The overlays deposited on 304L had the most uniform distribution of Cr (but not the highest Cr content) after exposure with all weld processes (Figures 125-127). The Ni distribution on the R139 overlays after exposure was more dependent upon weld process. The SAW and GMAW "deposited" overlays were the most uniform and the least uniform was obtained with the GTAW-HW process for all substrates.

Considerably more fluctuation in Cr and Ni was obtained after exposure in the overlays deposited on Type 310 (Figures 35 and 128). The largest change in the composition profiles of the overlays on Type 310 were obtained in the overlays deposited by the SAW and GMAW processes. The distribution of Ni was related to the Cr distribution in that the Ni decreased where there was an increase in Cr and vice versa for all weld processes. This relationship was maintained throughout the overlay except at the interface of the overlay and substrate.

In the overlays deposited on INCOLOY Alloy 800H the overlay deposited by the SAW process underwent the least change in distribution of Cr and Ni due to the exposure. A saw tooth type distribution was obtained with the inert gas deposited overlays (Figures 35 and 129). The Ni distribution was related to the Cr distribution (Cr high, Ni low and vice versa) throughout the overlays deposited by the SAW and GMAW processes and in the upper layer of the overlay deposited by the GTAW-HW process. The distribution of Cr and Ni near the interfaces of the overlays and substrates for all welding processes and in the lower level of the GTAW-HW deposited overlay varied independently of each other.

3.3.5.3.2. Aluminum Distribution. The distribution of Al as a function of depth from the surface of the overlays before and after exposure for 1000 hours at 982°C (1800°F) are given in Figures 40-45 and 130-135. A low value of Al was measured in all exposed overlays at the scale-metal interface. (NOTE: A low value of Al was measured at the surface in six of the nine double layer overlays in the as welded condition.) Al content increased at greater depths in the overlay and reached a maximum below the scale-metal interface. At points below the surface at depths greater than the point at which the maximum Al content was measured, the Al content decreased to an area near the interface of overlay and substrate. In some cases, a second low Al value was obtained which may have been located at the interface of the overlay layers. Generally, the most uniform distribution of Al after exposure was obtained in the overlays deposited by the GTAW-HW process. The change in the distribution profile was affected by substrate and weld process as follows.

With the SAW and GMAW processes, the largest change in the Al distribution due to exposure was obtained in the overlays deposited on 304L, whereas, with the GTAW-HW process the least change in overlay Al distribution was found in the overlay on Type 304L (Figures 43-45 and 133-135). With the GTAW-HW process, a much more uniform distribution was obtained after exposure in the overlays deposited on 310SS and INCOLOY Alloy 800H than was obtained in the "as welded" condition. The largest change in distribution of Al due to exposure of the overlays deposited on 304L was obtained in the overlay deposited by the GMAW process (Figures 40 and 130). This overlay also had the most fluctuation in Al content near the interface of overlay and substrate. In the overlays deposited on 310 the greatest change in the distribution of Al after exposure was obtained in the overlays deposited by the inert gas processes (Figures 41 and 131). The SAW and GTAW-HW deposited overlays had the most uniform distribution after exposure of the overlays deposited on 310 but the GTAW-HW overlay contained a much higher Al level (Figure 131). The GMAW deposited overlay had the most fluctuation in Al content near the interface of overlay and substrate and the GTAW-HW deposited overlay had the least fluctuation near the interface after exposure. In the overlays deposited on INCOLOY Alloy 800H, most change in Al distribution due to exposure occurred in the overlays deposited by the inert gas processes (Figures 42 and 132). Most changes occurred in the surface layer of the GMAW deposited overlay and in the lower layer of the GTAW-HW deposited overlay. The overlays deposited by the inert gas processes also had more uniform distribution of Al after exposure than the SAW deposited overlay on INCOLOY Alloy

800H. The most erratic distribution of Al at the overlay-substrate interface was obtained with the GMAW process; however, the distribution was more uniform after exposure than in the as welded condition.

3.3.5.3.3. Iron Distribution. The effect of exposure for 1000 hours at 982°C (1800°F) on the distribution of Fe in the R139 overlays was related to the welding process used for deposition and the substrate as follows.

After exposure all overlays deposited on 304L had a uniform distribution of Fe for a depth of 3-4 mm (0.12-0.16 inches) below the scale-metal interface. The least effect on Fe distribution in the overlays deposited on 304L was obtained in the overlay deposited by the GTAW-HW process (Figures 40 and 130). The most fluctuation in the Fe distribution near the interface of the overlay and 304L substrate was obtained in the overlay deposited by the GTAW-HW process. This fluctuation in Fe content was present in the as welded condition.

The exposure of the overlays on Type 310 stainless steel resulted in a change of Fe distribution near the scale-metal interface in the SAW deposited overlay and in the upper layer in the inert gas deposited overlays (Figures 41 and 131). The Fe content in the inert gas deposited overlays decreased from the scale-metal interface to a location below the surface which appeared to be the interface of the layers in the double layer overlay. Beyond this depth the Fe content increased with increasing depth to the interface of the overlay and substrate. The SAW deposited overlay had a minimum Fe content just below the scale-metal interface (1 mm or .04 inch), then increased to a higher value and was reasonably uniform to an area about 3 mm (0.12 inches) from the interface of overlay and substrate.

The distribution of Fe was more uniform after exposure than in the as welded condition in all overlays deposited on INCOLOY Alloy 800H regardless of the welding process used for deposition (Figures 42 and 132). The most uniform Fe distribution was obtained in the SAW deposited overlay. As had occurred in the overlays deposited on 310, the minimum Fe content in the overlays deposited by the inert gas processes on INCOLOY Alloy 800H was obtained below the surface of the overlay. At depths in the overlay greater than the point at which the minimum value was obtained, the Fe content increased to an area near the interface of overlay and substrate, except for some fluctuations in Fe content near the interface. The fluctuations measured after exposure were less than were obtained in the as welded condition.

The substrate upon which the overlays were deposited did not affect the uniformity of the Fe content after exposure in the overlays deposited by the SAW process (Figures 43 and 133). When deposited by the GMAW or GTAW-HW processes, the distribution of Fe in the overlays deposited on 310SS was most affected by the exposure (Figures 44, 45, 134 and 135). Very little change in Fe distribution took place due to exposure in the overlays deposited by the GTAW-HW process on 304L and INCOLOY Alloy 800H.

3.3.5.4. Additional Comments on the Distribution of Chromium. The change in the distribution of Cr (and in most cases, a simultaneous change in the distribution of Ni in the INCONEL Filler Metal 72 and the upper layer of R139 overlays) were probably associated with the precipitation and/or growth of the alpha chromium phase. The fluctuation of the Cr and Ni contents giving a saw tooth type composition profile is believed to be related to the high Cr phase, alpha Cr, which has been observed in alloys of this type(16). The saw tooth type distribution curve was observed in some overlays in the "as welded" condition (Table 80). In the pre-exposure condition, the fluctuation in Cr distribution was not as pronounced as was obtained by the exposure. In some cases, the fluctuation in Cr content was not observed until after exposure, or if present in the "as welded" condition was accentuated after exposure. In the first case, the precipitation of alpha Cr occurred during exposure, or if present in the as welded condition was too fine to be detected with our microprobe analysis. When the alpha Cr was present in the as welded condition, exposure at temperature resulted in further precipitation, agglomeration and/or growth. The latter was observed in stress rupture tests of INCONEL Filler Metal 72 weld metal at 982°C (1800°F)(17). As shown in Table 80, no single welding process deposited an overlay on all substrates with a microstructure which was more prone to segregation or precipitation of the second phase upon exposure to elevated temperature. However, none of the overlays deposited on 304L showed the saw tooth type distribution in the "as welded" condition. The overlays deposited with the welding processes not shown in Table 80 did not have the saw tooth type distribution in the composition profiles after exposure. The welding process which gave the most uniform distribution of Cr after exposure for the overlays deposited on each substrate is shown in Table 81. These are the overlays which were not listed in Table 80 (after exposure) except for the omission of the R139 overlay deposited on INCOLOY Alloy 800H by the GTAW-HW process.

The fluctuation of Cr and Ni which was observed in the AWS-ER309 overlays was much less than was observed in the R139 and INCONEL Filler Metal 72 overlays. It is not expected that the high Cr alpha Cr phase would form in the

AWS-ER309 type composition. The microstructure of the "as welded" AWS-ER309 overlays consisted of delta ferrite and austenite.

4.0. SUMMARY OF OBSERVATIONS

Some observations which were made are given below.

(a) High integrity single and double layer overlays of AWS-ER309 and INCONEL Filler Metal 72 were deposited with three welding processes on Types 304L and 310 stainless steel and INCOLOY Alloy 800H. Fifteen of the eighteen R139 overlays were sound and three had mixed quality.

(b) The % dilution of the filler metal by the substrate was affected by the welding process and the filler metal composition.

(c) The compositions of the deposited overlays were affected by the composition of the filler metal and substrate, the % dilution, and the % recovery of elements across the welding arc. In addition, when deposited with the SAW process, the composition of the flux also affected the composition of the overlay.

(d) The % recovery of the elements was affected by the welding process and the composition of the substrate and filler metal.

(e) The recovery of Al in the R139 overlays was affected more by the welding process used for deposition than the dilution factor.

(f) The room temperature tensile strength of as welded composite specimens was not affected appreciably by the welding process, substrate or filler metal.

(g) The 1000-hour stress rupture strength at 982°C (1800°F) was affected by the welding process and substrate composition. The highest stress rupture strength was obtained with overlays deposited by the inert gas welding processes on INCOLOY Alloy 800H.

(h) The hardness of the INCONEL Filler Metal 72 and R139 overlays increased and the hardness of the AWS-ER309 overlays decreased after exposure for 1000 hours at 1800°F. Generally, hardness decreased in the heat affected zone and the substrate after exposure.

(i) Room temperature tensile strength decreased on all weldments after exposure in the CGA for 1000 hours at 982°C.

(j) The 310SS weldments had the largest percentage decrease in room temperature tensile ductility after exposure.

(k) The corrosion test conditions were considered to be very severe based upon the corrosion of unwelded specimens of Types 304L and 310 stainless steels and INCOLOY Alloy 800H.

(l) The best corrosion resistance with the AWS-ER309 overlaid on 304L was obtained with the SAW process.

(m) The INCONEL Filler Metal 72 overlays had good corrosion resistance when deposited with all weld processes on all substrates investigated.

(n) The R139 overlays provided good protection from the CGA environment but the corrosion resistance was affected by the welding process used for deposition and by the composition of the substrate.

(o) No single welding process produced a microstructure in the "as deposited" overlay on all substrates which was more prone to segregation or precipitation of a second phase (or phases) after exposure.

5.0 CONCLUSIONS

All overlays improved the corrosion resistance of the non-surfaced base plates of types 304L and 310 stainless steel and INCOLOY alloy 800H in a 1000-hour test in a 1% H_2S coal gasification environment at 982°C (1800°F). The 44%Cr-Ni-Ti filler metal, INCONEL Filler Metal 72, provided better corrosion resistance than the most corrosion resistant base plate, Type 310, over the widest range of welding processes and substrates. Based upon stress rupture properties, metallurgical stability and corrosion resistance, INCONEL Filler Metal 72 deposited as a double layer on INCOLOY alloy 800H is recommended for consideration in coal gasifier service.

6.0 FUTURE CONSIDERATIONS

Other work which should be considered for a better understanding of the results reported is as follows:

(1) The INCONEL Filler Metal 72 is only slightly lower in Cr than *INCONEL alloy 671 (44% vs. 49%) and it is expected that its corrosion resistance in coal gasification atmospheres should be similar to alloy 671. However, since recent work at ITTRI has shown a "breakdown" in corrosion resistance of some alloys after long times, as a precaution it may be advisable to get longer time tests on the INCONEL Filler Metal 72 overlays.

*Trademark of the Inco family of companies.

(2) The microstructural changes that occurred in the substrate, overlay and at their interface should be determined.

(3) Experiments should be performed to establish if the loss in tensile strength and ductility was due all or in part to the CGA, the temperature, the overlay or the substrate. This could be done by determining properties after exposing unwelded base metal and composite specimens in an argon atmosphere for 1000 hours at 982°C (1800°F).

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TABLE 1

CHEMICAL ANALYSES OF BASE PLATES AND FILLER METALS (Wt.%)

Base Plate or Filler Metal		C	Cr	Ni	Mn	Si	Fe	Mo	Al	Ti	S	P
304L SS		.028	18.25	10.35	1.68	.52	68.86[a]	.27	-	-	.020	.015
310 SS		.055	26.1	19.7	1.77	.44	51.58[a]	.37	<.005	<.01	.016	.024
INCOLOY Alloy 800H		.07	19.84	32.09	.53	.13	46.00	-	.43	.50	-	.002
INCONEL Filler Metal[b]	72-1	.035	43.5	55.57[a]	.14	.09	-	-	.055	.61	.001	.003
" " " [c]	72-2	.077	44.1	55.09[a]	.06	.09	-	-	.08	.50	.001	.003
" " " [d]	72-3	.03	44.54	54.58	.02	.16	.20	-	.08	.93	-	.004
R139-1[b]		.079	30.4	50.41[a]	.53	.04	14.5	-	3.65	.38	.003	.004
R139-2[c]		.043	31.6	50.13[a]	.55	.06	14.0	-	3.22	.51	.003	.001
R139-3[b]		.046	32.2	47.95[a]	.50	.08	15.2	-	3.37	.65	.004	.001
AWS-ER 309		.062	24.6	13.5	2.3	.34	59.18[a]	-	-	-	.005	.021

NOTES:
(a) By difference.
(b) Melted and processed at IRDC.
(c) Melted at IRDC, processed at Huntington Alloys, Inc. (HAI).
(d) Melted and processed at HAI.

TABLE 2

WELDING PARAMETERS

		Gas Tungsten Arc				
Weld Process	-	With Hot Wire Add	Gas Metal Arc	Submerged Arc		
Filler Metal	-	All	All	309	72	139
Amperage	-	240	280	240	240	(d)240
Voltage	-	11	32/33	33	33	33
Polarity	-	DCSP	DCRP	DCSP	DCSP	DCSP
Travel Speed	mm/s (in/min)	.85(2)	2.12(5)	2.12(5)	2.12(5)	2.12(5)
Wire Speed	mm/s (in/min)	-	(c)80.4(190)	84.7 (200)	101.6 (240)	(d)97.4 (230)
Shield (argon)	m^3/hr (cf/hr)	1.2(40)	1.5(50)	-	-	-
Trailing Shield (argon)	m^3/hr (cf/hr)	0.35(12)	1.5(50)	-	-	-
Oscillation Width	mm(in)	15.9(5/8)	22.2(7/8	22.2 (7/8)	22.2 (7/8)	22/2 (7/8)
Oscillation Frequency	cpm	30	62	62	62	62
Bead Overlap	mm(in)	3.21(1/8)	6.3(1/4)	3.2 (1/8)	3.2 (1/8)	3.2 (1/8)
No. of Passes per Layer	-	(a) 21	(a) 21	(a) 14	(a) 14	(a) 14
Restraint	-	(b) Welded to 82mm (3-1/4) in) thick		IN787 Strongback		
Interbead Temp (max)	°C(°F)	121(250)	121(250)	121 (250)	121 (250)	121 (250)
Flux	-	-	-	ARCOS S4	INCO FLUX 6	INCO FLUX 6
Power Source	-	LINDE HWM-5	LINDE SVI-500	LINDE SVI-511	LINDE SVI-500	LINDE SVI-500
Hot Wire Amperage	-	100	-	-	-	-
Hot Wire Feed	mm/s (in/min)	25.4(60)	-	-	-	-
Tungsten Diameter	mm(in)	3.2(1/8)	-	-	-	-
Filler Wire Diameter	mm(in)	1.55(.062)	(c)1.55(.062)	1.55 (.062)	1.55 (.062)	(d)1.55 (.062)

EXCEPTIONS

(a) Second layer of double layer overlays made with one less pass.
(b) Weld 6180 and 6181 were restrained by clamping to the platen with 12 bolts and stainless steel plates.
(c) Welds coded 6210, 6211, 6216 and 6217; R139 filler metal had a wire diameter of 2.36 mm (.093in) and a wire speed of 36.0 mm/s (85in/min)
(d) Welds 6212, 6213, 6218 and 6219; 280 amperes, wire speed 44.9 mm/s (106 in/min) and 2.36 mm (.093in) diameter wire.

TABLE 3

IDENTIFICATION OF WELDMENTS

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

NOTES: (a) GMAW = Gas Metal Arc, SAW = Submerged Arc, GTAW-HW = Gas-Tungsten Arc with Hot Wire.

(b) INCONEL Filler Metal 72.

TABLE 4

THICKNESS OF OVERLAYS

Code	mm	Inches	Code	mm	Inches
6180	7.77	.306	6201	6.40	.252
6181	4.50	.177	6202	7.72	.304
6182	8.31	.327	6203	4.93	.194
6183	4.77	.188	6204	7.01	.276
6184	7.98	.314	6205	4.17	.164
6185	4.85	.191	6206	9.58	.377
6186	8.33	.328	6207	5.59	.220
6187	4.95	.195	6208	8.13	.320
6188	10.31	.406	6209	4.39	.173
6189	6.42	.253	6210	7.47	.294
6190	7.11	.280	6211	4.70	.185
6191	4.65	.183	6212	10.00	.394
6192	9.07	.357	6213	5.84	.230
6193	5.79	.228	6214	7.65	.301
6194	10.08	.397	6215	4.55	.179
6195	6.81	.268	6216	7.90	.311
6196	7.92	.312	6217	4.50	.177
6197	5.51	.217	6218	9.63	.379
6198	8.20	.323	6219	5.84	.230
6199	5.23	.206	6220	7.72	.304
6200	10.69	.421	6321	4.75	.187

NOTE (a) Original measurements in .01 inches, average of 24 measurements per weld from two specimens taken from both the longitudinal and transverse direction of welding.

TABLE 5

RESULTS ON WELDMENTS WITH MIXED RESULTS IN BEND TESTS - R139 FILLER METAL

Code No.	(b)Orientation	Weld Process	Substrate	% Elong. in 25.4 mm (1.0in)	Bend Angle	Remarks
(a)6206-7	Longitudinal	SAW	304L	22	180	
-8	"	"	"	16	35	Crack Opened at GTAW Repair
-1	Transverse	"	"	21	70	" " " " "
-2	"	"	"	14	44	Crack Opened below GTAW Repair
6208-7	Longitudinal	GTAW-HW	304L	21	180	
-8	"	"	"	24	58(c)	
6208-1&2	Transverse	"	"	21	180	
6218-7&8	Longitudinal	SAW	INCOLOY ALLOY 800H	21	180	
6218-1	Transverse	"	" "	9	28(c)	
-2	"	"	" "	20	109(c)	

NOTES: (a) All double layer overlays.
(b) Relationship of welding direction to 12.7 cm (5 inch) side of specimen.
(c) Small defects present before bending; tunneling defect repaired by GTAW process.

TABLE 6

EFFECT OF WELD PROCESS, SUBSTRATE AND FILLER METAL ON PERCENT DILUTION

Process	Substrate	Dilution,%					
		Single Layer			Double Layer		
		309	R139	FM72	309	R139	FM72
SAW	304L	25	12	21	14	8	13
	310	--	17	20	--	11	10
	800H	--	8	13	--	7	9
GMAW	304L	31	6	27	19	4	15
	310	--	8	22	--	3	16
	800H	--	5	22	--	2	9
GTAW-HW	304L	33	24	31	20	20	16
	310	--	19	27	--	9	15
	800H	--	18	20	--	12	11

TABLE 7

COMPOSITIONS OF OVERLAYS (Wt.%)

(a) Code	Weld Process	Substrate	Filler Metal	C	Cr	Ni	Mn	Si	Fe	Al	Ti	P	S
6180	GMAW	304L	ER309	.060	23.4	12.6	1.82	.46	(b) 61.63	-	-	.022	.007
6181	GMAW	304L	ER309	.057	22.7	12.1	1.72	.47	(b) 62.92	-	-	.026	.008
6182	SAW	304L	ER309	.076	24.2	12.8	1.90	.94	(b) 60.05	-	-	.021	.013
6183	SAW	304L	ER309	.068	22.9	11.9	1.84	.95	(b) 62.30	-	-	.027	.012
6184	GTAW-HW	304L	ER309	.049	23.5	12.7	1.97	.44	(b) 61.30	-	-	.020	.014
6185	GTAW-HW	304L	ER309	.039	22.2	12.3	1.91	.45	(b) 63.06	-	-	.024	.012
6186	GMAW	304L	FM72-1	.064	40.2	(b) 51.67	.36	.21	7.0	-	.48	.006	.005
6187	GMAW	304L	FM72-1	.046	36.0	(b) 42.38	.54	.26	20.4	-	.36	.007	.009
6188	SAW	304L	FM72-2	.075	41.4	52.1	.60	.36	6.4	-	.22	.005	.006
6189	SAW	304L	FM72-2	.050	37.6	43.9	.80	.39	16.8	-	.15	.009	.006
6190	GTAW-HW	304L	FM72-2	.054	40.3	48.6	.42	.15	10.5	-	.40	.008	.006
6191	GTAW-HW	304L	FM72-2	.048	35.8	38.1	.75	.23	22.9	-	.31	.014	.008
6192	GMAW	310	FM72-3	.034	40.1	43.8	.44	.21	7.3	-	.35	.008	.004
6193	GMAW	310	FM72-3	.040	36.5	37.9	.67	.27	20.7	-	.24	.012	.008
6194	SAW	310	FM72-2	.032	40.9	(b) 52.09	.52	.31	5.9	.060	.17	.003	.006
6195	SAW	310	FM72-2	.065	37.9	(b) 45.18	.65	.31	15.6	.052	.13	.007	.008
6196	GTAW-HW	310	FM72-2	.048	40.3	(b) 50.51	.34	.09	8.2	.058	.37	.008	.007
6197	GTAW-HW	310	FM72-2	.059	36.8	(b) 41.72	.61	.16	20.2	.049	.21	.011	.009
6198	GMAW	INCOLOY ALLOY 800H	FM72-3	.049	40.8	52.9	.22	.20	3.7	.15	.45	-	.001
6199	GMAW	" "	FM72-3	.078	34.6	46.2	.32	.20	18.6	.21	.42	-	.002
6200	SAW	" "	FM72-2	.078	40.6	53.9	.46	.40	3.6	.27	.16	.004	.003
6201	SAW	" "	FM72-2	.078	36.5	50.3	.44	.40	10.8	.26	.19	.004	.005
6202	GTAW-HW	" "	FM72-2	.045	39.1	52.2	.25	.14	6.5	.23	.42	.003	.006
6203	GTAW-HW	" "	FM72-2	.058	34.8	47.3	.30	.16	16.4	.30	.41	.003	.006
6204	GMAW	304L	R139-1	.063	33.9	45.0	.67	.11	19.0	3.2	.44	-	.003
6205	GMAW	304L	R139-1	.053	32.1	41.8	.76	.17	26.5	2.7	.39	-	.005
6206	SAW	304L	R139-1	.12	29.2	45.6	1.04	.80	15.2	2.0	.59	.005	.002
6207	SAW	304L	R139-1	.091	28.0	39.3	1.15	.65	20.4	1.8	.48	.012	.006
6208	GTAW-HW	304L	R139-2	.047	29.8	43.7	.64	.14	22.4	2.9	.36	.006	.007
6209	GTAW-HW	304L	R139-2	.028	28.9	36.0	.75	.14	32.1	2.4	.32	.011	.009
6210	GMAW	310	R139-3	.064	33.3	45.2	.59	.11	19.0	3.0	.40	.005	.007
6211	GMAW	310	R139-3	.057	31.7	38.7	.75	.16	25.3	2.6	.27	.004	.008
6212	SAW	310	R139-3	.076	32.2	44.3	.82	.73	19.8	1.8	.54	.006	.003
6213	SAW	310	R139-3	.068	31.3	36.4	.98	.70	31.4	1.0	.35	.009	.004
6214	GTAW-HW	310	R139-2	.046	32.3	45.4	.78	.15	22.9	2.8	.38	-	.006
6215	GTAW-HW	310	R139-2	.047	30.9	37.3	1.0	.23	32.3	2.0	.26	-	.009
6216	GMAW	INCOLOY ALLOY 800H	R139.3	.066	32.8	46.1	.53	.13	17.7	2.9	.43	.003	.004
6217	GMAW	" "	R139-3	.058	30.1	41.9	.53	.11	28.1	2.2	.41	.004	.002
6218	SAW	" "	R139-3	.072	31.7	45.7	.78	.80	19.0	1.7	.60	.003	.002
6219	SAW	" "	R139-3	.073	29.2	41.6	.73	.53	29.2	1.5	.50	.007	.001
6220	GTAW-HW	" "	R139-3	.042	30.6	41.5	.49	.04	22.1	2.9	.45	.004	.003
6321	GTAW-HW	" "	R139-2	.052	28.8	39.1	.49	.04	29.3	2.4	.43	.006	.004

NOTES: (a) Even numbered codes are double layer overlays; odd numbered codes are single layer overlays.

(b) By difference.

TABLE 8

PERCENT RECOVERY OF CALCULATED THEORETICAL VALUES

Code	Weld Process	Filler Metal and Substrate	C	Cr	Ni	Mn	Si	Fe	Al	Ti
6180	GMAW	309 on 304L	100	97	97	86	121	102	-	-
6181	"	" "	112	100	97	82	117	101	-	-
6182	SAW	" "	158	100	98	87	192	100	-	-
6183	"	" "	145	99	94	86	250	101	-	-
6184	GTAW-HW	" "	91	103	97	91	116	101	-	-
6185	"	" "	76	101	99	91	112	101	-	-
6186	GMAW	FM 72 on 304L	169	97	99	144	150	151	-	89
6187	"	" "	139	98	98	96	124	110	-	80
6188	SAW	" "	121	97	99	286	255	181	-	52
6189	"	" "	75	97	96	200	217	116	-	38
6190	GTAW-HW	" "	79	97	97	156	112	148	-	91
6191	"	" "	78	99	92	134	103	104	-	90
6192	GMAW	FM 72 on 310	106	94	86	275	117	160	-	45
6193	"	" "	113	90	81	172	123	182	-	33
6194	SAW	" "	43	95	98	288	238	189	-	39
6195	"	" "	89	94	94	167	387	151	-	32
6196	GTAW-HW	" "	67	96	98	162	82	150	-	88
6197	"	" "	83	94	92	120	89	145	-	58
6198	GMAW	FM 72 on 800H	120	96	100	244	125	87	136	55
6199	"	" "	201	88	93	246	133	176	134	54
6200	SAW	" "	101	94	99	418	308	257	270	35
6201	"	" "	103	89	97	367	400	181	200	38
6202	GTAW-HW	" "	62	93	98	227	140	198	192	87
6203	"	" "	76	89	94	200	163	178	200	82
6204	GMAW	R 139 on 304L	82	111	90	124	220	125	89	116
6205	"	" "	70	108	87	127	243	149	79	108
6206	SAW	" "	160	99	93	173	1026	81	60	151
6207	"	" "	125	97	86	172	632	97	56	145
6208	GTAW-HW	" "	120	102	94	107	175	122	96	77
6209	"	" "	71	96	89	91	70	118	98	82
6210	GMAW	R 139 on 310	136	103	96	113	122	119	91	65
6211	"	" "	122	100	85	125	145	140	84	45
6212	SAW	" "	153	100	96	141	405	110	61	90
6213	"	" "	144	100	84	136	500	147	36	65
6214	GTAW-HW	" "	104	103	95	124	118	131	94	82
6215	"	" "	104	101	84	128	144	153	77	63
6216	GMAW	R 139 on 800H	140	102	97	106	162	89	88	67
6217	"	" "	123	95	89	106	137	168	68	64
6218	SAW	" "	150	102	96	150	457	116	53	94
6219	"	" "	152	94	89	146	631	165	48	78
6220	GTAW-HW	" "	93	98	86	91	86	133	94	87
6321	"	" "	140	97	83	89	57	151	87	85

TABLE 9

THEORETICAL COMPOSITIONS OF (a) OVERLAYS BASED UPON DILUTION MEASUREMENTS AND 100% RECOVERY (WT%)

Code	Weld Process	Filler Metal and Substrate	C	Cr	Ni	Mn	Si	Fe	Al	Ti
6180	GMAW	309 on 304L	.060	24.01	13.06	2.12	.38	60.33(a)	-	-
6181	"	" "	.051	22.63	12.52	2.11	.40	62.18(b)	-	-
6182	SAW	" "	.048	24.17	13.09	2.18	.49	59.95(b)	-	-
6183	"	" "	.047	23.01	12.71	2.14	.38	61.59(b)	-	-
6184	GTAW-HW	" "	.054	24.04	13.10	2.17	.38	60.45(b)	-	-
6185	"	" "	.051	22.50	12.46	2.09	.40	62.36(b)	-	-
6186	GMAW	FM 72 on 304L	.038	41.47	52.01	.25	.14	4.63	-	.54
6187	"	" "	.033	36.68	43.36	.56	.21	18.59	-	.44
6188	SAW	" "	.062	42.73	52.74	.21	.15	3.53	-	.43
6189	"	" "	.067	38.67	45.69	.40	.18	14.46	-	.39
6190	GTAW-HW	" "	.068	41.53	49.82	.27	.13	7.10	-	.44
6191	"	" "	.062	36.09	41.53	.56	.22	21.35	-	.34
6192	GMAW	FM 72 on 310	.032	42.77	50.91	.16	.18	4.55	-	.78
6193	"	" "	.035	40.48	46.91	.39	.22	11.35	-	.72
6194	SAW	" "	.075	42.86	53.17	.18	.13	3.12	-	.43
6195	"	" "	.073	40.50	48.08	.39	.08	10.32	-	.40
6196	GTAW-HW	" "	.072	42.12	51.54	.21	.11	5.45	-	.42
6197	"	" "	.071	39.24	45.59	.51	.18	13.93	-	.36
6198	GMAW	FM 72 on 800H	.041	42.35	52.74	.09	.15	4.25	.11	.82
6199	"	" "	.039	39.10	49.63	.13	.16	10.28	.16	.84
6200	SAW	" "	.077	43.11	54.47	.11	.13	1.40	.10	.46
6201	"	" "	.076	40.95	52.10	.12	.10	5.98	.13	.50
6202	GTAW-HW	" "	.073	42.24	53.53	.11	.10	3.28	.12	.48
6203	"	" "	.076	39.25	50.49	.15	.10	9.20	.15	.50
6204	GMAW	R 139 on 304L	.077	30.50	49.90	.54	.05	15.22	3.59	.38
6205	"	" "	.076	29.67	48.01	.60	.07	17.76	3.43	.36
6206	SAW	" "	.075	29.43	47.20*	.62	.08	18.85(c)	3.36	.39
6207	"	" "	.073	28.94	45.60*	.67	.10	21.02(c)	3.21	.33
6208	GTAW-HW	" "	.039	30.96	46.74	.60	.08	18.34	3.03	.46
6209	"	" "	.039	28.40	40.58	.82	.17	27.17	2.45	.39
6210	GMAW	R 139 on 310	.047	32.16	47.21	.52	.09	16.00	3.31	.62
6211	"	" "	.047	31.71	45.69	.60	.11	18.11	3.10	.60
6212	SAW	" "	.050	32.05	45.99	.58	.18	17.96	2.97	.60
6213	"	" "	.047	31.17	43.15	.72	.14	21.39	2.80	.54
6214	GTAW-HW	" "	.044	31.47	47.70	.63	.09	17.48	2.99	.46
6215	"	" "	.045	30.55	44.35	.78	.13	21.14	2.61	.41
6216	GMAW	R 139 on 800H	.047	32.09	47.64	.50	.08	15.85	3.31	.64
6217	"	" "	.047	31.58	47.15	.50	.08	16.74	3.22	.64
6218	SAW	" "	.048	31.96	47.44	.52	.12	16.32	3.23	.64
6219	"	" "	.048	31.21	46.68	.50	.08	17.66	3.13	.64
6220	GTAW-HW	" "	.045	31.13	48.26	.54	.06	16.60	3.08	.50
6321	"	" "	.037	29.60	47.07	.55	.07	19.44	2.75	.51

(a) upper layer of double layer
(b) calculated based upon Fe content of filler and base metals established by difference
(c) calculated based upon Fe content of base metal established by difference
*calculated based upon Ni content of filler metal established by difference

TABLE 10

METHOD OF CALCULATION OF THEORETICAL COMPOSITIONS OF OVERLAYS (WT.%)

(A) For a single layer or first layer in a double layer overlay

$$\left(1 - \frac{\%\ \text{dilution of single layer}}{100}\right) \times (\%\ \text{element in filler metal}) + \left(\frac{\%\ \text{dilution of single layer}}{100}\right) (\%\ \text{element in base metal})$$

For the second layer in double overlays

$$\left(1 - \frac{\%\ \text{dilution of single layer}}{100}\right) \times (\%\ \text{element in filler metal}) + \left(\frac{\%\ \text{dilution of single layer}}{100}\right) (\%\ \text{element analyzed in single layer overlay})$$

For example - % Cr in Welds 6181 and 6180

W6181 Single layer or first layer of a double layer overlay, W6180

$$\left(1 - \frac{31}{100}\right)(24.60) + \left(\frac{31}{100}\right)(18.25) = (0.069)(24.60) + (.31)(18.25) =$$

$$16.97 + 5.66 = 22.63$$

W6180 Second layer of a double layer overlay

$$(.69)(24.60) + (.31)(22.70) = 16.97 + 7.04 = 24.01$$

TABLE 11

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF IRON IN THE OVERLAY
(% OF THEORETICAL COMPOSITION)

Process	SAW- Double Layer			SAW-Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	100	-	-	101	-	-
FM R 139	81	110	116	97	147	165
FM 72	181	189	257	116	151	181

Process	GMAW-Double Layer			GMAW-Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	102	-	-	101	-	-
FM R 139	125	119	89	149	140	168
FM 72	151	160	97	110	182	176

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	101	-	-	101	-	-
FM R 139	122	131	131	118	153	151
FM 72	148	150	198	104	145	178

TABLE 12

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF CHROMIUM IN THE OVERLAY (% OF THEORETICAL COMPOSITION)

Process	SAW Double Layer			SAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	100	-	-	99	-	-
FM R 139	99	100	102	97	100	94
FM 72	97	95	94	97	94	89

Process	GMAW Double Layer			GMAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	97	-	-	100	-	-
FM R 139	111	103	102	108	100	95
FM 72	97	94	96	98	90	88

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	103	-	-	101	-	-
FM R 139	102	103	98	96	101	97
FM 72	97	96	93	99	94	89

TABLE 13

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF NICKEL IN THE OVERLAY
(% OF THEORETICAL COMPOSITION)

Process	SAW-Double Layer			SAW-Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	98	-	-	94	-	-
FM R 139	97	96	96	86	84	89
FM 72	99	98	99	96	94	97

Process	GMAW Double Layer			GMAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	97	-	-	97	-	-
FM R 139	90	96	97	87	85	89
FM 72	99	86	100	98	81	93

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	98	-	-	99	-	-
FM R 139	94	95	86	89	84	83
FM 72	97	98	98	92	92	94

TABLE 14

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF SILICON IN THE OVERLAY
(% OF THEORETICAL COMPOSITION)

Process	SAW Double Layer			SAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	192	-	-	250	-	-
FM R 139	1000	405	457	650	500	631
FM 72	255	238	308	217	387	400

Process	GMAW Double Layer			GMAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	121	-	-	117	-	-
FM R 139	220	122	162	243	145	137
FM 72	150	117	125	124	123	133

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	116	-	-	112	-	-
FM R 139	175	118	86	70	114	57
FM 72	112	82	140	103	89	163

TABLE 15

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF MANGANESE IN THE OVERLAY (% OF THEORETICAL COMPOSITION)

Process	SAW Double Layer			SAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	87	-	-	86	-	-
FM R 139	173	141	150	172	136	146
FM 72	286	288	418	200	162	367

Process	GMAW Double Layer			GMAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	86	-	-	82	-	-
FM R 139	124	113	106	127	125	106
FM 72	144	275	244	96	172	246

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	91	-	-	91	-	-
FM R 139	107	124	91	91	128	89
FM 72	156	162	227	134	120	200

TABLE 16

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF TITANIUM IN THE OVERLAY
(% OF THEORETICAL COMPOSITION)

Process	SAW Double Layer			SAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM R 139	151	90	94	145	65	78
FM 72	51	40	35	38	32	38

Process	GMAW Double Layer			GMAW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM R 139	116	65	67	108	45	64
FM 72	89	45	55	80	33	54

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM R 139	77	82	87	82	63	85
FM 72	91	88	87	90	58	82

TABLE 17

EFFECT OF WELDING PROCESS, SUBSTRATE AND FILLER METAL ON THE RECOVERY OF CARBON IN THE OVERLAY (% OF THEORETICAL COMPOSITION)

Process / Substrate	SAW Double Layer 304L	310	800H	SAW Single Layer 304L	310	800H
FM 309	158	-	-	145	-	-
FM R 139	160	153	150	125	144	152
FM 72	121	43	101	75	89	103

Process / Substrate	GMAW Double Layer 304L	310	800H	GMAW Single Layer 304L	310	800H
FM 309	100	-	-	112	-	-
FM R 139	82	136	140	70	122	123
FM 72	169	106	120	139	113	201

Process / Substrate	GTAW-HW Double Layer 304L	310	800H	GTAW-HW Single Layer 304L	310	800H
FM 309	91	-	-	76	-	-
FM R 139	120	104	93	71	104	140
FM 72	79	67	62	78	83	76

TABLE 18

EFFECT OF WELD PROCESS, SUBSTRATE AND NUMBER OF LAYERS ON ALUMINUM CONTENT OF R139 OVERLAYS

Process	Substrate	No. of Layers	% Al	% Dilution	% Recovery[a]
SAW	304L SS	2	2.0	8	60
		1	1.8	12	56
	310SS	2	1.8	11	61
		1	1.0	17	36
	800H	2	1.7	7	53
		1	1.5	8	48
GMAW	304L SS	2	3.2	4	89
		1	2.7	6	79
	310SS	2	3.0	3	91
		1	2.6	8	84
	800H	2	2.9	2	88
		1	2.2	5	68
GTAW-HW	304L SS	2	2.9	20	96
		1	2.4	24	98
	310SS	2	2.8	9	94
		1	2.0	19	77
	800H	2	2.9	12	94
		1	2.4	18	87

(a) Percentage of theoretical composition based upon dilution measurement.

TABLE 19

DISTRIBUTION OF ELEMENTS-AWS-ER309 ON 304L-GMAW PROCESS-AS WELDED (WT.%)

Distance From Surface (mm)	Ni	Cr	Mn	S	Fe[b]
W6180 DOUBLE LAYER					
0	11.01	22.21	1.95	.00	64.85
1[a]	11.60	23.90	1.98	.02	64.48
2	12.24	23.85	1.93	.00	61.98
3	12.50	23.85	1.89	.02	63.63
4	12.12	23.70	1.97	.02	62.19
5	11.45	22.25	1.99	.01	64.30
6	11.38	22.40	2.01	.03	64.18
7	11.40	22.35	2.01	.00	64.24
Interface[c]					
7.6	10.85	18.77	1.79	.02	68.57
7.8	9.58	19.30	1.81	.00	69.31
8.0	9.42	19.20	1.85	.00	69.53
8.2	9.70	19.09	1.78	.00	69.43
9.0	10.02	18.95	1.83	.02	69.18
15.0[d]	10.16	18.97	1.83	.04	69.00
W6181 SINGLE LAYER					
0	11.30	22.75	1.84	.01	61.10
1	11.18	22.96	1.87	.03	63.95
2	11.37	22.79	1.87	.02	63.96
3	11.40	22.67	1.88	.02	64.03
4	11.53	22.64	1.84	.00	63.99
5	10.63	22.18	1.76	.03	66.40
Interface					
6	9.87	19.26	.00	.00	69.07
15[d]	10.03	19.19	.03	.03	69.02

(a) Original readings taken in 100 micron steps.
(b) Fe - by difference.
(c) Overlay and substrate.
(d) Approximate center of microprobe sample.

TABLE 20

DISTRIBUTION OF ELEMENTS - AWS-ER309 ON 304L - AS WELDED (Wt.%)

W6182 - Double Layer - SAW PROCESS

Distance From Surface (mm)	Ni	Cr	Mn	S	(a)Fe
0	12.14	24.96	1.85	.00	61.05
1	12.09	25.11	1.99	.00	60.81
2	12.28	25.09	2.12	.01	60.50
3	12.21	25.01	2.12	.00	60.66
4	12.33	25.01	2.05	.00	60.60
5	11.89	23.69	2.12	.02	62.29
6	11.79	23.50	1.98	.01	62.72
7	11.83	23.69	2.06	.00	62.42
8	11.91	23.69	2.10	.00	62.29
9	11.50	23.40	1.97	.04	63.09
Interface (b)					
10	10.54	19.44	1.88	.00	68.14
11	10.28	18.96	1.88	.00	68.95
15 (c)	10.44	18.77	1.83	.00	68.96

W6183 - Single Layer - SAW PROCESS

Distance From Surface (mm)	Ni	Cr	Mn	S	Fe
0	11.92	23.36	1.89	.02	62.82
1	11.66	23.31	2.01	.03	62.99
2	11.75	23.50	2.00	.02	62.72
3	11.74	23.20	2.00	.02	63.03
4	11.44	23.52	2.09	.00	62.94
5	11.68	23.21	1.99	.24	62.89
Interface (b)					
6	10.19	19.18	1.77	.03	68.84
7	10.40	18.92	1.83	.03	68.82
15(c)	10.11	18.94	1.71	.03	69.24

W6184 - Double Layer - GTAW-HW PORCESS

0	12.06	24.34	1.98	.03	61.59
1	12.26	24.91	2.19	.06	60.62
2	12.22	24.66	2.07	.02	61.00
3	12.41	24.33	2.14	.04	61.09
4	12.45	24.74	2.13	.02	60.66
5	12.28	24.43	2.05	.04	61.20
6	11.82	23.09	2.03	.01	63.06
7	11.93	22.15	2.05	.04	63.83
8	11.61	21.76	1.95	.05	64.63
Interface (b)					
9	9.98	19.04	1.75	.03	69.20
10	10.00	18.79	1.84	.08	69.22
15 (c)	10.09	18.81	1.73	.04	69.33

W6185 - Single Layer - GTAW-HW PROCESS

0	11.59	22.82	2.13	.02	63.43
1	11.80	23.24	2.03	.03	62.89
2	11.64	22.86	2.04	.04	63.42
3	11.77	22.19	2.04	.08	63.91
4	11.75	22.71	1.99	.05	63.49
5	11.08	22.40	1.99	.05	64.47
Interface (b)					
6	10.21	19.00	1.78	.04	68.97
7	10.36	18.59	1.77	.04	69.24
15 (c)	10.44	18.78	1.78	.04	68.97

NOTES: (a) Fe - by difference.
(b) Overlay and substrate.
(c) Approximate center of sample.

TABLE 21

EFFECT OF WELD PROCESS AND SUBSTRATE ON THE DEPTH OF 35 AND 40% CHROMIUM IN SINGLE AND DOUBLE LAYER INCONEL FILLER METAL 72 OVERLAYS

Substrate	SAW				GMAW				GTAW-HW			
	Distance From Surface		Distance From Interface		Distance From Surface		Distance From Interface		Distance From Surface		Distance From Interface	
	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
35% Cr Level - Double Layer												
304L	10.3	(0.41)	0.1	(0.004)	6.1	(0.24)	0.1	(0.004)	7.1[a]	(0.28)	0.4	(0.016)
310	9.4	(0.37)	0	(0)	7.9	(0.31)	0	(0)	7.9	(0.31)	0.1	(0.004)
INCOLOY Alloy 800H	10.1	(0.40)	0.1	(0.004)	5.9	(0.23)	1.3	(0.05)	6.8	(0.27)	0	(0)
35% Cr Level - Single Layer												
304L	6.6	(0.26)	0.1	(0.004)	4.2	(0.17)	0.4	(0.016)	4.1[b]	(0.16)	0.3	(0.012)
310	6.4	(0.25)	0	(0)	5.7	(0.23)	0	(0)	5.6	(0.22)	0.1	(0.004)
INCOLOY Alloy 800H	5.9	(0.23)	0.2	(0.008)	5.3[c]	(0.21)	0.1	(0.004)	3.5	(0.14)	0	0
40% Cr Level - Double Layer												
304L	6.6	(0.26)	3.8	(0.15)	4.3	(0.17)	1.9	(0.08)	4.5	(0.18)	3.0	(0.12)
310	8.0	(0.32)	1.4	(0.06)	5.3	(0.21)	2.6	(0.10)	7.1	(0.28)	0.9	(0.036)
INCOLOY Alloy 800H	6.0	(0.24)	4.2	(0.17)	5.3	(0.21)	1.9	(0.08)	5.1[d]	(0.20)	1.7	(0.07)
40% Cr Level - Single Layer												
304L	0.4	(0.16)	6.0	(0.24)	-	-	-	-	-	-	-	-
310	5.3[e]	(0.21)	1.1	(0.04)	-	-	-	-	-	-	-	-

NOTES:
(a) One reading <35% at 6 mm (0.24 in) below surface.
(b) Two readings <38% at 1 and 2 mm (0.04 and 0.08 in) below surface.
(c) One reading <35% at surface and 3 mm (0.12 in) below surface.
(d) One reading <40% at 6 mm (0.24 in) below surface otherwise >40% for complete depth of overlay, 6.8 mm (0.27 in).
(e) One reading <40% at 3 mm (0.12 in) below surface.

TABLE 22

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72
OVERLAYS ON 304L SUBSTRATE-GMAW PROCESS - AS WELDED (Wt.%)

W6186 - Double Layer					
Distance from Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	47.95	42.42	10.09	0.25	0.32
1	43.51	45.90	10.43	0.30	0.50
2	46.77	42.95	9.66	0.44	0.33
3	45.79	43.39	10.42	0.28	0.38
4	47.60	41.96	10.21	0.33	0.39
5	37.97	35.13	25.00	0.29	0.61
5.5	38.42	36.06	25.32	0.24	0.71
5.6	36.60	34.80	23.13	0.40	0.67
5.7	39.07	36.47	23.68	0.25	0.60
5.8	36.13	34.43	26.10	0.24	0.79
5.9	35.33	35.63	27.55	0.21	0.68
6.0	36.03	36.93	22.99	0.21	0.73
6.1	35.95	37.01	26.53	0.21	1.00
6.2	30.43	30.94	42.22	0.10	1.08
Interface - Overlay and Substrate					
6.3	9.94	18.97	67.85	0.00	1.79
6.4	9.81	19.11	68.34	0.00	1.76
6.5	10.32	19.01	67.98	0.00	1.72
6.6	10.09	19.00	68.02	0.00	1.77
11.2	10.30	18.76	67.55	0.00	1.83

W6187 - Single Layer					
Distance from Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	36.96	39.43	24.37	0.13	0.90
1	36.74	35.20	27.44	0.14	0.62
2	36.92	34.79	27.73	0.12	1.00
3	36.27	34.82	24.72	0.33	0.73
4	35.80	37.82	25.92	0.16	0.69
4.1	36.08	35.27	25.81	0.19	0.74
4.2	36.61	35.70	28.06	0.19	0.83
4.3	34.17	33.60	32.07	0.21	0.74
4.4	35.18	35.81	25.19	0.28	0.86
4.5	34.35	37.09	26.91	0.15	0.90
4.6	31.02	33.07	31.49	0.11	1.10
Interface - Overlay and Substrate					
4.7	9.74	18.99	67.45	0.00	1.68
4.8	10.43	18.92	67.71	0.00	1.87
4.9	9.97	19.20	67.18	0.00	1.65
5.0	9.60	19.37	67.64	0.00	1.72
9.6	10.27	18.99	67.47	0.00	1.75

TABLE 23

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 - 304L WELDMENTS, SAW PROCESS - AS WELDED (Wt.%)

Weld 6188 - Double Layer					
Distance From Top Surface (mm)	Cr	Ni	Mn	Fe	Ti
Edge	40.90	50.76	.45	7.27	.18
1	43.25	48.78	.53	6.72	.25
2	44.32	50.08	.77	7.03	.16
3	42.76	47.98	.56	6.33	.18
4	41.60	48.49	.44	6.71	.11
5	44.33	49.52	.56	6.58	.16
6	41.69	51.43	.45	6.50	.20
7	39.08	40.76	1.01	21.40	.12
8	36.38	39.65	.84	24.58	.09
9	35.55	38.58	.79	21.35	.15
10	37.07	40.16	.72	20.81	.11
10.1	37.40	38.72	.90	23.41	.15
10.2	34.95	37.97	.70	27.55	.23
10.3	36.93	39.49	.93	22.05	.12
10.4	32.69	35.14	1.03	27.61	.12
Interface					
10.5	19.43	9.62	1.71	68.52	.00
10.6	19.01	9.87	1.78	69.83	.00
10.7	19.62	10.13	1.41	68.47	.00
15.4	19.37	9.72	1.69	68.48	.00

Weld 6189 - Single Layer					
Distance From Top Surface (mm)	Cr	Ni	Mn	Fe	Ti
Edge	42.14	44.92	.91	14.95	.06
1	37.75	45.18	.60	16.89	.14
2	39.17	44.07	.78	16.68	.06
3	39.81	44.65	.74	15.35	.13
4	37.46	43.77	.71	15.32	.26
5	36.37	41.97	.71	20.58	.13
6	38.48	42.35	.80	19.95	.16
6.1	39.34	41.93	.92	18.47	.17
6.2	36.99	38.97	.77	23.16	.14
6.3	36.74	39.75	.93	22.46	.45
6.4	38.08	38.50	1.13	21.60	.11
6.5	36.11	36.88	1.04	25.08	.18
6.6	35.79	37.80	.99	25.03	.16
6.7	31.80	34.35	1.18	30.97	.10
Interface					
6.8	18.87	10.33	1.56	68.08	.00
6.9	19.12	10.32	1.86	69.11	.00
7.0	19.27	10.08	1.79	68.69	.00
11.7	19.49	9.93	1.83	68.86	.00

TABLE 24

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72
304L WELDMENTS - GTAW-HW PROCESS - AS WELDED (Wt.%)

Weld 6190 - Double Layer					
(a) Distance From Top Surface (mm)	Cr	Ni	Mn	Fe	Ti
Edge	41.85	46.58	.43	11.44	.28
1	41.14	44.67	.41	11.98	.24
2	42.76	44.62	.48	11.89	.42
3	42.78	45.48	.55	11.73	.43
4	42.99	44.82	.55	12.13	.27
5	36.00	37.01	.70	23.67	.13
6	33.27	35.52	.79	27.17	.14
7	36.67	35.81	.90	26.34	.25
7.1	36.16	35.51	.95	27.02	.12
7.2	34.07	33.84	.69	26.40	.20
7.3	37.11	36.37	.97	25.40	.19
7.4 (b)	35.92	30.61	.81	36.78	.10
7.5	29.05	24.56	1.21	44.84	.06
(c) Interface					
7.6	19.28	10.38	1.84	68.66	.00
7.7	19.26	9.67	1.83	69.92	.00
7.8	18.84	10.19	1.77	69.36	.00
7.9	18.97	9.70	1.81	69.07	.00
12.5	18.95	10.26	1.77	69.08	.01

Weld 6191 - Single Layer					
Distance From Top Surface (mm)	Cr	Ni	Mn	Fe	Ti
Edge	35.30	34.59	.85	29.58	.26
1	33.37	33.87	.75	27.53	.12
2	33.39	32.02	.82	31.01	.40
3	36.18	34.70	1.02	27.64	.32
4	35.61	33.73	1.00	29.96	.22
4.1	35.54	33.94	.99	30.52	.28
4.2	33.94	32.43	.82	29.52	.19
4.3 (b)	35.10	31.14	.97	35.76	.24
4.4 (b)	32.05	21.96	.96	50.92	.07
Interface					
4.5	19.03	9.80	1.86	71.51	.00
4.6	18.90	9.60	1.89	69.95	.00
4.7	19.07	10.07	1.84	68.90	.00
4.8	19.04	9.71	1.79	68.60	.00
9.4	19.36	9.59	1.80	69.17	.00

NOTES: (a) Top surface of overlay.
(b) Total too high.
(c) Interface of weld metal and substrate.

TABLE 25

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72
OVERLAY ON 310SS - GMAW PROCESS - AS WELDED (Wt.%)

Distance from Surface (mm)	Weld 6192 - Double Layer						Distance from Surface (mm)	Weld 6193 - Single Layer					
	Ni	Cr	Fe	Mn	Ti	Al		Ni	Cr	Fe	Mn	Ti	Al
0	44.75	40.46	12.73	0.43	.17	.28	0	39.08	36.15	23.42	.66	.11	.38
1	44.52	41.79	11.10	0.63	.21	.34	1	38.93	36.06	21.19	.93	.22	.19
2	45.45	41.57	11.11	0.62	.23	.41	2	38.51	38.92	20.93	.88	.13	.15
3	45.90	40.15	12.35	0.43	.20	.18	3	39.14	36.34	24.42	.78	.17	.09
4	45.36	41.16	13.00	0.48	.21	.47	4	39.83	36.40	23.15	.74	.12	.17
5	45.26	41.63	11.11	0.62	.33	.27	5	38.77	35.97	20.67	.89	.17	.18
6	37.78	36.11	24.41	0.73	.10	.25	5.5	38.53	36.61	22.59	.98	.22	.36
7	35.49	38.48	24.17	0.88	.18	.32	5.6	32.38	42.04	20.51	1.01	.16	.12
7.5	37.08	35.88	25.33	0.79	.21	.50	5.7	36.51	38.71	24.51	.70	.14	.24
7.6	39.22	37.50	21.33	0.86	.28	.25	5.8	34.25	37.94	21.49	.80	.15	.31
7.7	37.76	36.68	21.67	0.69	.20	.35	Interface						
7.8	39.08	38.68	20.99	0.92	.14	.00	5.9	18.82	25.97	50.52	1.67	.00	.00
7.9	39.87	37.79	21.01	0.84	.15	.31	6.0	19.21	25.94	51.03	1.69	.01	.00
Interface							6.1	18.85	25.54	52.21	1.74	.00	.00
8.0	18.88	26.12	52.54	1.60	.00	.00	10.8	19.04	26.21	49.70	1.72	.00	.00
8.1	18.78	26.28	52.32	1.70	.00	.00							
8.2	18.61	26.38	52.02	1.70	.03	.00							
12.9	18.71	25.55	49.62	1.90	.00	.00							

TABLE 26

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 - 310SS WELDMENTS - SAW PROCESS - AS WELDED (Wt.%)

Weld 6194 - Double Layer							Weld 6195 - Single Layer						
[a] Distance from top surface (mm)	Cr	Ni	Fe	Si	Mn	Ti	Distance from top surface (mm)	Cr	Ni	Fe	Si	Mn	Ti
Edge	38.44	52.40	5.37	.47	.53	.03	Edge	41.59	42.87	15.55	.46	.88	.05
1	43.57	52.54	5.48	.34	.54	.08	1	40.41	45.04	15.68	.31	.81	.16
2	43.22	52.31	5.21	.31	.60	.22	2	40.31	43.85	16.46	.22	.64	.11
3	42.74	53.16	5.29	.34	.50	.08	3	38.77	45.21	15.01	.47	.69	.07
4	42.91	52.16	5.02	.21	.52	.20	4	40.49	45.19	14.66	.42	.69	.17
5	40.12	45.80	14.94	.29	.56	.08	5	40.48	44.27	15.71	.44	.73	.13
6	41.60	43.45	15.73	.28	.76	.16	6	38.77	45.55	15.74	.34	.91	.15
7	40.58	43.62	16.07	.37	.78	.06	6.1	38.44	44.06	16.52	.22	.87	.21
8	40.20	44.01	17.06	.29	.90	.13	6.2	37.73	46.02	15.94	.35	.83	.21
9	39.00	45.71	16.95	.30	.95	.13	6.3	39.15	45.65	17.11	.39	.75	.11
9.1	39.89	45.35	17.24	.29	.83	.13	6.4	39.00	44.49	18.85	.36	.76	.10
9.2	41.32	46.77	15.59	.44	.69	.13	Interface						
9.3	38.78	44.58	16.69	.35	.82	.07	6.5	25.84	20.04	53.09	.36	1.56	.00
9.4	38.67	47.52	12.48	.42	.77	.14	6.6	25.77	19.54	51.87	.46	1.70	.00
[b] Interface							6.7	26.12	19.74	51.98	.47	1.73	.00
9.5	26.07	19.26	52.31	.39	1.61	.16	6.8	26.43	19.50	52.91	.41	1.81	.00
9.6	26.98	19.51	51.50	.43	1.73	.16	13.8	25.97	19.25	51.68	.40	1.70	.00
9.7	26.83	19.47	51.83	.43	1.68	.21							
14.7	27.30	19.15	50.68	.32	1.84	.00							

NOTES: (a) Top surface of overlay.
(b) Interface of weld metal and substrate.

TABLE 27

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72
310SS WELDMENTS - GTAW-HW PROCESS - AS WELDED (Wt.%)

Weld 6196 - Double Layer							Weld 6197 - Single Layer						
(a) Distance from top surface (mm)	Cr	Ni	Fe	Si	Mn	Ti	Distance from top surface (mm)	Cr	Ni	Fe	Si	Mn	Ti
Edge	41.37	42.75	11.64	.09	.44	.07	Edge	36.35	41.53	18.76	.33	.75	.09
1	41.22	47.83	11.88	.12	.39	.08	1	39.90	39.77	19.93	.18	.64	.05
2	43.55	46.44	10.91	.16	.41	.08	2	36.24	39.17	21.08	.25	.64	.06
3	41.26	45.79	11.73	.11	.44	.02	3	37.07	41.50	20.50	.20	.58	.07
4	41.00	47.80	10.53	.15	.40	.06	4	38.36	39.02	16.97	.29	.67	.05
5	41.18	47.99	11.72	.13	.38	.06	5	36.77	39.70	18.42	.35	.65	.03
6	40.03	40.26	20.21	.27	.69	.13	5.1	38.78	38.37	22.63	.19	.60	.03
7	40.78	40.03	19.89	.26	.74	.11	5.2	35.54	37.59	23.98	.22	.64	.00
7.5	38.35	39.94	20.68	.29	.70	.08	5.3	37.89	36.63	22.43	.21	.65	.03
7.6	37.92	40.47	22.80	.20	.79	.13	5.4	36.57	39.42	22.30	.22	.89	.03
7.7	37.55	37.74	23.98	.28	.83	.10	5.5	36.23	39.42	20.90	.30	.88	.05
7.8	38.06	35.98	25.94	.19	.89	.15	5.6	36.26	37.00	25.40	.33	.82	.02
7.9	36.86	38.14	28.83	.22	1.01	.05	5.7	34.28	33.95	26.92	.29	.89	.02
8.0	32.28	29.41	28.77	.22	.82	.06	Interface						
(b) Interface							5.8	26.60	18.62	53.76	.46	1.56	.02
8.1	25.35	19.20	52.97	.37	1.54	.00	5.9	26.02	18.93	52.41	.51	1.75	.00
8.2	27.09	19.41	50.71	.47	1.69	.00	6.0	25.84	18.67	51.45	.54	1.73	.00
8.3	26.17	19.26	52.42	.38	1.73	.00	6.1	26.04	19.27	52.36	.52	1.57	.00
13.0	27.25	19.43	50.88	.47	1.60	.00	11.1	26.97	18.97	51.83	.50	1.69	.00

NOTES: (a) Top surface of overlay.
(b) Interface of weld metal and overlay.

TABLE 28

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H SUBSTRATE - GMAW PROCESS - AS WELDED (Wt.%)

W6198 - Double Layer						W6199 - Single Layer					
Distance From Surface (mm)	Ni	Cr	Fe	Mn	Ti	Distance From Surface (mm)	Ni	Cr	Fe	Mn	Ti
0	48.91	40.79	8.92	.19	.20	0	40.83	34.32	19.87	.32	.26
1	49.04	40.15	9.75	.19	.38	1	43.06	35.47	19.71	.38	.61
2	48.44	41.29	9.90	.18	.23	2	42.99	35.43	20.66	.36	.47
3	49.83	41.05	9.83	.21	.30	3	44.22	33.88	20.25	.39	.36
4	47.68	42.46	9.11	.23	.24	4	43.08	35.59	19.43	.37	.32
5	47.91	42.06	9.39	.29	.34	5	42.81	34.94	21.36	.32	.28
6	43.39	34.67	21.85	.34	.32	5.1	44.17	35.49	18.80	.42	.23
7	43.05	33.68	20.45	.43	.45	5.2	44.16	38.08	17.81	.30	.50
7.1	41.46	34.39	21.82	.40	.44	5.3	43.77	37.60	16.72	.36	.40
7.2	41.45	35.30	20.89	.39	.44	5.4	42.66	33.37	16.66	.20	.35
Interface						Interface					
7.3	31.29	20.44	44.83	.75	.29	5.5	34.00	23.02	41.33	.75	.32
7.4	30.29	20.25	46.90	.67	.27	5.6	32.10	20.84	46.17	.73	.30
7.5	31.43	20.95	46.58	.69	.27	5.7	31.49	20.63	46.27	.67	.29
(a)12.2	31.60	20.87	46.40	.65	.26	(a)10.4	30.82	20.89	47.81	.71	.34

(a) 5 mm from interface

TABLE 29

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H - SAW PROCESS - AS WELDED (Wt.%)

W6200 - Double Layer					
Distance From Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	41.57	42.77	5.72	0.13	0.44
1	53.50	41.19	5.85	0.11	0.41
2	51.30	42.62	5.22	0.20	0.60
3	52.83	40.99	5.71	0.15	0.61
4	53.02	40.40	5.76	0.18	0.57
5	50.74	43.00	5.22	0.32	0.45
6	52.79	39.98	7.36	0.31	0.52
7	45.75	39.26	15.74	0.13	0.55
8	47.85	37.37	15.08	0.17	0.49
9	46.29	37.35	16.56	0.15	0.60
9.5	45.49	37.53	16.16	0.26	0.59
9.6	46.07	37.20	16.50	0.27	0.57
9.7	46.90	36.86	15.29	0.34	0.49
9.8	48.37	35.90	15.50	0.16	0.43
9.9	45.42	37.23	17.63	0.25	0.43
10.0	44.09	37.48	17.83	0.31	0.58
10.1	47.62	36.29	14.79	0.29	0.42
10.2	43.25	33.51	25.85	0.26	0.66
Interface - Overlay and Substrate					
10.3	31.75	20.31	47.05	0.25	0.77
10.4	31.88	20.66	46.22	0.34	0.77
10.5	31.28	20.60	46.63	0.34	0.64
10.6	31.12	20.53	46.72	0.31	0.74
15.2	31.08	19.81	46.96	0.34	0.77

W6201 - Single Layer					
Distance From Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	49.01	35.94	15.13	0.09	0.54
1	47.42	37.09	13.67	0.44	0.46
2	45.04	40.92	13.01	0.40	0.47
3	48.89	36.94	12.88	0.37	0.47
4	49.10	35.55	13.79	0.27	0.58
5	48.95	35.88	14.39	0.21	0.48
5.5	46.88	36.67	15.24	0.16	0.52
5.6	47.80	38.02	13.07	0.36	0.55
5.7	48.85	36.06	14.39	0.16	0.49
5.8	48.09	37.83	14.63	0.35	0.52
5.9	47.99	38.68	17.02	0.39	0.61
6.0	43.50	33.32	15.64	0.51	0.52
6.1	42.12	30.00	28.21	0.23	0.47
Interface - Overlay and Substrate					
6.2	32.02	20.40	46.78	0.30	0.70
6.3	31.75	20.68	46.54	0.33	0.63
6.4	31.70	20.41	45.81	0.39	0.67
6.5	31.99	20.53	45.90	0.36	0.68
11.1	31.72	20.42	46.48	0.32	0.67

TABLE 30

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H SUBSTRATE - GTAW-HW PROCESS - AS WELDED (Wt.%)

W6202 - Double Layer					
Distance From Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	52.49	40.96	7.57	0.65	0.18
1	48.48	44.32	8.45	0.26	0.28
2	51.58	41.58	7.49	0.33	0.19
3	52.02	40.41	8.43	0.20	0.27
4	52.32	40.29	7.90	0.35	0.25
5	51.63	40.11	9.11	0.23	0.23
6	49.31	39.09	8.78	0.44	0.30
6.1	51.30	41.07	8.75	0.35	0.25
6.2	49.99	42.83	7.89	0.23	0.26
6.3	49.71	42.45	7.71	0.40	0.19
6.4	50.67	41.50	8.54	0.24	0.28
6.5	51.89	41.38	8.51	0.34	0.33
6.6	49.94	42.03	8.54	0.30	0.32
6.7	46.67	43.63	8.59	0.44	0.26
6.8	47.30	41.18	9.94	0.26	0.32
Interface - Overlay and Substrate					
6.9	32.00	21.42	45.44	0.35	0.79
7.0	31.91	21.06	46.22	0.33	0.68
7.1	31.48	20.95	46.90	0.32	0.72
7.2	31.87	20.82	46.87	0.28	0.65
11.8	31.97	21.13	45.96	0.40	0.77

W6203 - Single Layer					
Distance From Surface (mm)	Ni	Cr	Fe	Ti	Mn
0	45.85	35.88	17.18	0.50	0.40
1	45.23	36.60	18.90	0.27	0.41
2	45.90	35.16	17.53	0.57	0.41
3	47.07	35.88	17.41	0.19	0.41
3.1	46.04	37.15	15.08	0.46	0.32
3.2	46.52	38.52	13.93	0.38	0.28
3.3	47.83	37.63	14.50	0.53	0.48
3.4	46.63	39.96	14.32	0.44	0.32
3.5	47.43	36.83	16.09	0.25	0.33
Interface - Overlay and Substrate					
3.6	31.54	20.70	46.10	0.30	0.74
3.7	32.10	21.12	46.52	0.33	0.71
3.8	31.73	21.07	46.15	0.38	0.78
3.9	32.34	21.13	46.15	0.54	0.70
8.5	31.59	21.04	46.20	0.32	0.68

TABLE 31

DISTRIBUTION OF ELEMENTS IN R139 OVERLAYS ON 304L SUBSTRATE - GMAW PROCESS - AS WELDED (Wt.%)

Distance from Surface (mm)	Weld 6204 - Double Layer						Distance from Surface (mm)	Weld 6205 - Single Layer					
	Ni	Cr	Fe	Mn	Ti	Al		Ni	Cr	Fe	Mn	Al	Ti
0	42.49	34.88	18.99	.50	2.37	.25	0	39.23	33.43	20.89	.76	2.78	.24
1	42.98	33.97	19.70	.61	2.85	.38	1	39.73	34.08	20.85	.84	2.82	.49
2	42.39	33.96	18.32	.56	2.66	.20	2	38.56	32.60	23.76	.63	2.69	.51
3	43.17	35.15	16.10	.57	2.93	.46	3	36.93	32.21	26.44	.85	2.39	.28
4	43.08	34.76	17.76	.53	3.04	.47	3.1	37.41	32.24	24.57	.71	2.69	.31
5	37.84	32.45	23.15	.97	3.07	1.41	3.2	36.81	32.55	25.09	.92	2.18	.23
6	36.85	30.84	26.90	.86	3.45	.85	3.3	35.56	31.48	26.79	.90	2.91	.53
6.5	36.26	31.02	28.76	.71	2.46	.26	3.4	33.42	30.84	31.32	.92	1.91	.22
6.6	36.80	32.02	27.52	.82	2.50	.39	3.5	36.49	32.09	28.05	.72	2.75	.30
6.7	37.01	32.51	26.13	.71	2.35	.29	3.6	31.49	31.75	32.74	.86	1.61	.15
6.8	36.52	31.28	28.93	.71	2.43	.32	Interface						
6.9	37.08	31.91	26.43	.87	2.36	.30	3.7	9.85	18.80	68.11	1.81	.00	.00
7.0	36.27	31.25	29.18	.83	2.20	.27	3.8	10.00	19.17	68.96	1.69	.00	.00
Interface(a)							3.9	9.97	19.09	67.07	1.85	.00	.00
7.1	9.89	21.20	67.99	1.79	.00	.03	8.6	9.67	19.37	68.55	1.66	.00	.00
7.2	10.52	19.45	67.93	1.79	.00	.00							
7.3	10.26	19.02	67.60	1.79	.00	.00							
12.0	9.28	18.46	65.52	1.73	.00	.00							

NOTE: (a) Overlay and substrate.

TABLE 32

DISTRIBUTION OF ELEMENTS - R139 ON 304L SAW PROCESS - AS WELDED (WT.%)

Distance from Surface (mm)	Ni	Cr	Mn	Al	Fe[a]
W6206 - Double Layer					
0	50.28	31.26	0.91	2.13	15.37
1	51.31	31.77	1.01	2.44	13.41
2	51.88	31.76	0.86	2.29	13.15
3	49.17	31.84	0.89	2.28	15.78
4	49.27	31.93	1.26	2.21	15.28
5	50.00	31.96	1.06	2.07	14.87
6	43.23	29.75	1.14	1.99	23.84
7	44.41	29.22	1.37	2.20	22.77
8	44.07	29.27	1.17	2.27	23.17
8.5	40.41	28.36	1.02	2.01	28.14
8.6	40.55	28.82	0.95	2.01	27.62
8.7	39.69	28.09	1.17	0.00	31.04
8.8	10.39	19.98	1.75	0.23	67.50
Interface[b]					
8.9	40.17	19.12	1.64	0.11	68.91
9	9.85	19.30	1.69	0.15	68.95
9.1	10.60	19.11	1.74	0.14	68.36
15	10.35	18.87	1.64	0.00	69.08
W6207 - Single Layer					
0	47.52	30.86	0.99	1.83	18.74
1	48.00	29.23	1.09	1.94	19.68
2	46.77	29.41	1.04	2.36	20.34
3	46.58	29.32	1.01	2.41	20.60
4	45.40	30.90	1.11	2.19	20.32
5	46.23	30.42	1.09	2.09	20.11
6	42.80	29.26	1.11	1.90	24.86
6.2	42.00	28.35	1.16	2.01	26.40
6.3	35.03	26.48	1.18	0.23	37.00
6.4	11.65	19.36	1.32	0.16	67.44
6.5	11.58	19.35	1.68	0.18	67.15
Interface					
6.6	12.00	18.99	1.70	0.19	67.05
6.7	11.07	19.44	1.75	0.26	67.41
6.8	11.94	18.95	1.67	0.12	67.25
13	11.00	19.49	1.69	0.00	67.75

(a) By difference
(b) Overlay and substrate

TABLE 33

DISTRIBUTION OF ELEMENTS - R139 ON 304L
GTAW-HW PROCESS - AS WELDED (WT.%)

Distance from Surface (mm)	Ni	Cr	Fe	Si	Mn	Al	Ti
W6208 - Double Layer							
0	39.82	29.90	25.24	.18	.90	3.48	.15
1	38.95	29.65	26.45	.08	.67	2.68	.16
2	40.03	29.42	25.05	.12	1.12	3.63	.22
3	39.88	29.83	24.54	.12	.89	3.37	.18
4	39.24	30.67	25.54	.08	.88	3.39	.19
5	39.57	31.17	24.87	.11	.85	3.17	.30
6	29.15	27.59	39.90	.33	1.05	2.05	.13
7	29.28	26.43	41.70	.28	1.30	2.34	.10
7.1	29.19	26.59	40.52	.28	1.39	2.39	.19
7.2	29.64	26.52	40.22	.22	1.10	2.09	.12
7.3	28.12	25.15	40.58	.28	1.07	2.09	.05
7.4	28.64	25.60	39.97	.31	1.11	2.13	.09
7.5	19.51	21.91	53.60	.35	1.33	.76	.03
7.6	19.57	22.73	52.92	.39	1.46	1.36	.06
7.7	22.28	23.14	44.85	.48	1.27	1.20	.10
7.8	17.05	21.75	54.91	.46	1.38	.83	.04
Interface[a]							
7.9	9.54	18.36	66.81	.49	1.77	.03	.00
8	9.80	18.35	66.66	.53	1.78	.00	.00
8.1	10.54	18.20	66.45	.49	1.81	.00	.00
12.8[b]	10.07	18.21	68.21	.56	1.68	.03	.01
W6209 - Single Layer							
0	34.83	29.03	31.96	-	.86	2.68	.33
1	34.66	29.20	31.63	-	1.05	2.11	.14
2	36.11	28.85	28.54	-	1.18	2.46	.21
3	35.54	28.71	31.65	-	.82	2.30	.19
4	33.18	26.80	36.76	-	1.11	2.04	.13
4.1	33.84	28.62	32.08	-	1.16	2.29	.21
4.2	34.28	28.44	32.66	-	1.01	2.06	.19
Interface[a]							
4.3	10.02	19.30	68.58	-	1.83	.00	.00
4.4	10.13	18.88	67.52	-	1.79	.02	.00
4.5	9.91	18.90	68.19	-	1.87	.00	.00
9.2[b]	9.67	18.99	68.58	-	1.74	.00	.00

(a) Overlay and substrate
(b) 5 mm from interface

TABLE 34

DISTRIBUTION OF ELEMENTS IN R139 OVERLAYS ON 310SS
GMAW PROCESS - AS WELDED (WT.%)

Distance From Edge (mm)	Ni	Cr	Fe	Si	Mn	Al	Ti
Weld 6211 -Single Layer							
0	34.47	31.08	32.00	.22	.93	2.56	.15
1	34.68	32.13	26.40	.38	.94	2.44	.17
2	34.71	31.85	28.04	.18	.94	2.56	.17
3	33.10	34.84	26.22	.13	.87	2.10	.24
4	35.76	32.39	28.83	.16	.94	2.36	.14
4.1	33.82	31.60	31.39	.25	.87	2.13	.15
4.2	33.76	31.16	27.09	.38	1.07	2.39	.13
4.3	33.35	31.64	31.25	.26	.97	2.31	.23
4.4	30.08	29.47	31.25	.22	1.08	2.53	.26
4.5	29.55	32.33	30.55	.27	1.06	2.52	.29
4.6	33.17	30.58	33.56	.19	.91	2.01	.10
4.7	34.15	29.95	31.43	.20	1.18	2.39	.15
4.8	31.96	30.53	33.53	.26	1.10	1.69	.02
Interface[a]							
4.9	19.48	27.50	50.84	.42	1.85	.15	.00
5.0	18.81	26.43	51.09	.39	1.73	.11	.00
5.1	18.83	26.47	51.12	.48	1.71	.08	.00
10.1	18.67	26.83	52.54	.37	1.59	.00	.00
Weld 6210 - Double Layer							
0	39.40	32.52	19.85	.13	.74	3.21	.23
1	43.00	31.26	18.80	.22	.56	2.71	.31
2	39.51	34.02	22.68	.09	.79	3.54	.53
3	39.12	33.54	22.98	.04	.57	2.68	.26
4	34.49	31.45	26.53	.19	.89	2.05	.33
5	35.04	32.00	26.11	.12	1.34	3.20	.13
6	34.87	31.55	30.48	.12	1.01	2.44	.27
7	34.10	31.46	29.74	.12	1.02	2.22	.15
7.1	33.60	31.49	30.00	.21	.98	2.29	.54
7.2	32.16	30.80	26.98	.23	1.00	1.97	.18
7.3	35.07	32.02	27.90	.13	1.04	2.68	.22
7.4	35.88	31.33	25.29	.18	.93	2.74	.26
7.5	34.74	31.81	28.05	.13	.89	2.54	.31
7.6	35.49	31.64	29.02	.15	.79	2.37	.20
7.7	33.19	29.07	29.33	.17	1.07	3.04	.23
7.8	28.97	29.71	36.11	.37	1.36	1.41	.14
Interface							
7.9	18.62	25.14	51.29	.41	1.70	.00	.01
12.8	18.40	25.44	51.35	.41	1.65	.00	.00

(a) Overlay and substrate

TABLE 35

DISTRIBUTION OF ELEMENTS -R139 OVERLAYS ON 310SS
SAW PROCESS - AS WELDED (WT.%)

Distance from Surface(mm)	Ni	Cr	Fe	Si	Mn	Ti	Al
Weld 6212- Double Layer							
0	44.63	33.91	17.70	.44	.90	.32	1.89
1	43.90	33.15	17.59	.61	1.12	.25	1.92
2	44.24	33.97	19.86	.33	.92	.39	1.81
3	42.66	31.68	18.65	.47	.92	.47	2.02
4	44.54	33.74	18.87	.49	.94	.33	1.87
5	44.26	33.31	18.93	.35	.92	.35	2.12
6	37.70	30.95	25.93	.44	1.14	.32	1.44
7	38.32	31.71	26.55	.23	.92	.41	1.19
8	38.83	30.99	24.68	.38	1.10	.49	1.55
9	38.23	31.83	26.44	.62	1.30	.16	1.51
10	37.75	30.28	25.19	.52	1.22	.30	1.72
10.5	37.42	31.79	24.85	.33	1.05	.37	1.53
10.6	35.61	31.04	25.05	.46	1.30	.37	1.57
10.7	28.61	30.25	38.07	.38	1.21	.08	.75
Interface(a)							
10.8	21.01	26.78	47.75	.30	1.88	.00	.16
10.9	20.43	26.10	47.10	.20	1.71	.00	.07
11.0	20.33	26.34	46.34	.20	1.59	.01	.16
15.7	19.36	25.66	50.18	.18	1.63	.00	.00
Weld 6213 - Single Layer							
0	34.25	29.64	30.98	.37	1.04	.15	1.13
1	32.99	29.87	30.49	.30	1.03	.15	1.25
2	34.36	31.39	26.75	.42	1.27	.62	1.50
3	33.99	31.01	29.16	.43	1.25	.32	1.41
4	34.47	31.34	27.83	.09	1.06	.30	1.40
5	34.42	30.91	24.22	.33	.96	.63	1.75
5.5	35.56	31.07	27.61	.21	1.21	.34	1.66
5.6	35.72	31.58	27.84	.14	1.27	.17	1.38
5.7	34.82	30.80	27.23	.17	1.37	.25	1.25
5.8	34.93	30.37	28.47	.42	1.24	.22	1.51
5.9	33.95	31.34	27.80	.41	1.29	.23	1.76
Interface(a)							
6	18.53	25.77	48.01	.14	1.58	.00	.14
6.1	18.89	25.69	47.88	.25	1.73	.00	.05
6.2	18.50	25.80	46.62	.24	1.72	.00	.09
10.9(b)	18.69	26.37	52.16	.15	1.52	.00	.00

(a) Overlay and substrate
(b) 5 mm from interface (fusion line)

TABLE 36

DISTRIBUTION OF ELEMENTS - R139 OVERLAYS ON 310SS - GTAW-HW PROCESS - AS WELDED (Wt.%)

Distance from Surface (mm)	Weld 6214 - Double Layer						Distance from Surface (mm)	Weld 6215 - Single Layer					
	Ni	Cr	Fe	Mn	Ti	Al		Ni	Cr	Fe	Mn	Ti	Al
0	40.10	33.24	21.42	.80	.28	1.87	0	33.83	29.87	31.96	.90	.12	1.15
1	40.09	32.16	24.16	.65	.34	2.50	1	34.53	29.27	31.36	1.11	.63	1.23
2	40.65	32.63	22.23	.63	.40	2.23	2	34.08	30.15	32.32	.91	.16	1.03
3	41.44	32.96	20.02	.98	.25	2.00	3	34.23	31.05	31.78	.97	.16	.91
4	40.81	33.14	23.59	.67	.65	2.80	4	33.69	30.19	33.15	.89	.12	.97
5	39.30	31.84	24.77	.75	.15	1.88	4.1	33.77	30.66	31.19	1.08	.25	1.30
6	34.57	31.45	30.74	.97	.38	1.63	4.2	33.31	29.98	28.79	1.30	.16	.87
6.5	34.21	30.31	30.65	1.07	.11	.94	4.3	32.90	30.28	29.64	1.27	.20	1.13
6.6	33.60	31.06	30.11	1.07	.18	1.04	4.4	33.85	31.12	31.59	1.05	.27	1.25
6.7	34.32	30.97	29.96	1.10	.20	1.25	4.5	31.96	30.43	33.26	1.16	.20	1.00
6.8	34.76	31.14	29.93	1.11	.21	1.12	4.6	31.30	29.75	34.83	1.03	.21	1.02
6.9	34.46	30.17	30.59	1.10	.48	1.60	Interface[a]						
7.0	34.79	30.97	31.92	.91	.21	1.22	4.7	23.81	27.34	44.69	1.37	.04	.00
7.1	27.26	30.02	39.47	1.12	.23	1.23	4.8	19.25	28.34	50.90	1.66	.02	.00
Interface[a]							4.9	18.89	26.39	53.18	1.62	.02	.00
7.2	18.78	25.91	49.28	1.32	.02	.00	5.0	19.18	26.18	52.14	1.68	.02	.00
7.3	18.92	25.80	52.66	1.66	.03	.00	9.6[b]	18.99	26.63	51.76	1.74	.02	.00
7.4	18.63	26.62	51.89	1.58	.03	.00							
7.5	18.53	26.10	52.26	1.69	.02	.00							
12.1[b]	18.73	26.24	50.67	1.77	.01	.00							

NOTES: (a) Overlay and substrate.
(b) 5 mm from interface (fusion line).

TABLE 37

DISTRIBUTION OF ELEMENTS -R139 OVERLAYS ON INCOLOY ALLOY 800H
GMAW PROCESS - AS WELDED (WT.%)

Distance From Surface (mm)	Ni	Cr	Fe	Mn	Ti	Al
Weld 6216 - Double Layer						
0	44.76	34.31	18.20	.57	.33	3.56
1	43.87	34.22	17.76	1.17	.31	3.36
2	44.69	33.28	16.99	.79	.40	3.98
3	44.82	33.51	16.59	.62	.50	3.21
4	43.36	33.32	17.31	.59	.69	3.23
5	41.98	31.80	24.56	.65	.26	3.41
6	42.07	32.92	21.66	.65	.63	3.28
7	41.76	31.59	22.49	.63	.51	2.72
7.1	40.40	31.28	22.35	.51	.59	2.54
7.2	41.52	31.06	25.10	.62	.31	2.94
7.3	40.78	31.57	25.22	.80	.26	3.05
7.4	41.10	32.13	25.32	.76	.31	3.77
7.5	40.42	30.60	22.88	.50	.50	2.98
7.6	40.90	30.19	25.35	.57	.41	2.36
Interface[a]						
7.7	31.59	20.12	44.53	.69	.34	.36
7.8	30.33	20.81	44.54	.73	.36	.55
7.9	30.84	20.65	45.19	.64	.34	.40
8	31.67	20.79	44.90	.66	.34	.34
12.6[b]	32.60	20.42	44.15	.69	.34	.43
Weld 6217 - Single Layer						
0	41.83	30.38	22.72	.60	.29	2.72
1	41.36	30.37	24.76	.64	.25	3.36
2	41.88	31.40	24.48	.70	.24	3.16
3	41.97	32.01	22.70	.51	.24	2.96
3.5	42.77	30.57	24.20	.51	.19	2.94
3.6	40.78	31.95	22.23	.77	.38	3.37
3.7	42.05	31.85	22.28	.67	.34	3.42
3.8	42.28	31.31	22.32	.68	.25	3.68
3.9	42.01	31.22	21.80	.59	.35	2.74
4	42.32	31.36	22.08	.67	.40	3.13
4.1	39.64	29.28	27.95	.67	.26	3.10
4.2	37.32	27.30	31.17	.78	.29	2.14
Interface[a]						
4.3	32.10	20.28	44.36	.74	.37	.36
4.4	32.20	20.95	43.96	.81	.40	.53
4.5	31.24	21.36	44.62	.75	.31	.45
4.6	31.91	20.62	44.54	.70	.31	.52
9.2[b]	31.92	21.27	44.68	.68	.35	.43

(a) Overlay and substrate (b) 5 mm from interface (fusion line)

TABLE 38

DISTRIBUTION OF ELEMENTS-R139 ON INCOLOY ALLOY 800H-SAW PROCESS-AS WELDED(WT.%)

Distance from Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6218 - Double Layer							
0	43.48	32.89	19.96	.30	.85	.66	1.90
1	41.79	32.43	20.39	.52	.82	.94	2.74
2	40.90	32.51	20.50	.28	.79	.69	2.20
3	40.31	33.04	20.06	.30	1.04	.97	2.10
4	44.65	32.79	18.32	.69	1.08	.74	1.93
5	43.86	33.77	17.84	.64	.81	.64	1.91
6	43.74	33.21	18.56	.59	.73	.60	2.09
7	41.23	30.50	24.02	.33	.99	.88	1.96
8	41.00	30.07	22.91	.53	.86	.66	1.72
9	40.94	29.97	25.30	.50	.86	.62	2.24
9.5	37.56	27.06	25.45	.52	.95	.70	1.59
Interface(a)							
9.6	31.45	20.27	43.01	.39	.57	.19	.43
9.7	31.55	20.40	45.37	.34	.56	.13	.29
9.8	30.80	20.39	45.37	.35	.74	.06	.41
9.9	31.39	20.33	45.09	.37	.63	.08	.41
14.5(b)	31.25	20.39	46.91	.33	.69	.16	.43
W6219 - Single Layer							
0	40.82	29.39	25.94	.29	.73	.64	1.76
1	40.95	29.61	26.53	.26	.69	.57	1.52
2	38.45	30.74	26.79	.24	.77	.60	1.83
3	41.19	30.40	25.29	.61	.99	.78	1.91
4	40.57	29.20	25.19	.30	.90	.43	2.19
5	37.64	28.14	25.76	.52	.81	.44	1.79
5.1	40.32	29.53	26.73	.51	.85	.43	2.16
5.2	40.71	28.67	26.17	.37	.79	.61	1.99
Interface(a)							
5.3	32.30	22.64	43.45	.63	.86	.61	1.19
5.4	31.87	20.02	45.82	.38	.75	.06	.46
5.5	31.72	20.16	47.85	.32	.63	.07	.58
10.2(b)	31.30	19.97	45.64	.27	.74	.11	.41

(a) Overlay and substrate
(b) 5 mm from interface

TABLE 39

DISTRIBUTION OF ELEMENTS-R139 ON INCOLOY ALLOY 800H-GTAW-HW PROCESS-AS WELDED (WT.%)

Distance from Surface(mm)	Ni	Cr	Fe	Mn	Ti	Al
W6220 Double Layer						
0	42.10	28.74	22.13	.65	.29	2.95
1	42.72	32.26	20.51	.73	.31	3.36
2	42.30	31.63	18.84	.80	.38	3.36
3	42.84	31.72	21.00	.78	.32	3.01
4	42.71	32.76	20.37	.73	.41	3.34
5	39.29	27.78	30.01	.55	.34	2.12
6	39.66	28.80	28.25	.75	.30	2.91
7	38.20	27.64	30.48	.61	.26	2.31
7.1	36.21	26.67	32.43	.49	.32	1.68
7.2	37.72	26.81	32.02	.65	.35	2.32
Interface[a]						
7.3	30.69	20.33	45.08	.78	.36	.39
7.4	30.76	23.78	45.08	.36	.39	.39
7.5	31.25	20.35	45.98	.77	.31	.43
12.2[b]	31.17	21.08	45.98	.79	.30	.44

Distance from Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6321 Single Layer							
0	41.05	28.64	26.84	.55	.57	.06	2.83
1	40.67	28.84	27.83	.41	.54	.01	2.30
2	41.22	28.62	27.18	.35	.81	.09	2.48
3	40.33	27.00	30.33	.31	.56	.01	2.21
4	40.34	28.28	29.60	.34	.71	.07	2.25
4.5	39.91	27.29	30.86	.34	.65	.02	2.12
Interface[a]							
4.6	31.52	20.55	45.33	.37	.69	.05	.44
4.7	31.98	20.13	46.54	.36	.71	.08	.38
4.8	31.95	20.09	47.02	.34	.71	.16	.28
9.5[b]	32.48	20.53	45.67	.28	.69	.08	.43

(a) Overlay and substrate
(b) 5 mm from interface

TABLE 40

EFFECT OF WELD PROCESS AND SUBSTRATE ON DEPTH OF 25% AND 30% CHROMIUM LAYERS R139 OVERLAYS

Substrate	Saw				GMAW				GTAW-HW			
	Distance From Surface		Distance From Fusion Line		Distance From Surface		Distance From Fusion Line		Distance From Surface		Distance From Fusion Line	
	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
25% Chromium Level - Double Layer												
304L	8.7	(0.35)	0.1	(0.004)	7.0	(0.28)	0	(0)	7.4	(0.29)	0.4	(0.016)
310	10.7	(0.42)	0	(0)	7.8	(0.31)	0	(0)	7.1	(0.28)	0	(0)
Incoloy Alloy 800H	9.5	(0.38)	0	(0)	7.6	(0.30)	0	(0)	7.2	(0.29)	0	(0)
25% Chromium - Single Layer												
304L	6.3	(0.25)	0.2	(0.008)	3.6	(0.14)	0	(0)	4.2	(0.17)	0	(0)
310	5.9	(0.23)	0	(0)	4.8	(0.19)	0	(0)	4.6	(0.18)	0	(0)
Incoloy Alloy 800H	5.2	(0.21)	0	(0)	4.2	(0.17)	0	(0)	4.5	(0.18)	0	(0)
30% Chromium Level - Double Layer												
304L	5.9	(0.23)	2.9	(0.12)	7.0	(0.28)	0	(0)	0	(0)	-	-
310	10.7	(0.42)	0	(0)	7.6	(0.30)	0	(0)	7.1	(0.28)	0	(0)
Incoloy Alloy 800H	9.0	(0.36)	0	(0)	7.6	(0.30)	0	(0)	4.5	(0.18)	2.8	(0.11)
30% Chromium Level - Single Layer												
304L	0.5	(0.020)	6.0	(0.24)	3.6	(0.14)	0	(0)	0	(0)	-	-
310	5.9	(0.23)	0	(0)	4.8	(0.19)	0	(0)	4.5	(0.18)	0.1	(0.004)
Incoloy Alloy 800H	0	(0)	-	-	4.0	(0.16)	0.2	(0.008)	0.2	(0.008)	0	(0)

TABLE 41

EFFECT OF WELD PROCESS AND SUBSTRATE ON THE NICKEL CONTENT AT THE SURFACE AND 1 mm (.04 INCH) BELOW THE SURFACE OF R139 OVERLAYS
(Wt.%)

Substrate	Location	SAW	Filler Metal(a)	GMAW	Filler Metal(a)	GTAW-HW	Filler Metal(a)
304L	Surface	50.3	50.4	42.5	50.4	39.8	50.1
	1 mm	51.3		43.0		38.9	
310SS	Surface	44.6	47.9	39.4	47.9	40.1	50.1
	1 mm	43.9		43.0		40.1	
800H	Surface	43.5	47.9	44.8	47.9	42.1	50.1
	1 mm	41.8		43.9		42.7	

(a) Ni content of filler metal used to deposit overlay

TABLE 42

IRON CONTENT AT AND NEAR THE SURFACE OF DOUBLE LAYER R139 OVERLAYS
(Wt.%)

	SAW		GMAW		GTAW-HW	
	Surface	1 mm(a)	Surface	1 mm(a)	Surface	1 mm(a)
304L	15.4	13.4	19.0	19.7	25.2	26.4
310 SS	17.7	17.6	19.8	18.8	21.4	24.2
800H	20.0	20.4	18.2	17.8	22.1	20.5

(a) 1 mm below surface (.04 in)

TABLE 43

STRESS RUPTURE TEST RESULTS

Code	Weld Process	Filler Metal	Substrate	No. Of Layers	Stress MPa	Stress Psi	Life in Hours	% Elongation 38 mm(1.5 Inch
6180	GMAW	309	304L	2	13.8	2000	72	21
					8.6	1250	630	23
					7.6	1100	846	21
6181	GMAW	309	304L	1	13.8	2000	52	15
					10.3	1500	189	16
					6.9	1000	1084	23
6182	SAW	309	304L	2	13.8	2000	47	27
					10.3	1500	139	21
					5.9	850	2352	31
6183	SAW	309	304L	1	13.8	2000	54	27
					10.3	1500	104	17
					6.9	1000	342	22
					4.8	700	4282	30
6184	GTAW-HW	309	304L	2	13.8	2000	74	19
					10.3	1500	268	20
					8.6	1250	609	21
					7.6	1100	861	21
6185	GTAW=HW	309	304L	1	13.8	2000	65	21
					10.3	1500	205	23
					8.6	1250	611	22
					7.6	1100	1331	27
6186	GMAW	FM 72	304L	2	17.2	2500	100	13
					13.8	2000	293	9
					10.3	1500	879	12
6187	GMAW	FM 72	304L	1	17.2	2500	31	15
					13.8	2000	71	14
					10.3	1500	558	20
					9.3	1350	922	26
6188	SAW	FM 72	304L	2	13.8	2000	48	15
					10.3	1500	118	13
					8.6	1250	301	11
					6.9	1000	653	16
6189	SAW	FM 72	304L	1	13.8	2000	35	15
					10.3	1500	131	10
					8.6	1250	384	13
					6.9	1000	497	11
6190	GTAW-HW	FM 72	304L	2	13.8	2000	126	15
					10.3	1500	244	10
					7.6	1100	1109	13
					6.2	900	2184	11
6191	GTAW-HW	FM 72	304L	1	13.8	2000	89	22
					10.3	1500	261	9
					8.6	1250	1074	12

TABLE 43 (continued)

Code	Weld Process	Filler Metal	Substrate	No.Of Layers	Stress MPa	Stress Psi	Life In Hours	% Elongation 38 mm(1.5 Inc
6192	GMAW	FM 72	310	2	20.7	3000	73	16
					13.8	2000	256	30
					9.0	1300	938	10
6193	GMAW	FM 72	310	1	20.7	3000	66	17
					13.8	2000	223	15
					10.3	1500	835	18
					8.3	1200	601	21
6194	SAW	FM 72	310	2	15.9	2300	99	17
					13.8	2000	142	13
					10.3	1500	400	15
					7.9	1150	1159	19
6195	SAW	FM 72	310	1	15.9	2300	74	11
					13.8	2000	228	17
					10.3	1500	522	20
					8.3	1200	1143	18
6196	GTAW-HW	FM 72	310	2	19.0	2750	157	21
					15.9	2300	306	13
					13.8	2000	379	13
					10.3	1500	847	9
6197	GTAW-HW	FM 72	310	1	15.9	2300	144	11
					13.8	2000	240	18
					10.3	1500	721	20
					9.3	1350	807	17
6198	GMAW	FM 72	800H	2	31.0	4500	99	9
					24.1	3500	221	7
					17.2	2500	523	10
					13.8	2000	1408	10
6199	GMAW	FM 72	800H	1	31.0	4500	72	5
					24.1	3500	228	11
					17.2	2500	711	10
					15.2	2200	1345	9
6200	SAW	FM 72	800H	2	20.7	3000	164	12
					17.2	2500	240	6
					13.8	2000	468	7
					10.3	1500	1023	7
6201	SAW	FM 72	800H	1	31.0	4500	83	10
					20.7	3000	316	9
					17.2	2500	526	6
					13.8	2000	693	8
6202	GTAW-HW	FM 72	800H	2	31.0	4500	102	24
					20.7	3000	333	9
					17.2	2500	521	13
					13.8	2000	1366	11
6203	GTAW-HW	FM 72	800H	1	31.0	4500	111	7
					24.1	3500	270	13
					20.7	3000	432	17
					17.2	2500	959	18

TABLE 43 (continued)

Code	Weld Process	Filler Metal	Substrate	No.of Layers	Stress MPa	Stress Psi	Life In Hours	% Elongation in 38 mm(1.5 Inches)
6204	GMAW	R 139	304L	2	17.2	2500	62	12
					13.8	2000	183	11
					9.6	1400	1040	22
6205	GMAW	R 139	304L	1	17.2	2500	48	20
					13.8	2000	165	19
					9.6	1400	785	21
6206	SAW	R 139	304L	2	13.8	2000	87	15
					10.3	1500	530	17
					9.3	1350	637	11
					8.3	1200	731	13
6207	SAW	R 139	304L	1	13.8	2000	110	9
					8.6	1250	353	10
					6.9	1000	915	14
					8.2	800	2017	11
6208	GTAW-HW	R 139	304L	2	17.2	2500	98	23
					13.8	2000	283	16
					10.3	1500	1106	13
6209	GTAW-HW	R 139	304L	1	13.8	2000	65	13
					10.3	1500	437	16
					8.3	1200	831	13
6210	GMAW	R 139	310	2	20.7	3000	61	23
					17.2	2500	178	19
					13.8	2000	304	17
					9.0	1300	969	15
6211	GMAW	R 139	310	1	20.7	3000	88	26
					17.2	2500	185	30
					13.8	2000	318	26
					9.0	1300	1919	31
6212	SAW	R 139	310	2	24.1	3500	73	13
					17.2	2500	263	15
					12.1	1750	753	15
					10.3	1500	903	10
6213	SAW	R 139	310	1	20.7	3000	108	21
					17.2	2500	152	18
					12.1	1750	675	23
					10.3	1500	906	23
6214	GTAW-HW	R 139	310	2	24.1	3500	81	25
					20.7	3000	149	19
					17.2	2500	210	20
					13.1	1900	914	27
6215	GTAW-HW	R 139	310	1	24.1	3500	53	15
					20.7	3000	115	17
					17.2	2500	194	20
					13.1	1900	703	27
6216	GMAW	R 139	800H	2	31.0	4500	100	14
					24.1	3500	242	9
					20.0	2900	467	19
					16.2	2350	1519	13

TABLE 43 (continued)

Code	Weld Process	Filler Metal	Substrate	No. Of Layers	Stress MPa	Stress Psi	Life In Hours	% Elongation in 38 mm (1.5 Inches
6217	GMAW	R 139	800H	1	31.0	4500	102	9
					24.1	3500	247	7
					20.0	2900	554	13
					16.2	2350	1435	11
6218	SAW	R 139	800H	2	31.0	4500	81	9
					24.1	3500	203	8
					16.2	2350	813	15
					14.5	2100	1243	5
6219	SAW	R 139	800H	1	31.0	4500	73	13
					24.1	3500	202	8
					16.2	2350	764	7
					14.5	2100	1240	9
6220	GTAW-HW	R 139	800H	2	37.1	5385	44	12
					31.0	4500	86	8
					20.7	3000	364	9
					15.9	2300	1191	15
6321	GTAW-HW	R 139	800H	1	31.0	4500	98	11
					24.1	3500	253	9
					20.7	3000	403	9
					16.9	2450	852	12

TABLE 44

STRESS IN MPa (psi) TO PRODUCE RUPTURE IN 100 HOURS AT 982°C (1800°F)

Process	SAW - Double Layer			SAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	11.6 (1675)	-	-	10.3 (1500)	-	-
FM R139	15.2 (2200)	22.4 (3250)	30.0 (4300)	13.8 (2000)	21.0 (3050)	29.0 (4200)
FM 72	11.0 (1600)	15.9 (2300)	24.7 (3575)	11.0 (1600)	15.4 (2225)	29.3 (4250)

Process	GMAW - Double Layer			GMAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	13.1 (1900)	-	-	11.7 (1700)	-	-
FM R139	15.9 (2300)	19.3 (2800)	31.0 (4500)	15.2 (2200)	20.0 (2900)	31.0 (4500)
FM 72	17.2 (2500)	18.6 (2700)	31.0 (4500)	13.6 (1975)	17.9 (2600)	29.7 (4300)

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	13.1 (1900)	-	-	10.3 (1500)	-	-
FM R139	17.2 (2500)	22.4 (3250)	29.3 (4250)	15.7 (2275)	20.7 (3000)	31.0 (4500)
FM 72	14.0 (2025)	20.7 (3000)	31.0 (4500)	13.3 (1925)	17.7 (2575)	32.1 (4650)

TABLE 45

STRESS IN MPa (psi) TO PRODUCE RUPTURE IN 1000 HOURS AT 982°C (1800°F)

Process	SAW - Double Layer			SAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	6.9 (1000)	-	-	5.9 (860)	-	-
FM R139	6.7 (970)	9.7 (1400)	15.2 (2200)	6.6 (960)	9.7 (1400)	15.0 (2175)
FM 72	6.2 (900)	8.1 (1175)	10.3 (1500)	6.4 (925)	8.6 (1250)	10.3 (1500)

Process	GMAW - Double Layer			GMAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	7.4 (1075)	-	-	7.0 (1010)	-	-
FM R139	9.7 (1400)	8.8 (1275)	(a)17.6 (2550)	9.3 (1350)	10.5 (1525)	17.6 (2550)
FM 72	10.2 (1475)	8.8 (1275)	15.2 (2200)	9.1 (1325)	9.7 (1400)	16.2 (2350)

Process	GTAW-HW Double Layer			GTAW-HW Single Layer		
Substrate	304L	310	800H	304L	310	800H
FM 309	7.4 (1075)	-	-	7.9 (1150)	-	-
FM R139	10.5 (1525)	12.1 (1750)	16.6 (2400)	7.8 (1125)	12.1 (1750)	16.2 (2350)
FM 72	7.6 (1100)	9.8 (1425)	14.8 (2150)	8.6 (1250)	9.0 (1300)	15.9 (2300)

TABLE 46

VICKERS HARDNESS NUMBER OF WELDMENTS BEFORE AND AFTER EXPOSURE IN CGA - SAW PROCESS

Condition	As Welded - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	1000 Hrs in CGA at 982°C (1800°F) - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	As Welded - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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	1000 Hrs in CGA at 982°C (1800°F) - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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 47

VICKERS HARDNESS NUMBER OF WELDMENTS BEFORE AND AFTER EXPOSURE IN CGA - GMAW PROCESS

Condition	As Welded - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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

Condition	1000 Hrs in CGA											
Location	Overlay			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	208	134	170	139	144	168	150

Condition	As Welded - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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

Condition	1000 Hrs in CGA								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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 48

VICKERS HARDNESS NUMBER OF WELDMENTS BEFORE AND AFTER EXPOSURE IN CGA - GTAW-HW PROCESS

Condition	As Welded - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	After 1000 Hrs in CGA at 982°C (1800°F)											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	As Welded - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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	After 1000 Hrs in CGA at 982°C (1800°F)								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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 49

CHANGE IN VICKERS HARDNESS NUMBER AFTER CGA EXPOSURE

Condition	GMAW Process - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	GMAW Process - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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	SAW Process - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	-18	-	-	-21	-	-	-34	-	-	-27	-	-
FM-R139	+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	SAW Process - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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	GTAW-HW Process - Double Layer											
Location	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
Substrate	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	GTAW-HW Process - Single Layer								
Location	Overlay			Heat Affected Zone			Base Metal		
Substrate	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 50

ROOM TEMPERATURE TENSILE PROPERTIES(a) - AS WELDED

Code	Weld Process	Filler Metal	Substrate	0.2% Yield Strength MPa	0.2% Yield Strength psi	Tensile Strength MPa	Tensile Strength psi	% Elongation in 50.8mm (2 inches)
6180(b)	GMAW	AWS-ER309	304L	373	54410	577	83700	57.0
6181	GMAW	309	304L	337	48850	557	80850	57.0
6182	SAW	309	304L	368	53350	586	84950	52.5
6183	SAW	309	304L	344	49950	565	81950	57.0
6184	GTAW-HW	309	304L	388	56250	579	84050	51.0
6185	GTAW-HW	309	304L	350	50700	564	81800	53.0
6186	GMAW	INCONEL FILLER METAL 72	304L	372	54000	589	85450	38.5
6187	GMAW	FM72	304L	333	48300	564	81850	46.5
6188	SAW	FM72	304L	347	50400	566	82150	46.5
6189	SAW	FM72	304L	333	48250	561	82400	46.0
6190	GTAW-HW	FM72	304L	378	54900	584	84650	48.5
6191	GTAW-HW	FM72	304L	365	53000	595	86350	49.5
6192	GMAW	FM72	310	359	52050	595	86250	50.5
6193	GMAW	FM72	310	335	48600	577	83700	48.0
6194	SAW	FM72	310	350	50750	596	86500	40.0
6195	SAW	FM72	310	345	50050	582	84400	40.0
6196	GTAW-HW	FM72	310	391	56650	625	90650	30.0
6197	GTAW-HW	FM72	310	362	52450	616	89350	45.0
6198	GMAW	FM72	INCOLOY ALLOY 800H	334	48500	588	85300	49.5
6199	GMAW	FM72	800H	299	43300	573	83150	50.0
6200	SAW	FM72	800H	336	48750	573	83150	35.0
6201	SAW	FM72	800H	299	43400	571	82750	37.0
6202	GTAW-HW	FM72	800H	367	53250	615	89200	48.0
6203	GTAW-HW	FM72	800H	324	47000	602	87350	44.0
6204	GMAW	R139	304L	353	51020	595	86250	50.5
6205	GMAW	R139	304L	340	49350	576	83550	54.5
6206	SAW	R139	304L	352	51050	578	83800	38.0
6207	SAW	R139	304L	348	50500	593	86050	47.0
6208	GTAW-HW	R139	304L	377	54700	586	85050	50.5
6209	GTAW-HW	R139	304L	339	49100	588	85300	55.0
6210	GMAW	R139	310	371	53750	615	89150	44.5
6211	GMAW	R139	310	339	49200	585	84850	41.5
6212	SAW	R139	310	359	52050	598	86750	49.0
6213	SAW	R139	310	315	45700	587	85200	50.0
6214	GTAW-HW	R139	310	367	53300	591	85750	46.5
6215	GTAW-HW	R139	310	344	49900	599	86900	53.0
6216	GMAW	R139	INCOLOY ALLOY 800H	339	49200	597	86600	48.5
6217	GMAW	R139	800H	304	44100	577	83650	50.0
6218	SAW	R139	800H	333	48300	588	85250	46.0
6219	SAW	R139	800H	298	43250	576	83600	48.0
6220	GTAW-HW	R139	800H	342	49650	588	85300	50.0
6321	GTAW-HW	R139	800H	309	44750	573	83150	48.5

NOTES: (a) Average of two tests.

(b) Even numbered codes had double layer overlays and odd numbered codes had single layer overlays.

TABLE 51

ROOM TEMPERATURE TENSILE PROPERTIES AFTER EXPOSURE IN CGA[a]

No.[b]	Process	Filler Metal	Substrate	0.2% Yield Strength MPa	0.2% Yield Strength psi	Tensile Strength MPa	Tensile Strength psi	% Elongation in 50.8 m^2 (2 in)	
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	[c]
6213	"	"	"	244	35,400	390	56,600	11.0	
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	[c]
6321	"	"	"	271	39,250	444	64,350	16.2	

NOTES: (a) Average of two tests.

(b) Even numbered welds are double layer overlays and odd numbered welds are single layer overlays.

(c) One sample broke outside gage length.

TABLE 52

PERCENTAGE DECREASE IN TENSILE STRENGTH DUE TO EXPOSURE IN CGA

Process	SAW - Double Layer			SAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
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	**GMAW - Double Layer**			**GMAW - Single Layer**		
Substrate	**304L**	**310**	**800H**	**304L**	**310**	**800H**
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	**GTAW-HW - Double Layer**			**GTAW-HW - Single Layer**		
Substrate	**304L**	**310**	**800H**	**304L**	**310**	**800H**
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 53

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

Process	SAW - Double Layer			SAW - Single Layer		
Substrate	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	GMAW - Double Layer			GMAW - Single Layer		
Substrate	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	GTAW-HW - Double Layer			GTAW-HW - Single Layer		
Substrate	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 54

TENSILE ELONGATION (PERCENT IN 50.8 mm) AFTER EXPOSURE IN CGA

Process	SAW - Double Layer			SAW - Single Layer		
Substrate	304L	310	800H	304L	310	800H
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	**GMAW - Double Layer**			**GMAW - Single Layer**		
Substrate	304L	310	800H	304L	310	800H
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	**GTAW-HW - Double Layer**			**GTAW-HW - Single Layer**		
Substrate	304L	310	800H	304L	310	800H
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 55

WEIGHT CHANGE AND PENETRATION DUE TO EXPOSURE OF UNCLAD SUBSTRATES

Sample	(a) Surface Loss mm	in	(a) Maximum Depth of Affected Metal mm	in	Total Affected Metal mm	in	Change in Weight g/cm Undescaled	Descaled
304L-1	NOT MEASURABLE						-308	-1346
304L-2	"	"					-318	-1329
304L-3	"	"					-472	-1266
304L-4	"	"					-639	Destroyed
310-5	.0152	.0006	.3200	.0126	.3352	.0132	+30.6	-85.8
310-6	.0305	.0012	.1143	.0045	.1448	.0057	+ 6.2	-129.1
310-7	.0203	.0008	.1219	.0048	.1422	.0056	+ 9.0	-55.5
310-8	.0152	.0006	.1168	.0046	.1320	.0052	+12.4	-20.2
Avg.	.0165	.0008	.1682	.0066	.1885	.0074		
800H-10	.2870	.0113	2.675	.1053	2.962	.1166	+43.0	-320.4
800H-11	.1041	.0041	2.670	.1051	2.774	.1092	+206.8	-261.0
800H-12	.1803	.0071	2.570	.1012	2.750	.1083	+72.2	-413.0
800H-13	.1981	.0078	1.090	.0429	1.288	.0507	-40.5	-163.0
Avg.	.1924	.0076	2.251	.0886	2.443	.0962		

NOTE: (a) Original measurements in microns.

TABLE 56

EFFECT OF EXPOSURE ON THE THICKNESS[a] OF WELDMENTS (NOT DESCALED)

Code	Weld Process	No. of Layers	Filler Metal	Substrate	Thickness[b] (in) As Welded	Thickness[b] (in) After Exposure	Change (in)
6180	GMAW	2	309	304L	1.489	1.498	+.009
6181	GMAW	1	309	304L	1.269	1.306	+.037
6182	SAW	2	309	304L	1.570	1.574	+.004
6183	SAW	1	309	304L	1.321	1.339	+.018
6184	GTAW-HW	2	309	304L	1.515	1.540	+.025
6185	GTAW-HW	1	309	304L	1.285	1.370	+.085
6186	GMAW	2	FM72	304L	1.529	1.533	+.004
6187	GMAW	1	FM72	304L	1.270	1.272	+.002
6188	SAW	2	FM72	304L	1.673	1.683	+.010
6189	SAW	1	FM72	304L	1.347	1.346	-.001
6190	GTAW-HW	2	FM72	304L	1.448	1.444	-.004
6191	GTAW-HW	1	FM72	304L	1.238	1.237	-.001
6192	GMAW	2	FM72	310	1.562	1.562	0
6193	GMAW	1	FM72	310	1.309	1.319	+.010
6194	SAW	2	FM72	310	1.703	1.705	+.002
6195	SAW	1	FM72	310	1.396	1.393	-.003
6196	GTAW-HW	2	FM72	310	1.528	1.527	-.001
6197	GTAW-HW	1	FM72	310	1.308	1.312	+.004
6198	GMAW	2	FM72	INCOLOY ALLOY 800H	1.546	1.548	+.002
6199	GMAW	1	FM72	"	1.309	1.310	+.001
6200	SAW	2	FM72	"	1.723	1.730	+.007
6201	SAW	1	FM72	"	1.402	1.404	+.002
6202	GTAW-HW	2	FM72	"	1.543	1.543	0
6203	GTAW-HW	1	FM72	"	1.326	1.326	0
6204	GMAW	2	R139	304L	1.536	1.541	+.005
6205	GMAW	1	R139	304L	1.301	1.305	+.004
6206	SAW	2	R139	304L	1.676	1.671	-.005
6207	SAW	1	R139	304L	1.359	1.362	+.003
6208	GTAW-HW	2	R139	304L	1.524	1.525	+.001
6209	GTAW-HW	1	R139	304L	1.273	1.283	+.010
6210	GMAW	2	R139	310	1.563	1.560	-.003
6211	GMAW	1	R139	310	1.322	1.326	+.004
6212	SAW	2	R139	310	1.656	1.650	-.006
6213	SAW	1	R139	310	1.375	1.374	+.001
6214	GTAW-HW	2	R139	310	1.546	1.550	+.004
6215	GTAW-HW	1	R139	310	1.307	1.308	+.001
6216	GMAW	2	R139	INCOLOY ALLOY 800H	1.600	1.617	+.017
6217	GMAW	1	R139	"	1.335	1.334	-.001
6218	SAW	2	R139	"	1.671	1.681	+.010
6219	SAW	1	R139	"	1.391	1.394	+.003
6220	GTAW-HW	2	R139	"	1.540	1.541	+.001
6321	GTAW-HW	1	R139	"	1.317	1.321	+.004

NOTES: (a) Overlay on both surfaces.
(b) mm = in. x 25.4.

TABLE 57

MEASUREMENTS FROM OUTER SCALE OF AFFECTED METAL OF OVERLAYS

Code	Weld Process	No. of Layers	Scale Thickness (a) (in) A	Scale Thickness (a) (in) B	Internal Oxidation (in) A	Internal Oxidation (in) B	Internal Sulfidation (in) A	Internal Sulfidation (in) B	Subscale Porosity (in) A	Max. Depth of Affected Metal (in) A	Max. Depth of Affected Metal (in) B
					309 on 304L						
6180	GMAW	2	.0008	.0110	.0019	-	-	.0122	-	.0027	.0232
6181	GMAW	1	.0062	.0115	.0275	-	.0275	.0290	-	.0337	.0405
6182	SAW	2	.0007	.0010	.0019	-	-	.0015	-	.0026	.0025
6183	SAW	1	.0013	.0080	.0021	-	.0024	.0123	-	.0037	.0203
6184	GTAW-HW	2	.0086	.0045	.0137	-	.0137	.0055	-	.0223	.0505
6185	GTAW-HW	1	.0204	.0180	-	-	-	.0063	-	.0204	.0243
					FM72 on 304L						
6186	GMAW	2	.0001	.0010	-	.0035	-	-	.0028	.0001	.0045
6187	GMAW	1	.0005	.0015	-	.0039	-	-	.0036	.0005	.0054
6188	SAW	2	.0002	.0008	-	.0002	-	-	.0005	.0002	.0010
6189	SAW	1	.0003	.0005	-	.0060	-	-	.0029	.0003	.0065
6190	GTAW-HW	2	.0007	.0010	-	.0040	-	-	.0030	.0007	.0050
6191	GTAW-HW	1	.0002	.0007	-	.0077	-	-	.0088	.0002	.0084
					FM72 On 310						
6192	GMAW	2	.0004	.0005	-	.0005	-	-	.0028	.0004	.0010
6193	GMAW	1	.0004	.0002	-	.0003	-	-	.0024	.0004	.0005
6194	SAW	2	.0004	.0005	-	.0015	-	-	.0024	.0004	.0020
6195	SAW	1	.0002	.0005	-	.0010	-	-	.0018	.0002	.0015
6196	GTAW-HW	2	.0002	.0010	.0005	.0027	-	-	.0031	.0007	.0037
6197	GTAW-HW	1	.0006	.0007	.0020	.0018	-	-	.0030	.0026	.0025
					FM72 on 800H						
6198	GMAW	2	.0002	.0005	.0011	.0050	.0020	-	-	.0025	.0055
6199	GMAW	1	.0003	.0008	.0027	.0057	-	-	.0032	.0030	.0065
6200	SAW	2	.0001	.0005	-	.0013	-	-	-	.0001	.0018
6201	SAW	1	.0003	.0006	-	-	-	-	.0025	.0003	.0006
6202	GTAW-HW	2	.0001	.0015	-	.0030	-	-	.0028	.0001	.0045
6203	GTAW-HW	1	.0003	.0005	-	.0065	-	-	.0005	.0003	.0070
					R139 on 304L						
6204	GMAW	2	.0012	.0015	.0022	-	.0025	.0060	-	.0037	.0075
6205	GMAW	1	.0011	.0015	.0027	-	.0032	.0054	-	.0043	.0069
6206	SAW	2	.0007	.0051	.0021	-	.0093	.0063	-	.0100	.0114
6207	SAW	1	.0012	.0027	.0022	-	.0061	.0056	-	.0073	.0083
6208	GTAW-HW	2	.0008	.0020	.0023	-	-	.0080	-	.0031	.0100
6209	GTAW-HW	1	.0023	.0045	.0039	-	.0039	.0059	-	.0062	.0104
					R139 on 310						
6210	GMAW	2	.0004	.0010	.0019	.0030	-	-	.0064	.0023	.0040
6211	GMAW	1	.0001	.0010	.0011	-	-	.0075	.0062	.0012	.0085
6212	SAW	2	.0001	.0010	.0010	.0021	-	-	.0050	.0011	.0031
6213	SAW	1	.0009	.0008	.0022	.0022	-	-	.0055	.0031	.0030
6214	GTAW-HW	2	.0007	.0010	.0020	.0025	-	-	.0042	.0027	.0035
6215	GTAW-HW	1	.0005	.0006	.0020	.0019	-	-	.0052	.0025	.0025
					R139 on 800H						
6216	GMAW	2	.0007	.0008	.0015	.0027	-	-	-	.0022	.0035
6217	GMAW	1	.0007	.0005	.0019	.0025	-	-	.0076	.0026	.0030
6218	SAW	2	.0006	.0006	.0021	.0021	-	-	.0044	.0027	.0027
6219	SAW	1	.0003	.0008	.0012	.0072	-	-	.0098	.0015	.0080
6220	GTAW-HW	2	.0008	.0006	.0023	.0027	-	-	.0075	.0031	.0033
6321	GTAW-HW	1	.0008	.0010	.0020	.0025	-	-	.0060	.0028	.0035

NOTES: (a) A - Investigator A, measured at a single reference point. Measured in microns and converted to inches.

B - Investigator B, maximum scale thickness and penetration in one inch specimen.

To convert inches to millimeters, multiply by 25.4.

TABLE 58

ELEMENTS IDENTIFIED IN SCALE BY X-RAY SCANNING

Weld No.	Process	Overlay-Substrate	Elements in Scale	Probable Scale Specie
6180	GMAW	309-304L	Cr, Fe, O, less Ni than overlay	Fe-Cr(a) Spinel, Cr Oxide under Spinel
6190	GTAW-HW	72-304L	High Cr, O, some Ti, no Fe or Ni	Cr_2O_3+Ti
6194	SAW	72-310	Cr, O, no Fe, Ni or Ti	Cr_2O_3
6198	GMAW	72-800H	Cr, O, some Ti no Fe or Ni	Cr_2O_3+Ti
6208	GTAW-HW	139-304L	Al, Cr, O, some Fe and Ti, no Ni - Al in lower part of scale	Cr_2O_3 and Al_2O_3
6212	SAW	139-310	Cr, O, trace of Ti, Al, Si and Fe	Cr_2O_3
6216	GMAW	139-800H	Cr, Al, O, some Fe and Ni	Cr_2O_3, Al_2O_3

NOTE: (a) From microstructural study.

TABLE 59

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE[a] - AWS-ER309 OVERLAYS ON 304L - GMAW PROCESS
(Wt.%)

Distance From Surface (mm)[b]	Ni	Cr	Fe	Mn	Si
W6180 Double Layer					
0	12.80	22.92	60.75	1.63	.37
1	12.13	23.59	58.44	1.94	.48
2	12.09	23.49	61.13	1.80	.39
3	12.46	23.50	60.33	1.86	.45
4	12.24	23.33	60.84	1.86	.55
4.1	12.36	23.46	60.81	1.96	.35
4.2	11.99	23.71	60.87	1.79	.44
4.3	11.93	23.77	60.96	1.80	.44
4.4	12.46	23.88	60.37	1.82	.44
Interface-Between Layers					
4.5	12.51	23.90	60.85	1.86	.39
4.6	12.16	23.96	61.74	1.89	.51
4.7	11.42	23.08	62.58	2.01	.41
9.4[c]	10.59	18.63	67.74	1.58	.48
W6181 Single Layer					
0	12.28	21.18	62.54	1.55	.35
1	10.66	22.41	61.40	2.07	.44
2	11.43	22.55	61.93	1.99	.55
3	11.60	21.89	61.85	2.06	.45
4	11.86	21.53	62.79	2.01	.37
4.1	12.14	20.46	63.14	1.81	.52
4.2	11.51	21.88	64.40	1.86	.44
Interface-Between Overlay and Substrate					
4.3	10.13	19.06	68.96	1.55	.51
4.4	9.79	18.66	68.49	1.73	.62
4.5	9.68	19.01	68.76	1.55	.45
9.2[c]	9.92	18.60	65.11	1.75	.52

(a) 1000 hours in a CGA at 982°C (1800°F)
(b) Metal below scale
(c) 5 mm from interface

TABLE 60

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - AWS-ER309
OVERLAYS ON 304L - SAW PROCESS (Wt.%)

W6182 - Double Layer						W-6183 - Single Layer					
(a)Distance From Surface (mm)	Ni	Cr	Fe	Mn	Si	(a)Distance From Surface (mm)	Ni	Cr	Fe	Mn	Si
0	13.32	23.74	61.34	.77	.84	0	11.27	22.30	61.27	1.67	.56
1	12.85	24.08	60.34	1.57	.82	1	10.28	23.34	61.96	1.79	.53
2	12.32	24.23	61.05	1.70	.83	2	10.80	23.35	63.95	1.43	.50
3	12.72	23.74	60.71	1.65	.88	3	11.12	22.68	61.63	1.68	.54
4	12.22	23.89	59.31	1.76	.76	3.1	11.51	23.26	60.03	1.58	.56
5	12.27	23.84	61.80	1.57	.95	3.2	12.72	23.60	61.02	1.71	.47
6	12.15	24.17	59.60	1.90	.82	Interface					
7	12.14	24.06	62.49	1.71	.73	3.3	11.66	21.43	64.67	1.37	.45
7.5	11.67	24.07	61.00	1.64	.84	3.4	11.09	18.97	67.52	1.48	.28
7.6	11.33	23.88	61.45	1.60	.72	3.5	10.17	18.52	68.10	1.40	.23
7.7	12.02	24.79	61.04	1.48	.81	3.6	9.84	19.31	67.75	1.45	.30
7.8	12.72	24.16	60.72	1.80	.82	(b) 8.2	9.45	19.24	69.59	1.41	.34
7.9	11.82	23.93	60.79	1.81	.85						
8.0	11.35	24.43	61.27	1.68	.78						
Interface											
8.1	11.40	20.11	66.40	1.51	.56						
8.2	10.96	19.66	67.62	1.42	.52						
8.3	10.79	19.76	67.79	1.41	.52						
(b)13.0	10.57	18.59	68.04	1.41	.51						

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 61

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - AWS-ER309 OVERLAYS ON 304L - GTAW-HW PROCESS (Wt.%)

W6184 Double Layer						W6185 Single Layer					
(a)Distance From Surface (mm)	Ni	Cr	Fe	Mn	Si	(a)Distance From Surface (mm)	Ni	Cr	Fe	Mn	Si
0	12.23	23.70	60.91	1.99	.54	0	11.47	21.54	67.81	.44	.36
1	12.56	23.30	58.68	1.88	.41	1	11.74	22.99	63.77	1.94	.54
2	12.67	23.57	61.15	2.13	.53	2	11.55	22.93	64.37	1.99	.57
3	12.50	23.26	62.33	2.05	.46	3	11.19	22.24	64.14	2.08	.42
3.1	12.82	23.27	60.95	2.05	.45	Interface - estimated location					
3.2	12.69	23.91	62.83	1.96	.40	4	9.86	19.00	68.57	1.84	.56
Interface (between layers)											
3.3	11.68	22.56	62.46	2.30	.46						
3.4	11.63	20.87	61.01	2.02	.39						
3.5	11.28	22.35	65.31	2.05	.45						
(b) 8.2	11.65	22.76	63.34	2.09	.47						

NOTES: (a) Metal surface below scale.
(b) Analysis indicates overlay not substrate.

TABLE 62

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON 304L - GMAW PROCESS (Wt.%)

Weld 6186 - Double Layer							Weld 6187 - Single Layer						
Distance from Surface (mm) [a]	Ni	Cr	Fe	Mn	Ti	Si	Distance from Surface (mm) [a]	Ni	Cr	Fe	Mn	Ti	Si
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 [b]	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 [b]	9.55	19.11	68.46	1.81	.00	.45							

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 63

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON 304L - SAW PROCESS (Wt.%)

Weld 6188 - Double Layer							Weld 6189 - Single Layer						
Distance from Surface[a] (mm)	Ni	Cr	Fe	Mn	Ti	Si	Distance from Surface[a] (mm)	Ni	Cr	Fe	Mn	Ti	Si
0	53.22	37.59	7.00	.36	.13	.53	0	43.35	33.29	21.10	.44	.05	.41
1	52.61	38.23	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 64

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON 304L - GTAW-HW PROCESS (Wt.%)

Weld 6190 - Double Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	33.91	51.75	13.18	.32	.15	.30
1	46.40	40.49	13.42	.43	.15	.24
2	50.75	35.71	14.00	.46	.31	.19
3	46.88	38.54	14.95	.46	.14	.23
4	46.94	35.85	14.11	.45	.21	.21
5	40.29	32.47	26.34	.68	.06	.28
5.5	36.59	32.70	26.33	.76	.41	.23
5.6	35.97	38.73	25.05	.80	.44	.24
5.7	39.60	34.21	26.32	.78	.35	.29
5.8	39.49	33.01	27.23	.84	.18	.18
5.9	38.03	33.12	26.58	.75	.31	.36
6.0	37.85	32.48	29.47	.84	.24	.33
6.1	36.39	32.53	29.93	.84	.21	.31
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

Weld 6191 - Single Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	39.19	33.20	27.34	.36	.02	.37
1	34.83	30.58	31.91	.75	.00	.30
2	36.95	32.46	30.58	.82	.11	.25
3	34.35	32.06	32.41	.73	.04	.37
4	35.00	32.11	32.27	.84	.06	.30
4.1	33.79	33.49	31.84	.60	.20	.25
4.2	33.34	29.81	34.37	1.08	.08	.32
Interface						
4.3	19.09	25.78	49.34	1.26	.00	.46
4.4	9.94	19.12	68.28	1.58	.00	.65
4.5	10.48	19.56	67.68	1.49	.00	.72
9.2[b]	10.24	19.48	68.11	1.41	.00	.54
(c)	13.39	18.99	65.44	.73	.22	.21

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

TABLE 65

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON 310SS - GMAW PROCESS (Wt.%)

Weld 6192 - Double Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	52.36	25.35	11.06	.21	.00	.32
1	44.63	43.70	7.60	.40	.45	.15
2	46.51	42.51	9.50	.46	.18	.30
3	43.05	42.49	10.93	.34	.26	.20
4	49.98	36.57	9.53	.39	.20	.21
5	36.69	51.06	10.99	.33	.19	.16
6	40.79	34.08	20.72	.85	.35	.29
7	36.96	37.09	23.17	.79	.07	.32
8	40.86	32.28	22.56	.43	.03	.06
8.1	24.91	49.96	22.35	.79	.03	.27
8.2	41.24	32.96	21.12	.87	.10	.31
8.3	43.76	29.67	17.30	.78	.04	.32
8.4	40.17	31.92	23.14	.89	.29	.33
Interface						
8.5	24.57	41.17	31.45	1.26	.13	.31
8.6	22.60	26.57	44.34	1.57	.00	.41
8.7	19.66	25.73	48.73	1.70	.00	.28
13.4[b]	18.52	25.67	51.56	1.68	.00	.28

Weld 6193 - Single Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	37.63	35.98	25.52	.47	.01	.26
1	34.12	37.23	26.59	.85	.11	.36
2	38.89	34.63	24.23	.95	.09	.28
3	41.35	31.01	25.97	.87	.13	.32
4	39.91	31.84	21.51	.94	.08	.28
5	39.51	32.40	25.63	.91	.07	.32
5.1	38.49	35.42	24.89	.82	.03	.40
5.2	38.41	35.68	25.03	.85	.08	.35
5.3	40.30	32.17	23.19	.79	.28	.34
5.4	40.06	31.21	24.66	.85	.37	.32
5.5	41.33	31.64	23.99	.46	.04	.21
5.6	39.74	34.92	24.99	.86	.07	.31
5.7	41.25	31.89	24.38	.91	.05	.38
5.8	38.27	30.67	23.96	.82	.07	.33
5.9	27.35	28.31	40.62	.84	.18	.30
Interface						
6.0	13.92	36.41	43.35	1.04	.00	.26
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 66

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON 310SS - SAW PROCESS (Wt.%)

Weld 6194 - Double Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	55.81	38.62	5.82	.19	.04	.46
1	55.96	38.35	5.45	.55	.12	.45
2	55.61	38.67	5.80	.45	.16	.38
3	55.91	38.40	5.98	.38	.15	.29
4	56.00	38.32	5.52	.51	.14	.38
5	54.97	38.99	5.95	.54	.19	.44
6	55.57	37.91	3.78	.53	.11	.38
7	48.01	35.84	16.25	.72	.08	.46
8	47.92	35.16	16.04	.82	.04	.49
9	47.06	34.99	16.77	.81	.11	.40
10	45.88	35.17	17.42	.91	.00	.45
10.1	45.51	35.01	11.13	.79	.05	.39
10.2	47.10	34.23	18.13	.95	.16	.48
10.3	45.54	33.52	20.41	1.07	.35	.52
Interface						
10.4	24.14	29.45	42.11	1.39	.00	.44
10.5	21.13	26.47	44.57	1.51	.00	.44
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

Weld 6195 - Single Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Si
0[a]	47.51	35.02	17.26	.26	.05	.71
1	48.01	34.63	16.08	.81	.06	.37
2	47.27	34.79	17.33	.78	.10	.38
3	47.21	32.80	18.11	.83	.12	.47
4	47.05	32.15	18.56	.76	.05	.43
5	47.57	34.44	17.34	.77	.06	.46
5.5	44.94	34.82	17.42	.71	.12	.37
5.6	44.27	34.84	18.45	.76	.16	.49
5.7	32.88	38.14	18.72	.70	.25	.46
5.8	20.77	34.03	37.63	.86	.12	.50
5.9	19.19	31.67	50.65	.67	.00	.21
6.0	19.54	27.31	52.56	1.20	.00	.45
Interface						
6.1	19.94	25.41	53.12	1.55	.00	.41
6.2	19.30	26.14	52.37	1.68	.03	.50
6.3	20.32	25.25	53.40	1.46	.00	.66
11.0[b]	17.87	24.68	53.53	1.83	.00	.36

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

TABLE 67

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE INCONEL FILLER METAL 72 OVERLAYS ON 310SS - GTAW-HW PROCESS (WT.%)

Distance From Surface (mm) [a]	Ni	Ce	Fe	Mn	Ti	Si
W6196 - Double Layer						
0	38.22	49.25	14.08	.28	.06	.14
1	45.66	40.87	12.81	.54	.15	.17
2	31.02	53.98	14.55	.50	.13	.07
3	51.06	33.73	13.42	.50	.08	.23
4	42.04	43.07	12.98	.58	.11	.18
5	27.85	50.38	15.68	.59	.03	.14
6	49.19	36.59	12.59	.49	.06	.15
7	43.50	34.07	22.87	.69	.04	.22
7.5	39.70	35.79	23.39	.90	.08	.23
7.6	31.45	41.95	24.68	.90	.10	.20
7.7	42.65	33.18	19.00	.96	.14	.28
7.8	41.31	33.06	26.23	.84	.19	.19
7.9	20.44	34.25	46.12	1.22	.00	.45
Interface						
8.0	20.78	23.60	53.28	1.63	.02	.44
8.1	19.93	25.82	53.38	1.71	.00	.43
8.2	19.66	26.00	52.86	1.82	.00	.46
12.9 [b]	19.45	26.33	52.21	1.68	.00	.43
W6197 - Single Layer						
0	43.89	33.30	23.96	.32	.19	.22
1	36.29	42.07	22.42	.84	.11	.29
2	35.08	43.26	20.73	.64	.08	.15
3	40.77	34.83	21.91	.81	.09	.25
4	35.34	40.98	22.02	.99	.06	.20
4.5	39.73	33.56	20.45	.80	.07	.22
4.6	31.52	42.07	24.78	.84	.04	.25
4.7	33.34	39.91	24.44	.91	.10	.27
4.8	39.15	33.64	27.17	.67	.05	.16
4.9	39.99	34.09	25.61	.95	.11	.30
5	40.88	33.80	25.40	.95	.09	.22
5.1	38.17	32.02	23.67	.54	.08	.12
5.2	34.56	31.52	23.62	.99	.06	.26
5.3	29.74	29.75	35.40	1.11	.08	.27
Interface						
5.4	21.14	27.01	44.96	1.27	.06	.41
5.5	19.31	26.13	52.59	1.54	.00	.40
5.6	19.16	25.88	53.59	1.80	.03	.42
10.3 [b]	18.87	26.26	51.78	1.67	.00	.43

(a) Metal below scale
(b) 5 mm from interface

TABLE 68

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H - GMAW PROCESS (Wt.%)

Distance From Surface (mm)(a)	W6198 - Double Layer Ni	Cr	Fe	Mn	Ti	Si	Distance From Surface (mm)(a)	W6199 - Single Layer Ni	Cr	Fe	Mn	Ti	Si
0	54.35	37.77	7.04	.03	.71	.16	0	43.09	35.11	16.19	.07	.03	.16
1	53.82	38.26	5.92	.17	.49	.08	1	47.58	32.60	17.00	.38	.47	.10
2	52.78	38.26	6.32	.17	.55	.07	2	47.11	32.57	17.58	.32	.41	.18
3	55.58	37.18	5.76	.14	.47	.02	3	46.31	32.70	18.30	.32	.48	.11
4	53.58	37.53	6.51	.21	.45	.13	4	45.67	32.84	17.49	.32	.46	.14
5	54.69	37.19	6.73	.14	.47	.13	5	46.84	33.73	16.43	.28	.42	.15
6	44.60	34.97	16.39	.24	.46	.09	5.1	47.47	31.90	17.35	.34	.51	.16
7	45.99	34.97	16.84	.34	.38	.12	5.2	47.54	32.56	19.23	.31	.32	.12
7.1	46.55	34.97	18.04	.35	.36	.16	5.3	47.93	33.00	12.88	.38	.43	.12
7.2	48.04	33.36	17.51	.19	.58	.02	5.4	43.15	30.13	21.44	.33	.39	.14
7.3	49.35	32.54	16.09	.31	.45	.06	5.5	45.38	29.14	24.91	.40	.37	.12
7.4	40.56	39.25	16.72	.29	.36	.07	5.6	48.78	26.90	22.03	.40	.57	.12
7.5	49.45	30.53	15.07	.31	.57	.11	Interface						
Interface							5.7	31.40	21.14	39.01	.57	.24	.07
7.6	32.99	24.60	38.95	.31	.79	.04	5.8	31.14	20.33	44.47	.68	.27	.16
7.7	30.46	21.49	43.49	.49	.31	.14	5.9	31.35	20.09	44.96	.67	.48	.15
7.8	30.26	20.39	45.30	.76	.31	.17	10.6(b)	30.74	20.11	44.06	.63	.66	.18
12.5(b)	31.44	20.21	45.73	.67	.25	.14							

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 69

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H - SAW PROCESS (Wt.%)

Distance From Surface (mm)(a)	W6200 - Double Layer Ni	Cr	Fe	Mn	Ti	Si	Distance From Surface(mm)(a)	W6201 - Single Layer Ni	Cr	Fe	Mn	Ti	Si
0	54.32	38.99	6.00	.32	.09	.51	0	49.60	35.26	16.19	.38	.07	.45
1	50.59	42.08	5.42	.50	.26	.49	1	50.12	34.39	15.93	.52	.29	.39
2	55.03	37.33	5.64	.38	.21	.36	2	50.05	34.18	15.56	.51	.23	.40
3	52.83	40.18	5.63	.53	.22	.45	3	45.67	37.46	14.47	.48	.55	.38
4	55.20	38.16	5.43	.51	.21	.46	4	47.78	34.29	15.57	.48	.20	.30
5	57.25	37.67	5.47	.51	.17	.53	5	46.52	36.58	15.91	.53	.21	.41
6	56.52	38.51	5.24	.41	.20	.53	5.5	51.10	33.17	15.24	.48	2.70	.32
7	46.63	37.31	15.56	.56	.18	.25	5.6	49.38	33.08	15.11	.52	.32	.34
8	45.84	35.99	15.99	.56	.18	.37	5.7	40.51	26.84	26.56	.63	.85	.20
9	47.35	35.38	16.19	.56	.26	.45	Interface						
10	46.94	33.98	13.10	.47	.19	.35	5.8	31.23	21.05	45.53	.73	.27	.13
10.1	47.72	32.84	16.69	.49	.35	.32	5.9	32.41	20.49	45.74	.62	.63	.11
10.2	42.01	30.09	17.98	.59	.39	.34	6.0	32.04	20.85	46.30	.72	.34	.17
10.3	36.47	27.27	29.59	.60	.25	.24	6.1	31.64	19.91	46.63	.69	.35	.18
10.4	34.44	24.36	35.39	.67	.28	.23	6.2	31.23	19.65	46.63	.69	.33	.18
10.5	32.31	21.18	46.20	.69	.37	.18	6.3	31.71	20.74	46.05	.73	.31	.16
Interface							10.7(b)	31.92	20.82	46.09	.67	.26	.18
10.6	30.19	20.99	45.90	.66	.26	.12							
10.7	29.13	21.20	46.48	.65	.33	.09							
10.8	29.77	20.73	46.41	.69	.37	.14							
15.5(b)	29.52	20.82	44.64	.57	.36	.13							

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 70

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - INCONEL FILLER METAL
72 OVERLAYS ON INCOLOY ALLOY 800H - GTAW-HW PROCESS (Wt.%)

Distance From Surface (mm)(a)	W6202 - Double Layer						Distance From Surface (mm)(a)	W6203 - Single Layer					
	Ni	Cr	Fe	Mn	Ti	Si		Ni	Cr	Fe	Mn	Ti	Si
0	52.96	35.04	10.99	.15	.42	.14	0	49.28	32.61	17.19	.15	.39	.15
1	45.31	38.99	9.39	.25	.22	.11	1	46.14	34.13	17.07	.37	.29	.10
2	49.16	38.05	9.12	.27	.24	.16	2	46.42	33.91	16.86	.44	.38	.15
3	50.51	37.30	9.68	.29	.25	.13	3	48.17	34.39	16.22	.31	.31	.11
4	50.05	39.83	9.93	.29	.26	.13	4	46.67	33.92	12.48	.36	.38	.19
5	54.14	36.25	9.74	.30	.33	.08	5	48.03	33.09	16.07	.41	.31	.08
6	41.50	33.02	23.52	.44	.20	.07	5.1	47.41	33.46	16.12	.35	.36	.06
7	42.18	33.01	22.06	.42	.35	.13	5.2	40.34	38.99	20.67	.54	.29	.02
8	39.05	29.49	25.99	.54	.30	.14	Interface						
8.1	37.30	28.23	32.12	.55	.19	.07	5.3	31.93	28.12	41.72	.68	.25	.25
8.2	33.20	27.04	32.34	.55	.18	.16	5.4	30.11	21.07	35.83	.69	.38	.08
8.3	22.38	45.34	30.81	.59	.24	.08	5.5	29.73	20.95	45.33	.71	.35	.16
8.4	40.86	29.27	23.49	.42	.30	.14	5.6	29.72	20.78	45.03	.74	.33	.14
8.5	37.09	27.08	32.73	.55	.27	.14	10.2(b)	29.45	21.36	46.18	.81	.25	.15
Interface													
8.6	29.34	20.54	45.41	.67	.32	.06							
8.7	30.49	21.12	46.02	.73	.35	.18							
8.8	30.13	20.68	46.17	.79	.33	.12							
8.9	30.17	20.69	46.14	.73	.34	.11							
13.5(b)	30.90	20.04	46.12	.75	.24	.16							

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 71

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - R139 OVERLAYS ON 304L - GMAW PROCESS (Wt.%)

W6204 - Double Layer

Distance From Surface (mm)(a)	Ni	Cr	Fe	Mn	Ti	Si	Al
0	45.11	28.86	20.26	.49	.34	.05	2.91
1	46.60	28.38	18.19	.65	.59	.11	4.17
2	47.05	26.12	19.49	.70	.73	.08	2.85
3	47.75	25.33	19.40	.59	.34	.09	2.60
4	41.65	26.57	24.81	.83	.48	.18	3.57
5	40.97	25.92	25.09	.84	.39	.14	3.29
6	36.96	27.67	25.81	.76	.40	.12	3.03
6.1	40.60	28.61	26.61	.68	.29	.00	3.10
6.2	39.60	28.94	27.62	.84	.64	.22	3.56
6.3	34.02	27.74	34.12	.84	.33	.14	1.57
6.4	22.68	24.98	45.93	1.14	.28	.33	1.28
6.5	15.16	23.05	58.53	1.21	.41	.30	1.68
Interface							
6.6	10.66	20.38	61.29	1.80	.03	.62	.02
6.7	9.64	19.12	68.19	1.80	.00	.52	.00
6.8	9.69	19.43	68.36	1.76	.00	.56	.00
11.5(b)	10.45	18.76	69.65	1.71	.00	.60	.00

W6205 - Single Layer

0	39.56	28.13	29.25	.23	.51	.22	1.15
1	38.29	31.15	23.67	.78	.25	.19	2.88
2	40.13	30.33	26.25	.78	.66	.16	2.79
3	36.29	32.90	26.43	.96	.53	.12	2.80
4	35.63	31.91	24.14	.71	.47	.41	2.32
4.1	35.41	25.22	35.71	1.16	.55	.33	.89
Interface							
4.2	9.50	19.51	67.38	1.38	.00	.53	.00
4.3	10.10	19.16	66.48	1.72	.00	.47	.00
4.4	10.03	19.35	65.69	1.71	.00	.57	.00
9.1(b)	10.56	18.96	62.64	1.78	.04	.54	.00

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 72

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - R139
OVERLAYS ON 304L - SAW PROCESS (Wt.%)

W6206 - Double Layer

Distance From Surface (mm)(a)	Ni	Cr	Fe	Mn	Ti	Si	Al
0	49.86	24.46	18.23	.38	.32	.76	.93
1	45.13	28.92	19.47	.82	.56	.72	2.52
2	48.63	29.15	19.33	.74	.49	.51	2.30
3	45.99	29.77	19.24	1.04	.46	.89	2.86
4	44.96	29.43	18.96	1.06	.56	.77	2.63
5	45.42	28.76	16.84	.89	.49	.61	2.56
6	48.65	29.52	18.67	.94	.50	.69	2.45
7	39.99	28.07	27.69	1.34	.45	.77	2.23
8	36.19	27.33	27.22	1.22	.31	.64	1.93
8.5	38.69	27.91	28.49	1.13	.16	.62	2.26
8.6	38.34	27.12	28.30	1.31	.06	.71	2.04
8.7	38.54	26.98	28.66	1.22	.06	.76	1.71
8.8	38.89	27.81	29.38	1.22	.02	.68	1.39
8.9	39.56	27.74	30.49	1.31	.03	.71	1.51
9.0	32.53	26.76	33.14	1.45	.08	.71	.44
9.1	26.45	25.66	46.66	1.32	.83	.53	.25
Interface							
9.2	9.39	19.14	67.79	1.72	.00	.61	.00
9.3	10.02	18.96	65.83	1.63	.00	.47	.00
9.4	10.04	19.18	64.30	1.61	.00	.57	.00
14.1(b)	9.38	19.10	65.79	1.69	.00	.50	.00

W6207 - Single Layer

0	39.02	26.02	33.17	.36	.25	.73	1.16
1	36.33	27.85	27.46	1.08	.33	.73	2.21
2	35.18	27.68	30.85	1.13	.33	.65	2.11
3	35.56	28.45	29.45	.78	.25	.54	2.12
4	37.25	27.59	29.59	1.13	.48	.78	2.06
5	34.83	26.53	30.08	1.23	.80	.67	1.74
5.1	33.56	27.43	28.04	1.23	.04	.70	1.42
5.2	10.83	24.38	64.18	1.49	.53	.57	.49
Interface							
5.3	9.74	19.23	66.56	1.66	.00	.51	.00
5.4	9.90	19.16	65.96	1.78	.00	.58	.00
10.2(b)	9.69	19.10	66.05	1.76	.00	.58	.00

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 73

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - R139
OVERLAYS ON 304L - GTAW-HW PROCESS (Wt.%)

W6208 - Double Layer

Distance From Surface (mm)(a)	Ni	Cr	Fe	Mn	Ti	Si	Al
0	45.39	25.78	26.49	.35	.20	.11	2.06
1	43.69	25.55	25.17	.73	.20	.07	3.21
2	45.70	25.69	25.08	.83	.22	.15	3.03
3	46.48	25.85	24.71	.86	.30	.14	2.90
4	39.71	27.82	27.10	.91	.27	.19	2.47
5	32.29	25.73	38.97	1.17	.06	.22	2.23
6	32.11	25.08	39.64	1.10	.06	.30	2.10
7	32.56	25.24	39.56	1.08	.03	.18	2.14
8	14.86	21.49	55.65	1.36	.07	.42	.43
8.1	15.99	24.47	49.64	1.35	.04	.31	.45
8.2	16.11	22.25	50.00	1.41	.10	.33	.12
Interface							
8.3	10.62	21.01	65.41	1.48	.00	.33	.02
8.4	10.35	19.41	63.12	1.67	.02	.58	.03
8.5	10.36	18.50	68.20	1.70	.01	.56	.00
8.6	10.14	18.69	68.21	1.77	.00	.61	.00
13.2(b)	10.14	19.35	67.62	1.81	.00	.52	.00

W6209 - Single Layer

0	39.55	26.55	33.29	.34	.83	.19	1.13
1	37.81	26.96	31.32	.93	.13	.24	2.75
2	36.51	27.18	31.24	.95	.07	.20	2.48
3	38.73	26.85	31.17	.96	.17	.18	2.53
4	37.10	26.86	32.23	.76	.06	.16	2.36
4.5	41.19	25.73	29.09	.94	.16	.12	2.82
4.6	38.19	27.30	29.62	.98	.07	.21	2.49
4.7	33.00	25.93	32.44	1.23	.41	.25	.79
Interface							
4.8	10.12	19.17	64.41	1.79	.00	.45	.06
4.9	10.16	18.51	69.22	1.79	.02	.45	.00
5.0	10.29	18.07	69.42	1.83	.02	.42	.00
9.7(b)	10.55	18.13	68.16	1.82	.00	.49	.00

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 74

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - R139
OVERLAYS ON 310SS - GMAW PROCESS (Wt.%)

W6210 - Double Layer

Distance From Surface (mm)(a)	Ni	Cr	Fe	Mn	Ti	Si	Al
0	43.19	30.08	22.42	.30	.27	.15	2.44
1	41.58	36.36	18.61	.84	.13	.08	3.12
2	39.78	38.75	17.88	.87	.25	.07	3.56
3	35.03	34.54	16.49	.90	.11	.14	3.62
4	38.55	27.75	26.93	1.08	.05	.21	3.00
5	39.77	28.11	28.32	1.08	.13	.19	2.25
6	31.63	33.05	29.82	1.07	.06	.16	2.70
7	37.25	27.79	29.52	.97	.12	.18	3.30
7.1	38.99	28.15	30.16	1.11	.13	.23	1.36
7.2	37.17	27.23	31.73	1.06	.03	.20	2.69
7.3	38.11	27.56	30.66	1.29	.06	.27	1.86
Interface							
7.4	22.80	26.70	48.86	1.14	.02	.61	.73
7.5	17.07	27.01	53.64	1.41	.01	.68	.08
7.6	19.28	25.60	53.20	1.41	.00	.68	.26
12.3(b)	19.01	27.00	52.98	1.67	.00	.47	.20

W6211 - Single Layer

0	37.76	29.40	31.21	.38	.21	.21	1.43
1	39.95	27.21	29.37	.88	.17	.12	3.03
2	40.83	26.00	28.42	1.06	.21	.15	2.62
3	38.67	27.93	30.22	.94	.19	.17	2.60
4	41.06	23.95	29.27	.97	.16	.18	2.11
4.5	39.77	27.74	30.64	.62	.03	.08	1.83
4.6	40.31	26.60	28.11	1.01	.43	.13	2.66
4.7	34.89	33.82	28.95	1.02	.08	.17	1.70
4.8	36.26	29.18	34.06	1.14	.18	.20	2.51
Interface							
4.9	16.16	29.71	51.48	1.72	.00	.51	.13
5.0	17.81	29.57	51.33	1.83	.00	.47	.04
5.1	16.67	29.72	51.41	1.88	.05	.46	.66
9.8(b)	18.53	26.59	51.14	1.83	.00	.42	.07

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 75

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE - R139
OVERLAYS ON 310SS - SAW PROCESS (Wt.%)

W6212 - Double Layer

Distance From Surface (mm)(a)	Ni	Cr	Fe	Mn	Ti	Si	Al
0	43.45	31.19	21.51	.44	.43	.86	.54
1	42.19	32.70	17.72	.83	.72	.68	2.18
2	45.12	29.24	21.79	1.22	.32	.67	1.81
3	36.10	35.14	21.55	1.27	.47	.77	1.64
4	45.04	29.66	21.57	1.20	.38	.39	1.80
5	44.23	29.15	21.20	1.27	.39	.75	1.87
6	38.70	28.76	21.94	1.35	.37	.68	1.49
7	35.64	34.13	28.08	.93	.20	.50	1.12
8	40.17	30.33	26.53	1.44	.21	.60	1.52
8.5	40.01	29.39	26.17	1.18	.04	.61	1.83
8.6	40.47	29.68	27.77	1.36	.02	.65	1.50
8.7	39.04	29.51	27.98	1.28	.00	.74	1.41
8.8	39.55	28.68	27.68	1.32	.06	.60	1.62
8.9	40.48	28.10	28.66	.94	.06	.41	1.51
9.0	35.38	29.96	24.78	1.40	.01	.52	1.14
9.1	19.27	25.87	52.37	1.50	.01	.32	.62
Interface							
9.2	19.84	24.87	52.37	1.68	.00	.37	.10
9.3	19.38	35.60	52.55	1.85	.00	.27	.27
9.4	20.06	25.33	51.96	1.84	.01	.20	.11
14.1(b)	19.54	25.54	51.11	1.80	.00	.31	.14

W6213 - Single Layer

0	39.74	27.79	30.49	.56	.43	.54	.86
1	36.37	30.13	28.69	1.36	.14	.53	1.92
2	40.20	28.25	26.77	1.41	.22	.54	1.79
3	39.17	28.86	28.73	1.30	.19	.60	1.68
4	39.40	27.83	27.89	1.32	.19	.53	1.55
5	38.69	28.88	27.91	1.42	.34	.50	1.60
6	37.24	29.22	27.42	1.37	.06	.52	1.36
6.1	35.63	27.75	27.61	1.37	.13	.49	1.07
6.2	32.72	27.06	34.62	1.60	.00	.20	.25
Interface							
6.3	19.94	24.53	52.08	1.78	.00	.26	.23
6.4	19.82	24.98	52.39	1.88	.02	.29	.24
6.5	19.89	24.71	52.60	1.73	.04	.30	.31
11.2(b)	19.16	26.02	51.28	1.78	.02	.20	.25

NOTES: (a) Metal surface below scale.
(b) 5 mm from interface.

TABLE 76

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE R139 OVERLAYS ON 310 SS GTAW-HW PROCESS-(WT.%)

Distance from Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6214 - Double Layer							
0	45.58	27.80	23.66	.33	.49	.06	1.34
1	46.02	25.76	21.78	.28	.84	.04	3.58
2	44.46	26.35	21.95	.27	.94	.00	3.15
3	46.75	25.33	22.09	.25	.54	.02	3.21
4	42.68	30.20	18.85	.26	.90	.00	3.38
5	46.30	26.23	20.97	.24	.89	.01	3.38
6	38.36	28.67	26.36	.14	.84	.07	2.46
7	36.21	26.96	32.90	.07	1.12	.12	2.25
7.1	35.60	27.35	34.21	.16	1.24	.09	1.65
Interface							
7.2	20.45	25.47	49.03	.00	1.45	.33	.85
7.3	19.33	25.49	51.84	.00	1.66	.36	.00
7.4	19.63	26.24	51.81	.00	1.84	.34	.16
12.1(b)	18.58	24.99	51.09	.00	1.78	.33	.07
W6215 - Single Layer							
0	37.62	29.55	30.22	.19	.67	.13	.73
1	36.04	29.33	28.99	.15	.96	.08	2.27
2	37.42	28.33	27.22	.11	1.17	.13	2.84
3	40.14	25.97	24.81	.12	1.02	.12	2.24
4	33.64	32.97	30.66	.17	.67	.09	2.36
4.5	37.47	26.69	28.19	.13	.64	.00	2.72
4.6	38.38	26.05	30.56	.27	1.03	.10	2.36
4.7	36.21	26.85	30.06	.24	1.24	.18	2.16
Interface							
4.8	27.40	25.88	42.05	.11	1.74	.32	.52
4.9	20.45	24.48	48.88	.00	1.69	.34	.27
5.0	19.76	24.35	48.80	.00	1.76	.33	.08
9.7(b)	19.07	25.58	48.09	.00	1.76	.40	.20

(a) Metal below scale
(b) 5 mm from interface

TABLE 77

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE R139 OVERLAYS ON INCOLOY ALLOY 800H-GMAW PROCESS-(WT.%)

Distance from(a) Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6216 - Double Layer							
0	47.16	29.45	20.37	.15	.37	.06	2.30
1	49.36	25.46	19.47	.26	.64	.09	3.19
2	48.25	28.57	20.11	.48	.46	.09	3.34
3	48.03	28.62	14.80	.32	.67	.07	2.97
4	45.51	30.87	20.44	.32	.67	.07	3.36
5	41.29	28.32	25.04	.32	.66	.09	2.70
6	39.26	31.52	26.28	.39	.65	.06	2.66
6.5	42.50	26.67	27.32	.37	.71	.07	2.75
6.6	37.19	25.86	27.39	.37	.34	.13	2.11
6.7	42.21	26.91	24.78	.55	.67	.00	2.41
6.8	42.79	26.54	22.81	.31	.65	.10	2.39
6.9	39.38	26.89	29.03	.32	.71	.12	2.36
7.0	33.58	23.82	33.85	.33	.66	.12	1.55
Interface							
7.1	31.17	20.59	45.40	.29	.59	.15	.57
7.2	31.37	20.50	47.03	.38	.68	.14	.35
7.3	30.21	20.93	45.87	.38	.59	.10	.31
12.0(b)	30.93	20.68	46.36	.18	.71	.17	.36
W6217 - Single Layer							
0	35.34	34.25	24.64	.51	.47	.11	1.73
1	35.79	36.44	24.01	.29	.68	.09	2.86
2	38.64	31.74	25.32	.28	.60	.07	2.60
3	40.68	29.54	25.71	.35	.72	.10	2.96
3.5	40.60	27.10	27.69	.35	.71	.18	2.81
3.6	41.06	28.48	27.91	.32	.61	.13	2.83
3.7	33.00	23.78	32.02	.24	.70	.10	2.28
Interface							
3.8	30.79	20.85	47.13	.13	.56	.15	.48
3.9	31.30	20.98	46.21	.34	.81	.13	.42
4.0	30.86	20.67	47.33	.36	.71	.17	.44
8.7(b)	31.58	19.87	46.63	.32	.75	.11	.48

(a) Metal below scale
(b) 5mm from interface

TABLE 78

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE R139 OVERLAYS ON INCOLOY ALLOY 800H - SAW PROCESS
(Wt.%)

Distance from (a) Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6218 Double Layer							
0	45.62	30.73	20.44	.06	.26	1.01	.90
1	46.56	29.73	20.61	.44	1.05	.93	2.31
2	47.53	28.87	20.33	.45	.98	.86	1.91
3	48.79	27.74	20.38	.38	.82	.74	2.13
4	41.10	29.49	21.20	.33	.92	.73	2.37
5	40.05	30.18	26.97	.45	.89	.62	1.76
6	41.04	28.69	26.03	.40	.92	.64	1.74
7	41.61	28.86	27.01	.33	.79	.58	1.96
8	39.30	26.30	29.03	.37	.81	.50	1.44
8.5	43.02	25.70	27.65	.45	.85	.34	1.64
Interface							
8.6	31.70	21.12	43.78	.28	.72	.11	.66
8.7	31.53	20.80	44.78	.42	.75	.13	.47
8.8	32.07	20.96	44.92	.27	.68	.14	.30
13.5 (b)	31.43	20.78	45.66	.24	.72	.15	.38
W6219 Single Layer							
0	41.26	27.45	25.15	.24	.45	1.05	.74
1	40.42	27.46	24.31	.45	1.04	.86	1.93
2	39.86	27.58	23.89	.69	.95	.71	1.87
3	40.55	27.41	23.51	.25	1.07	.66	2.32
4	40.92	27.39	25.31	.33	1.10	.70	2.03
5	39.93	27.10	25.07	.41	.98	.58	2.19
5.5	42.03	25.85	22.63	.43	.90	.54	2.06
Interface							
5.6	30.16	20.62	42.93	.41	.66	.13	.89
5.7	30.81	20.03	43.28	.32	.69	.04	.74
5.8	30.96	20.24	42.31	.30	.71	.07	.65
10.5 (b)	30.46	20.17	42.24	.37	.78	.06	.54

(a) Metal surface below scale
(b) 5mm from interface

TABLE 79

DISTRIBUTION OF ELEMENTS AFTER EXPOSURE R139 OVERLAYS ON INCOLOY ALLOY 800H-GTAW-HW PROCESS(WT.%)

Distance from (a) Surface(mm)	Ni	Cr	Fe	Ti	Mn	Si	Al
W6220 Double Layer							
0	45.84	28.80	22.81	.38	.33	.08	2.25
1	44.44	28.89	22.52	.27	.58	.11	3.14
2	45.54	27.04	22.82	.26	.62	.09	3.35
3	41.67	33.09	18.54	.36	.69	.11	3.15
4	41.24	32.05	23.06	.30	.60	.10	2.86
5	41.23	26.46	29.06	.29	.59	.11	2.59
6	39.93	27.03	28.98	.27	.55	.08	2.62
7	41.26	25.99	28.47	.20	.63	.12	2.43
7.1	39.47	25.30	29.60	.30	.68	.15	2.49
7.2	41.18	25.57	26.85	.30	.70	.14	2.43
7.3	40.08	25.50	29.67	.23	.70	.09	2.39
7.4	38.00	24.96	29.77	.32	.62	.18	1.76
Interface							
7.5	30.83	20.64	44.86	.38	.60	.14	.43
7.6	31.19	20.55	45.15	.32	.68	.14	.59
7.7	29.58	20.90	45.00	.33	.73	.15	.48
12.4(b)	30.27	20.52	45.04	.24	.64	.11	.59
W6321 Single Layer							
0	46.67	25.82	26.76	.07	.32	.18	1.16
1	43.53	27.26	24.62	.13	.65	.15	2.64
2	44.01	26.81	26.04	.29	.58	.08	2.60
3	43.53	28.43	25.85	.25	.58	.08	2.91
4	40.08	26.07	30.00	.28	.62	.08	1.60
4.1	36.01	24.20	39.12	.25	.60	.14	1.36
4.2	36.89	23.15	37.98	.35	.66	.10	1.42
Interface							
4.3	30.83	20.95	45.74	.23	.57	.21	.79
4.4	30.81	20.29	46.36	.31	.72	.18	.66
4.5	30.32	20.84	45.57	.26	.66	.14	.40
9.2(b)	32.12	20.32	46.52	.23	.73	.13	.53

(a) Metal surface below scale
(b) 5mm from interface

TABLE 80

WELD PROCESSES WHICH GAVE (a) SAW TOOTH TYPE DISTRIBUTION OF Cr (b) IN OVERLAYS ON VARIOUS SUBSTRATES

Filler Metal	304L	310	INCOLOY Alloy 800H
		As Welded	
AWS-ER309	None	-	-
R139	None	GMAW and SAW in Upper Layers (c)	GMAW(c)
INCONEL Filler Metal 72	None	GMAW (Lower Layer)	SAW (Upper Layer)
		After Exposure	
AWS-ER309	GTAW-HW(d)	-	-
R139	GMAW(c)	SAW, GMAW GTAW-HW(c)	GMAW
INCONEL Filler Metal 72	GMAW, SAW	GMAW (Lower Layer) GTAW-HW	SAW (Upper Layer)

(a) For areas in overlay other than area adjacent to the interface of the overlay and substrate.

(b) Ni distribution was affected in a similar manner in the INCONEL Filler Metal 72 overlays and the upper layer of R139 overlays after exposure.

(c) Moderate fluctuation.

(d) Very small fluctuations in distribution.

TABLE 81

WELDING PROCESS WHICH GAVE MOST UNIFORM DISTRIBUTION OF (a) CHROMIUM IN OVERLAYS AFTER EXPOSURE

Filler Metal	Substrate		
	304L	310	INCOLOY Alloy 800H
AWS-ER309	SAW	-	-
R139	SAW, GTAW-HW(b)	GTAW-HW(c)	SAW(b)
INCONEL Filler Metal 72	GTAW-HW	SAW	GMAW

(a) For areas in overlay other than area adjacent to the interface of overlay and substrate.

(b) SAW process had low values of aluminum.

(c) None of the R139 overlays on 310 had a uniform distribution.

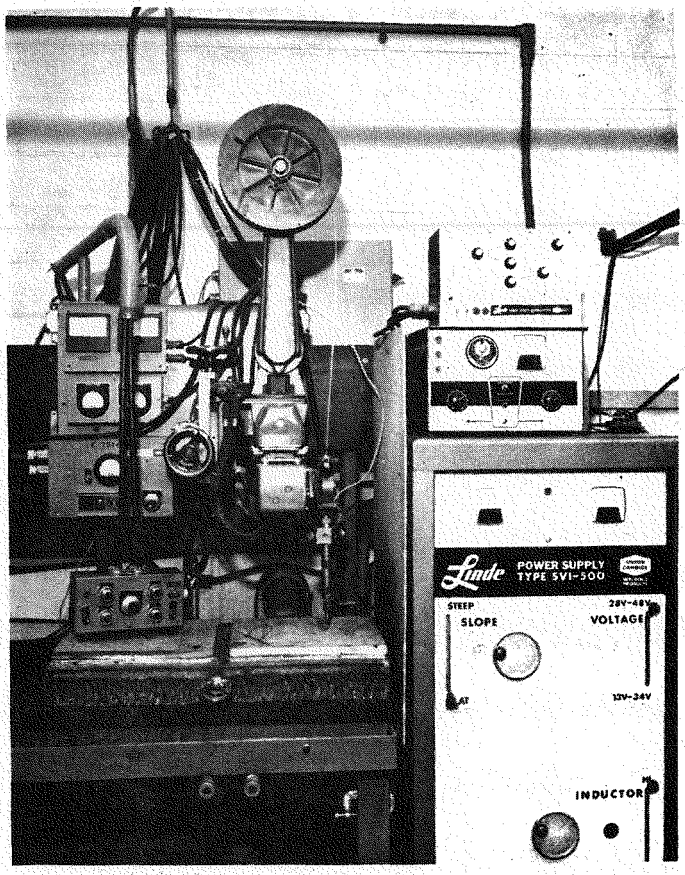
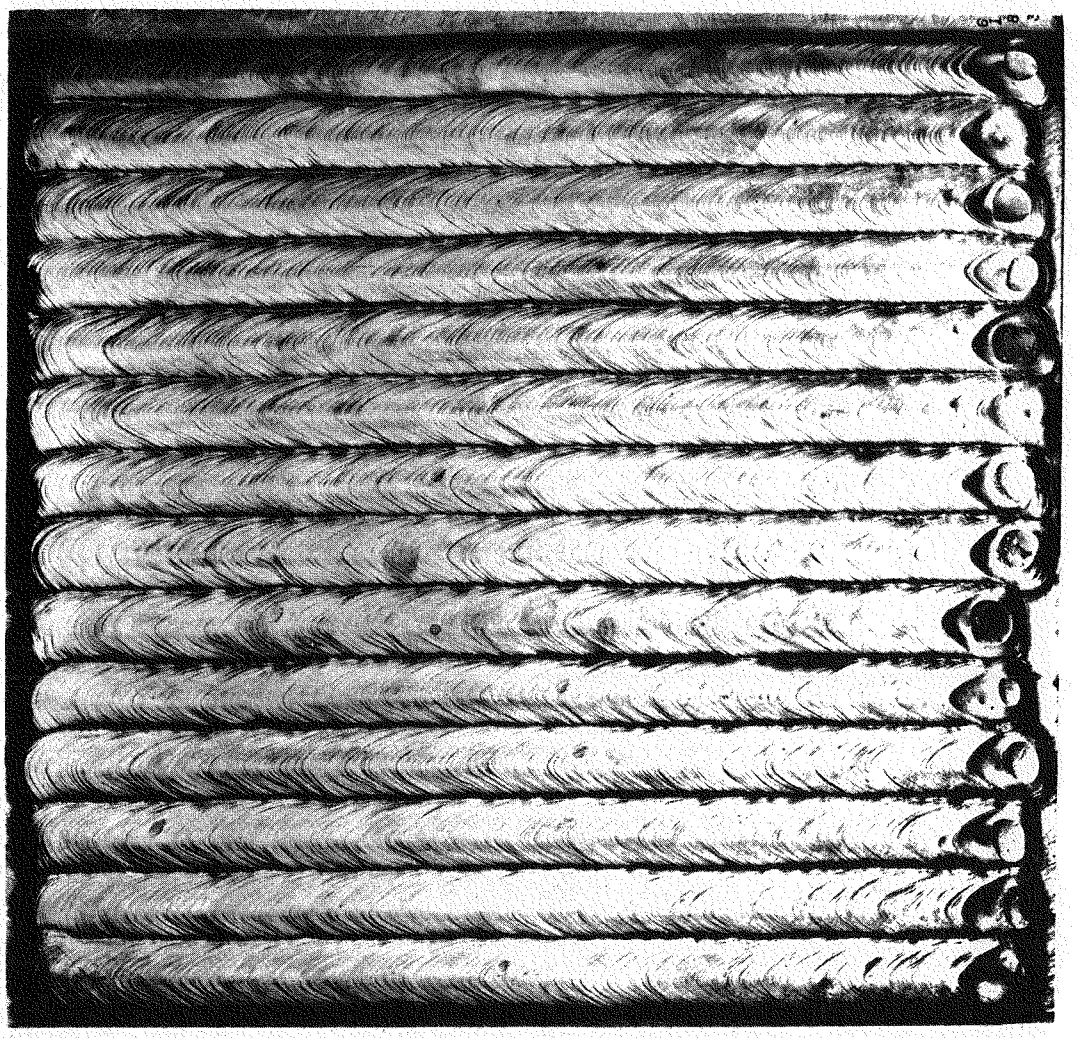
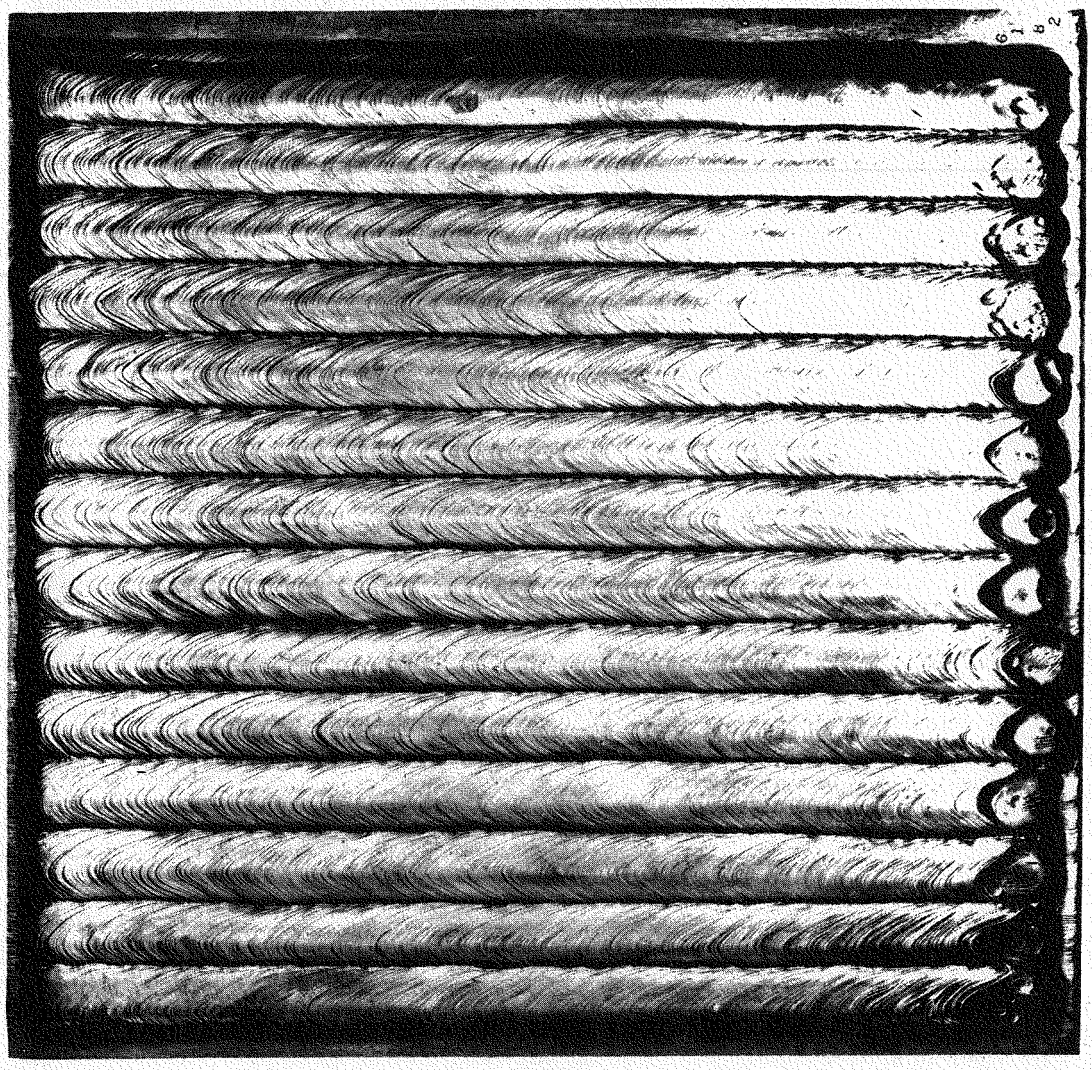


FIGURE 1: Power supply and equipment for submerged-arc welding.



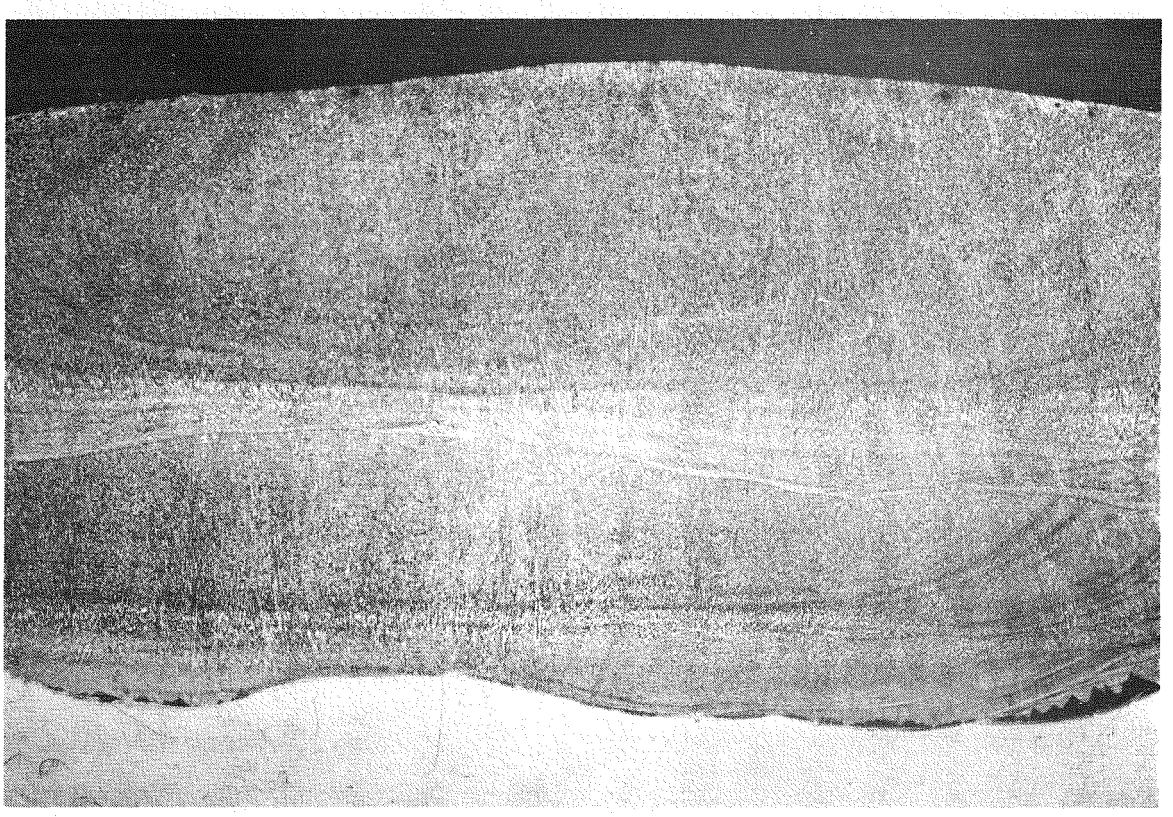
REDUCED 25% ~1/2X

FIGURE 2: Weld No. 6183, AWS-ER309 overlay on AISI 304L base plate, single layer, submerged-arc welding process.



REDUCED 25% ~1/2X

FIGURE 3: Weld No. 6182, AWS-ER309 overlay on AISI 304L base plate, double layer, submerged-arc welding



10X

FIGURE 4: Cross section of W6182, AWS-ER309 overlay on 304L, double layer, submerged arc process.

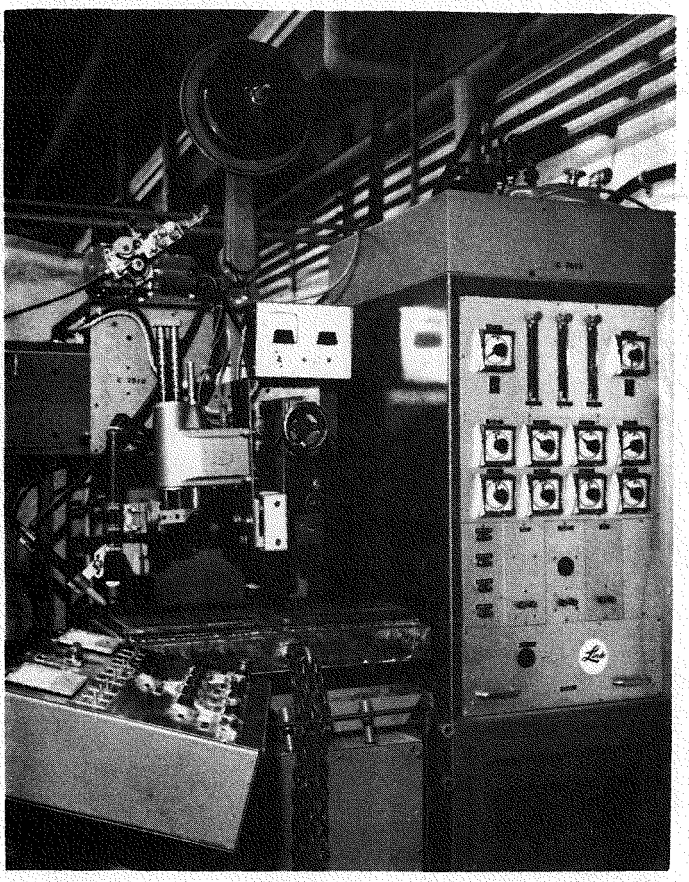
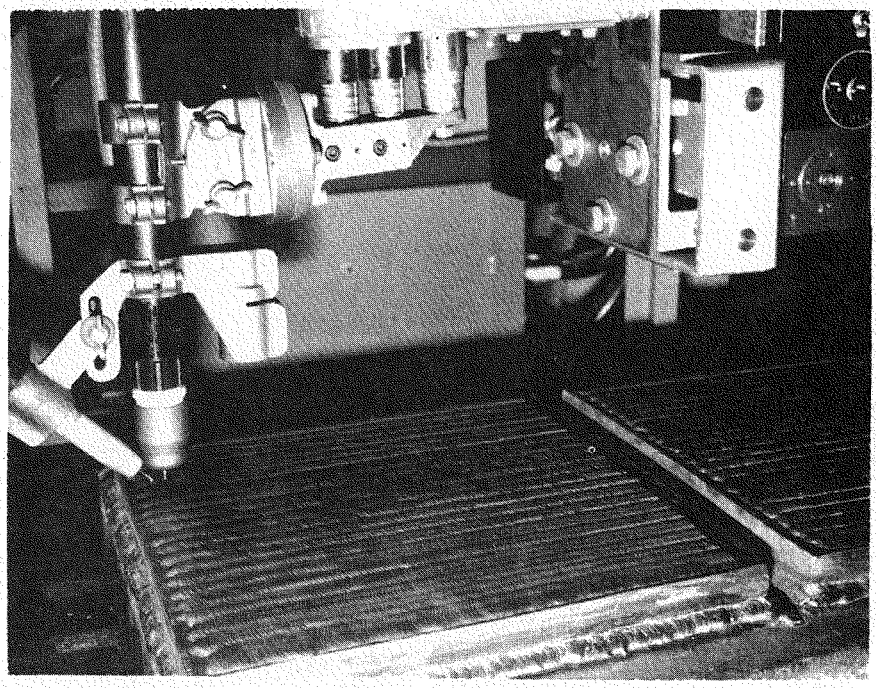


FIGURE 5: Power supply and equipment for gas tungsten-arc welding with hot wire addition.

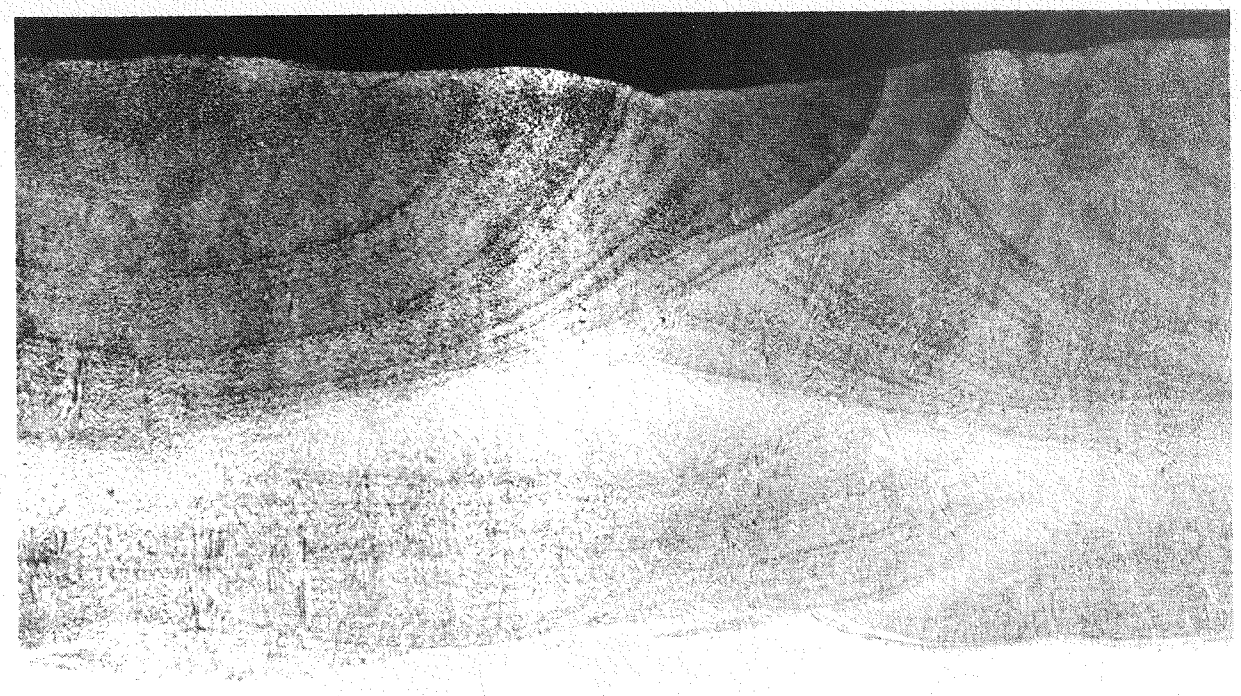


REDUCED 25% ~1/2X

FIGURE 6: Close-up of filler metal and tungsten electrode, gas tungsten-arc with hot wire addition.

REDUCED 25% ~1/2X

FIGURE 7: Weld No. 6184, AWS-ER309 overlay on AISI 304L base plate, double layer, gas tungsten-arc with hot wire welding process.



10X

FIGURE 8: Cross section of W6184, AWS-ER309 overlay on 304L, double layer, gas tungsten-arc hot wire process.

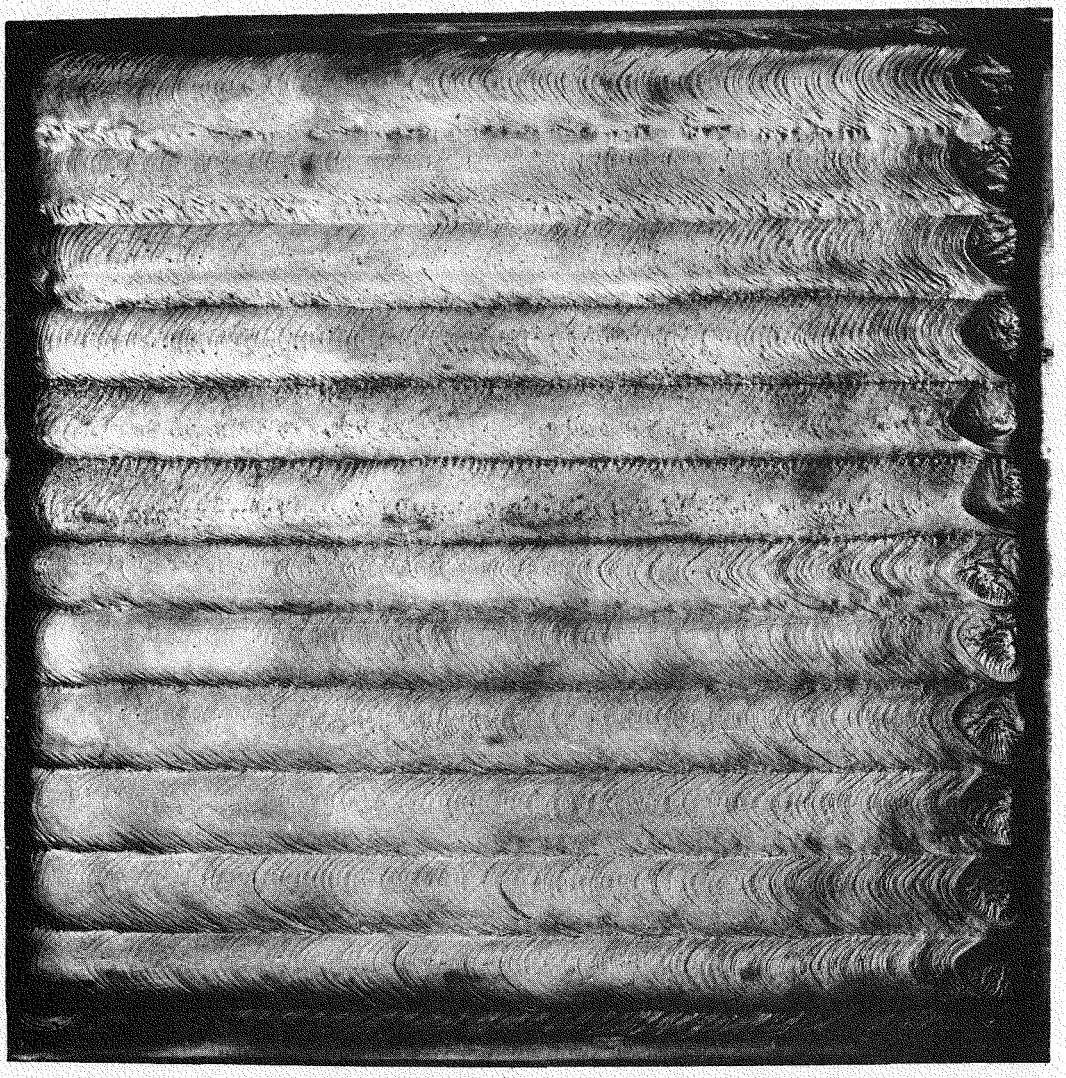
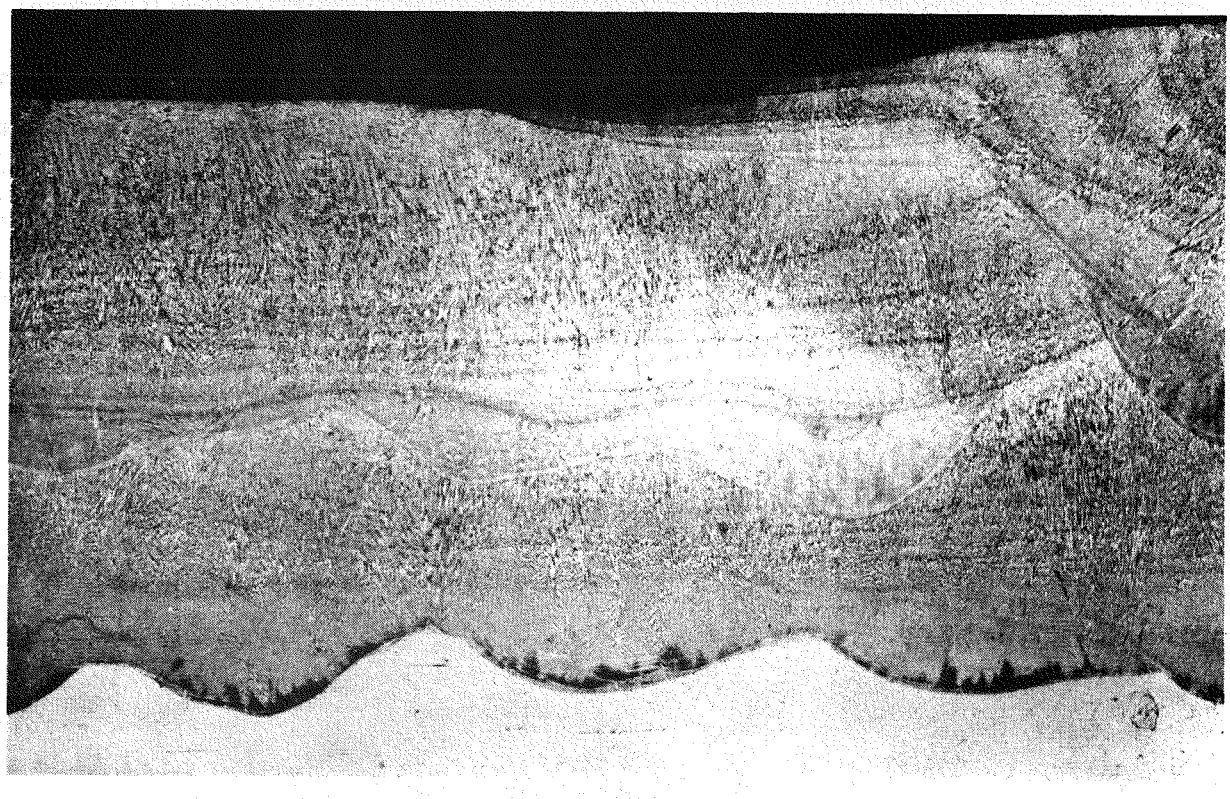


FIGURE 9: Weld No. 6180, AWS-ER309 overlay on AISI 304L base plate, double layer, gas metal-arc welding process.



10X

FIGURE 10: Cross section of W6180, AWS-ER309 overlay on 304L, double layer, gas metal-arc process.

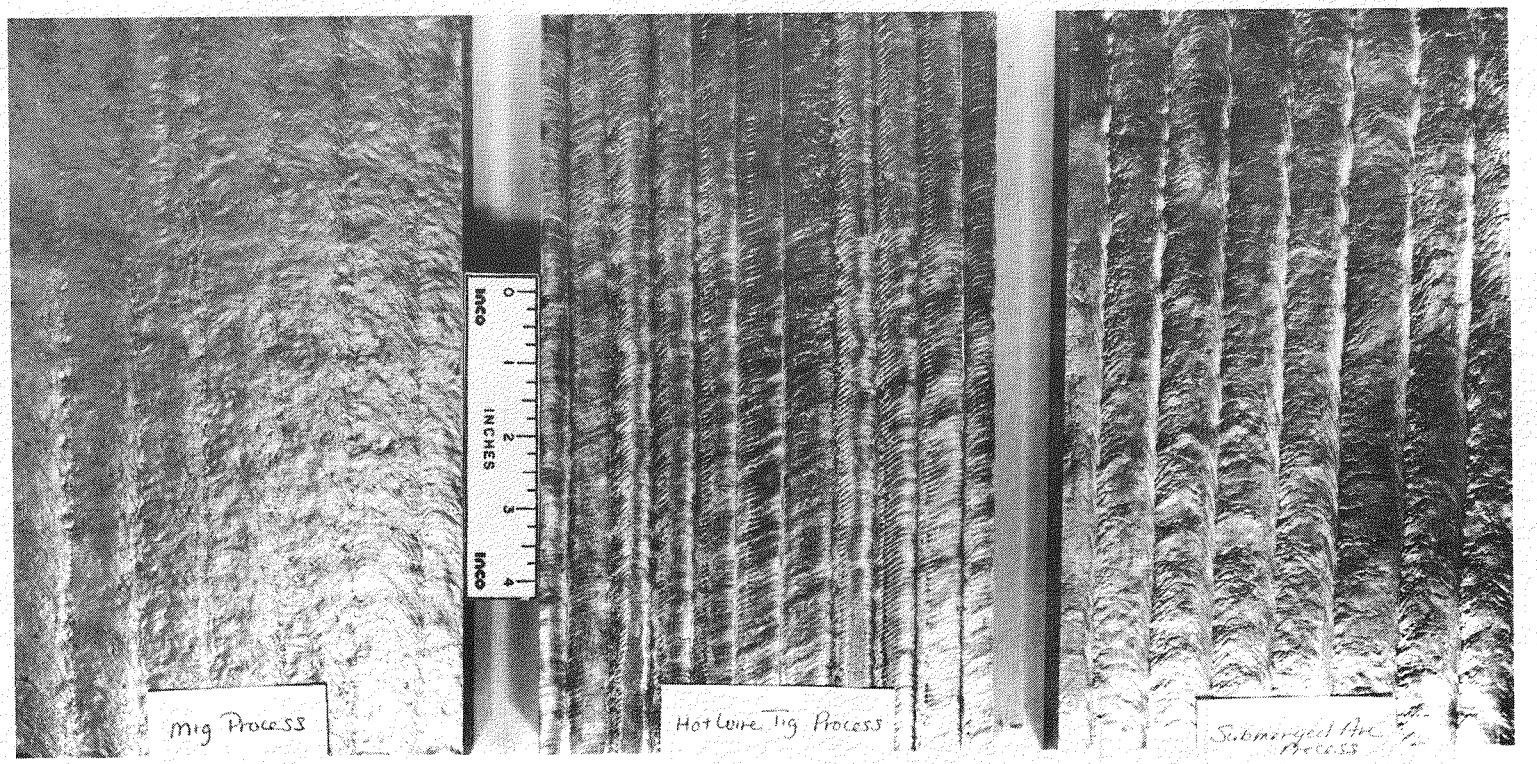


FIGURE 11: As welded surface appearance of INCONEL Filler Metal 72 overlays.

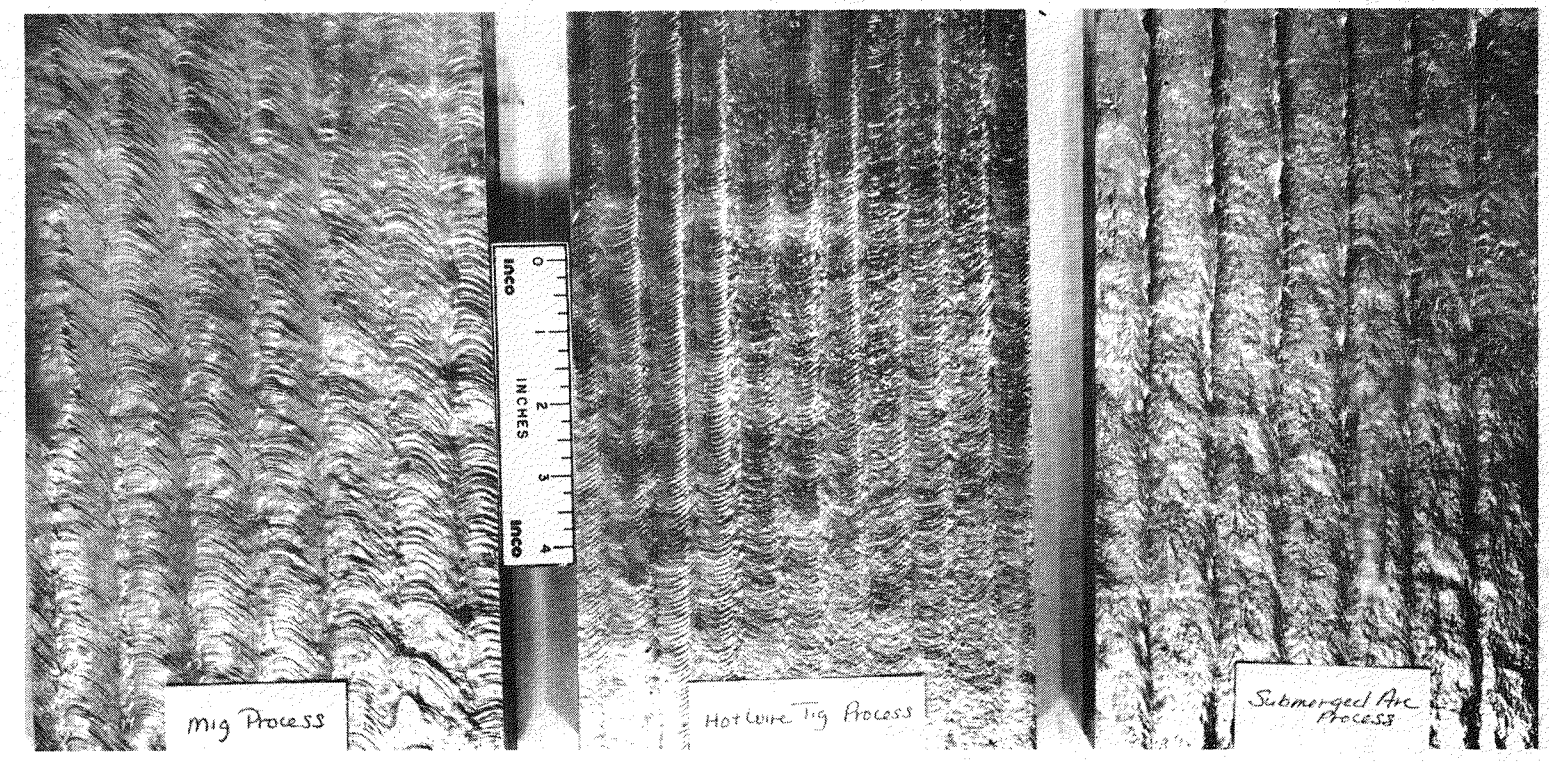
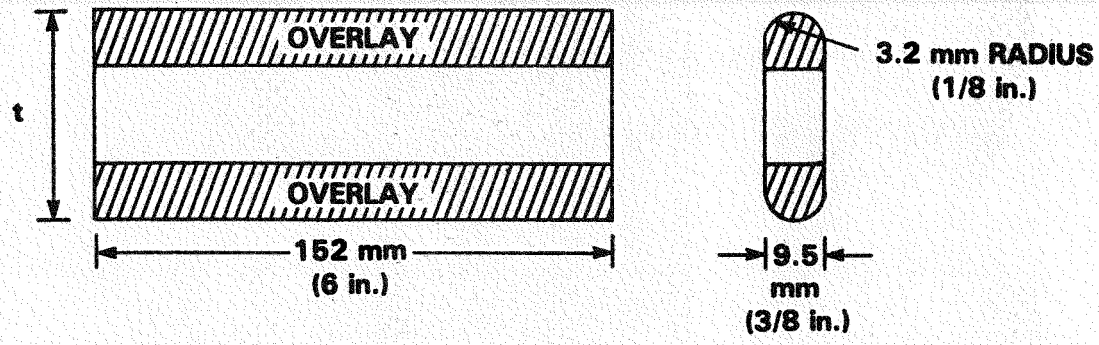


FIGURE 12: As welded surface appearance of Experimental R139 Filler Metal overlays.



t = 32–41 mm (1 1/4–1 5/8 in.)

FIGURE 13. – DIMENSIONS OF BEND SPECIMENS

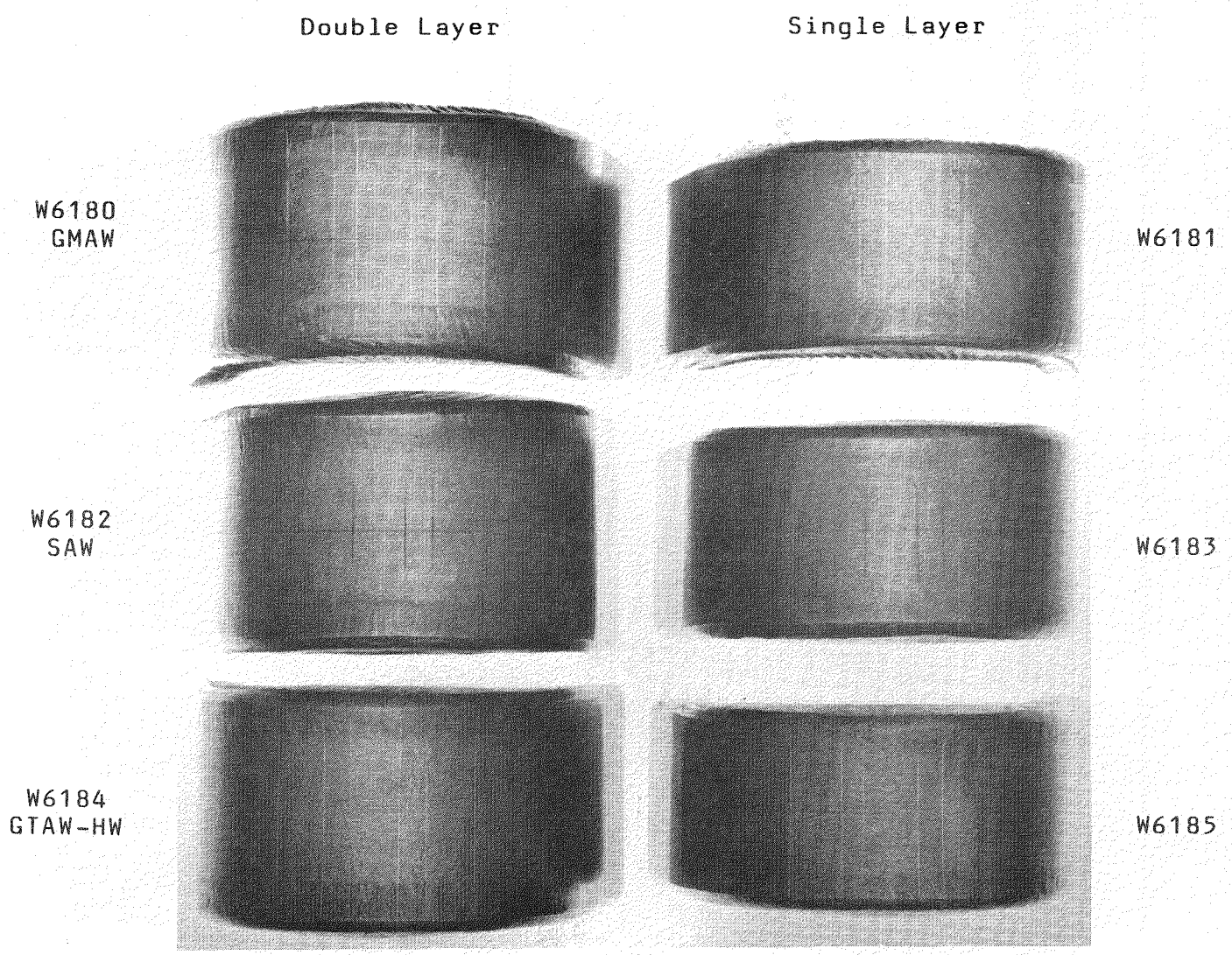


FIGURE 14: AWS-ER309 overlays on 304L bend specimens after testing.

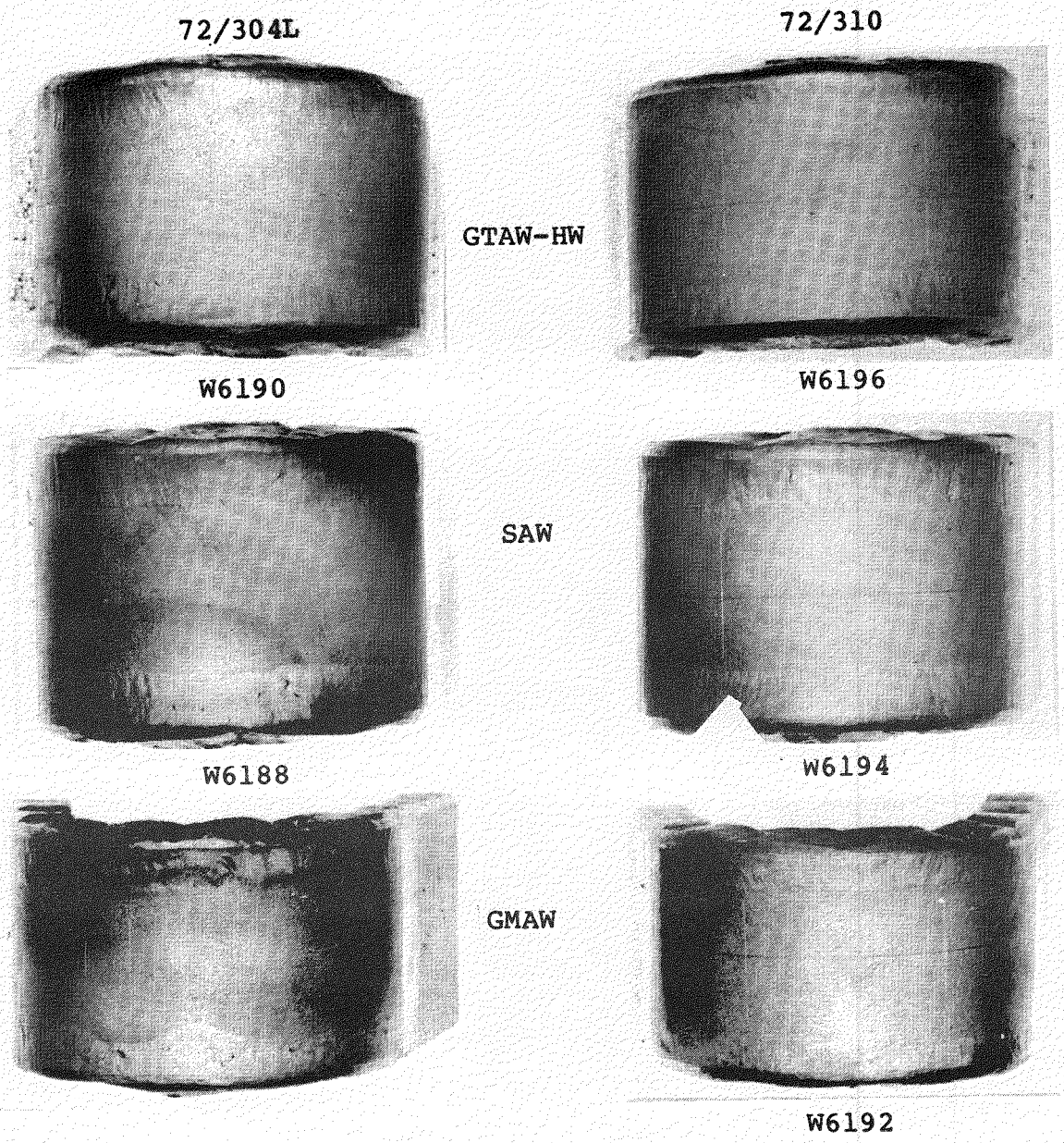


FIGURE 15: INCONEL Filler Metal 72 overlays on 304L and 310SS bend specimens.

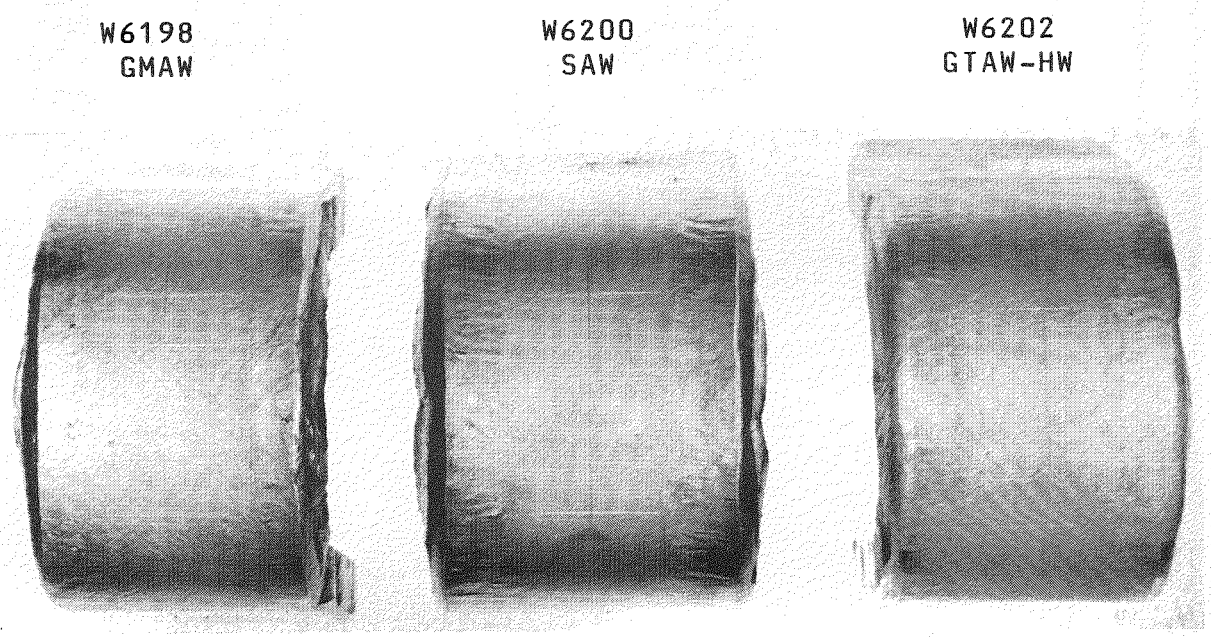


FIGURE 16: INCONEL Filler Metal 72 overlays on INCONEL alloy 800H - bend specimens.

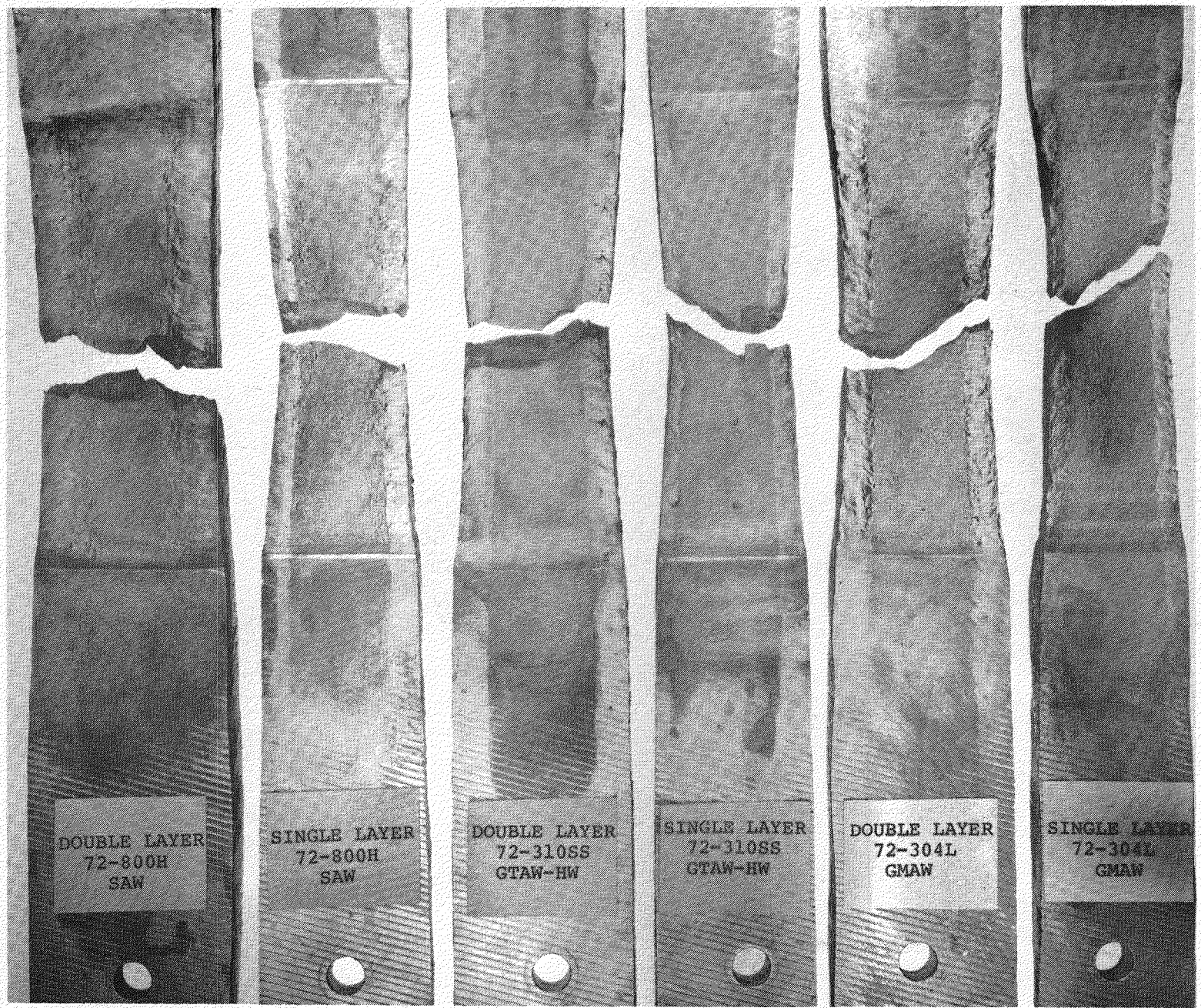


FIGURE 17: Integrity of INCONEL Filler Metal 72 overlays after tensile testing. As-Welded (~3/4X).

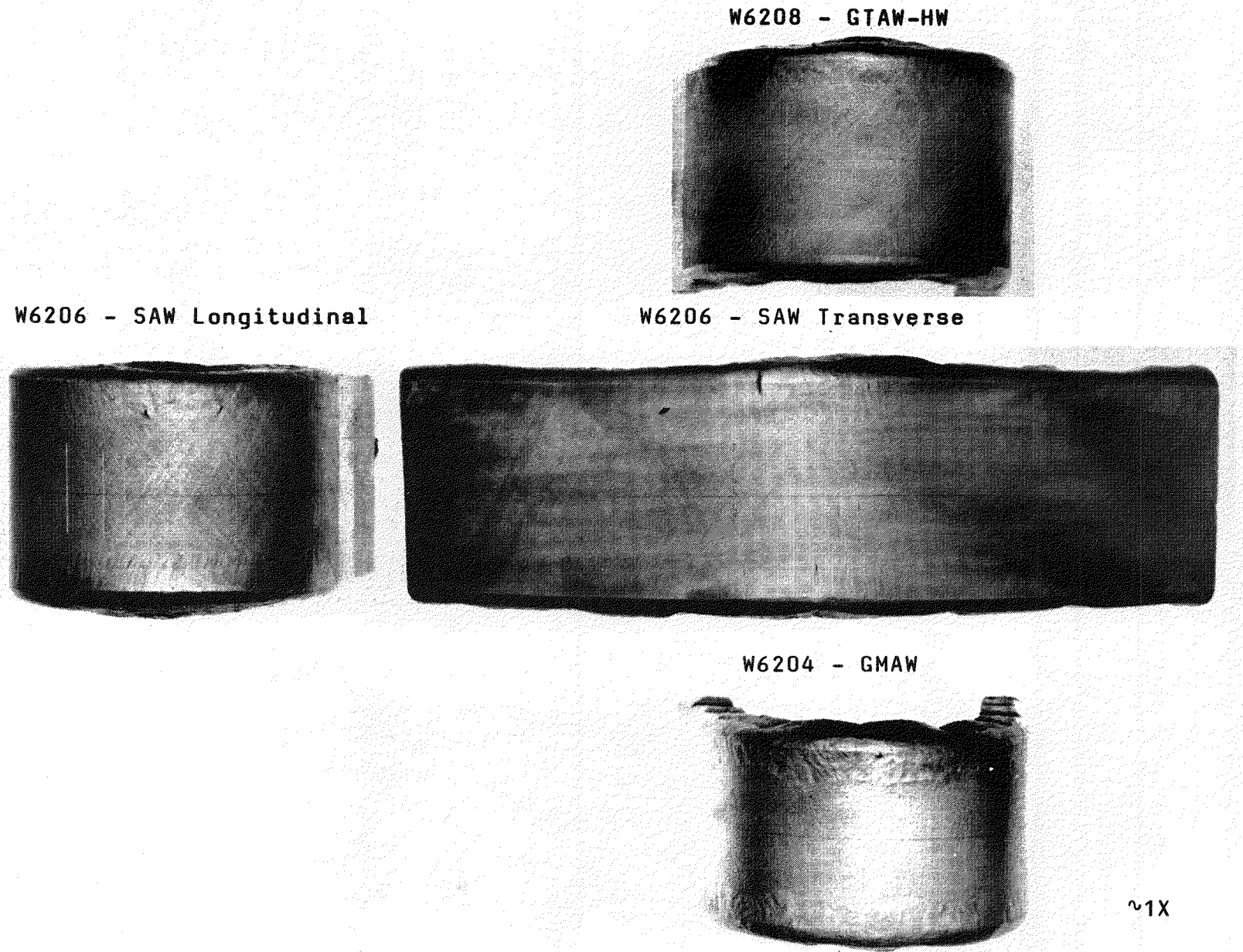
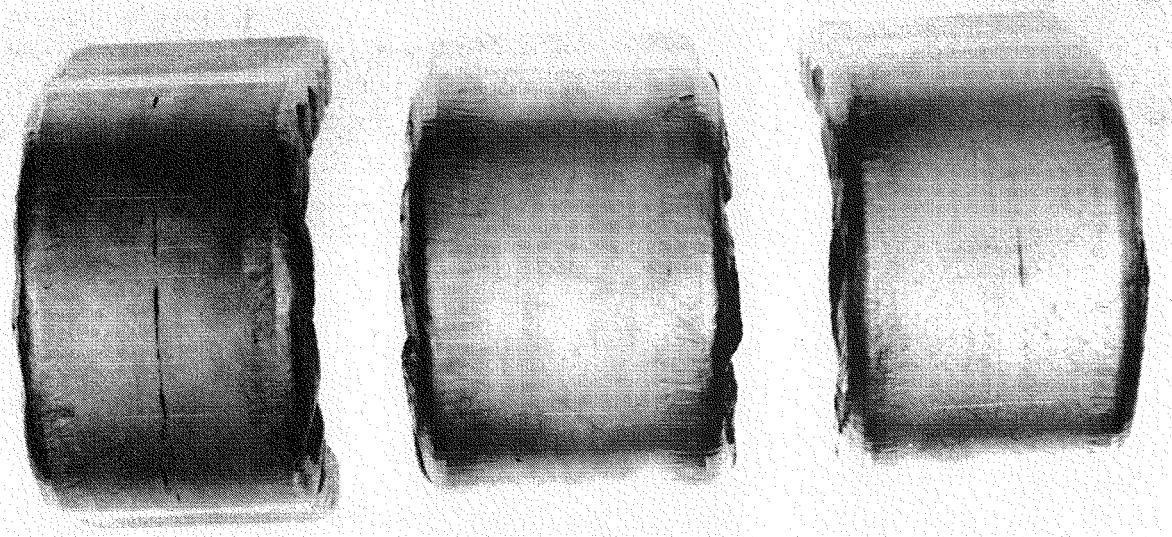


FIGURE 18: R139 Filler Metal overlays on 304L SS bend specimens.

W6210 GMAW W6212 SAW W6214 GTAW-HW



~1X

FIGURE 19: R139 Filler Metal overlays on 310 SS bend specimens.

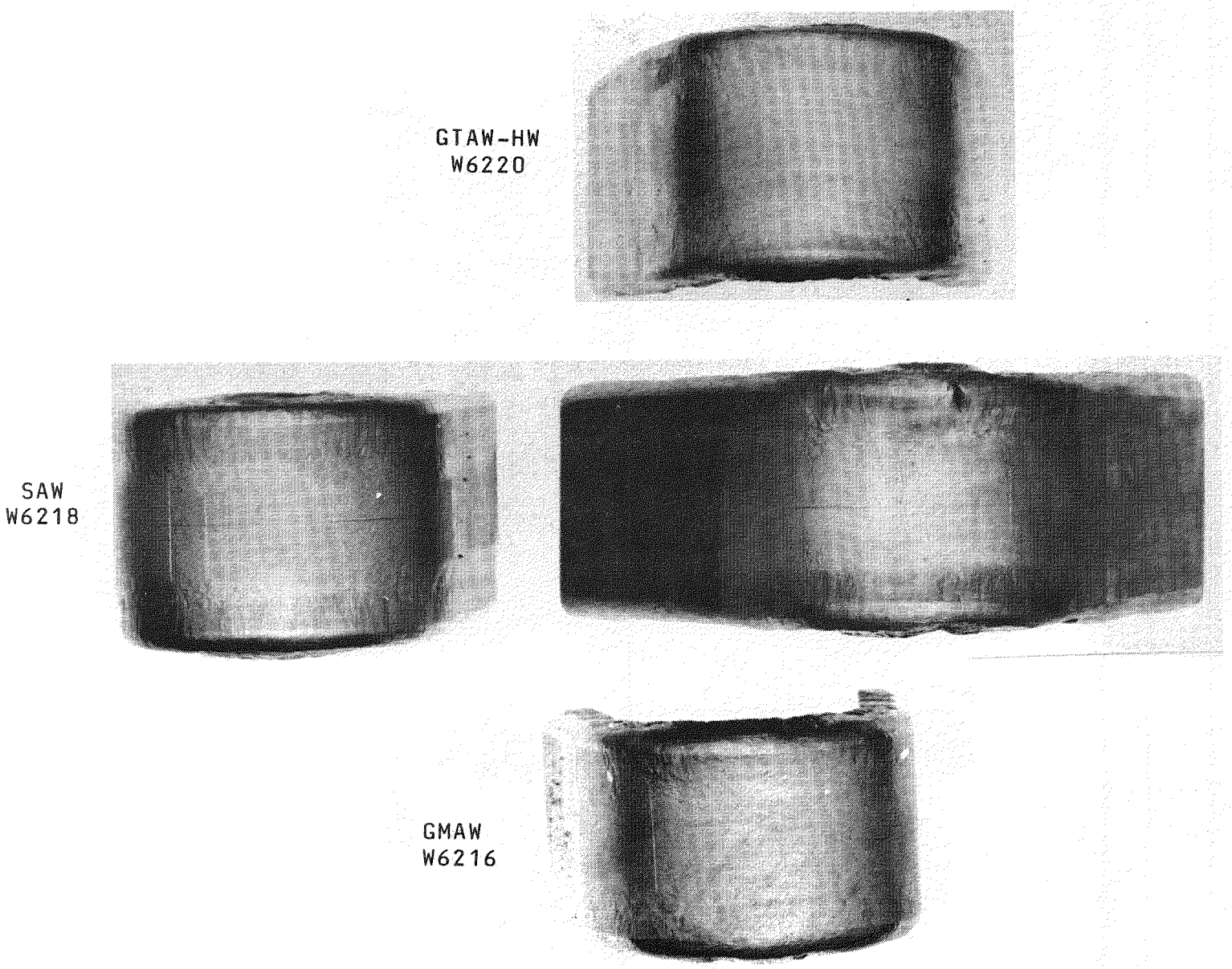


FIGURE 20: R139 overlays on INCOLOY alloy 800H bend specimens.

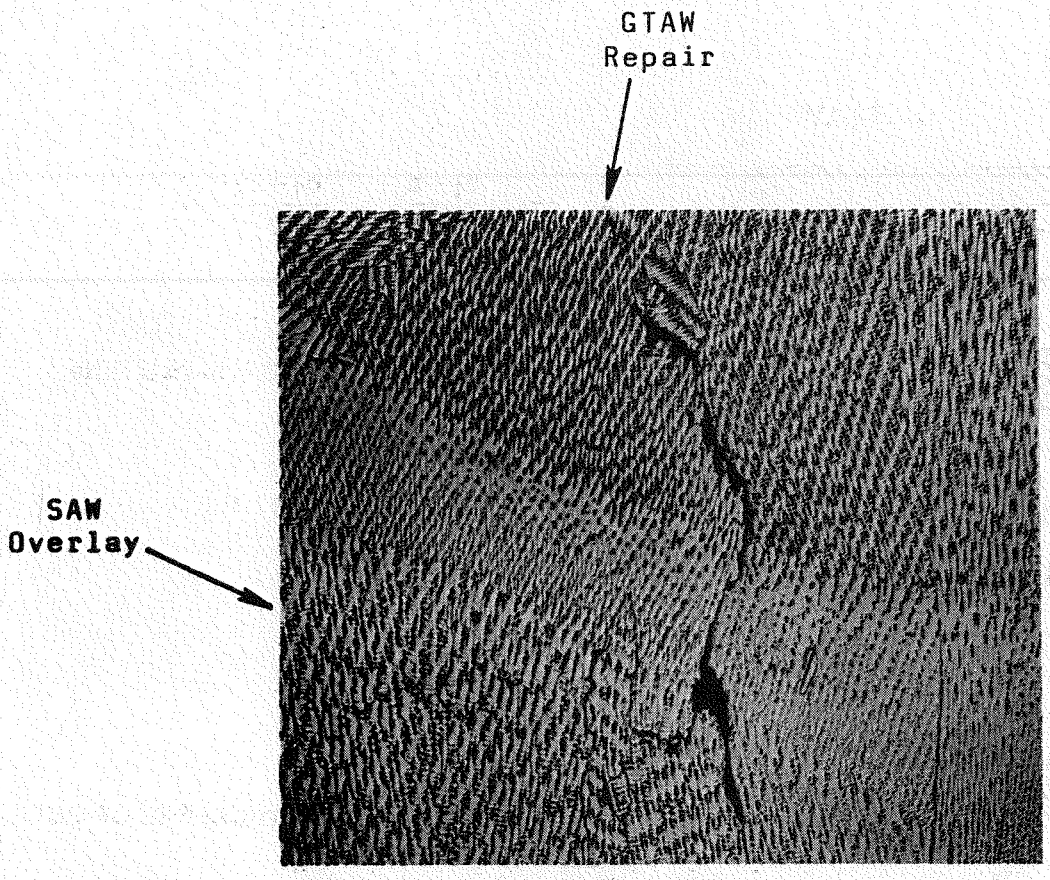


FIGURE 21: W6206, defect at fusion area of GTAW process repair of SAW process overlay, R139 Filler Metal.

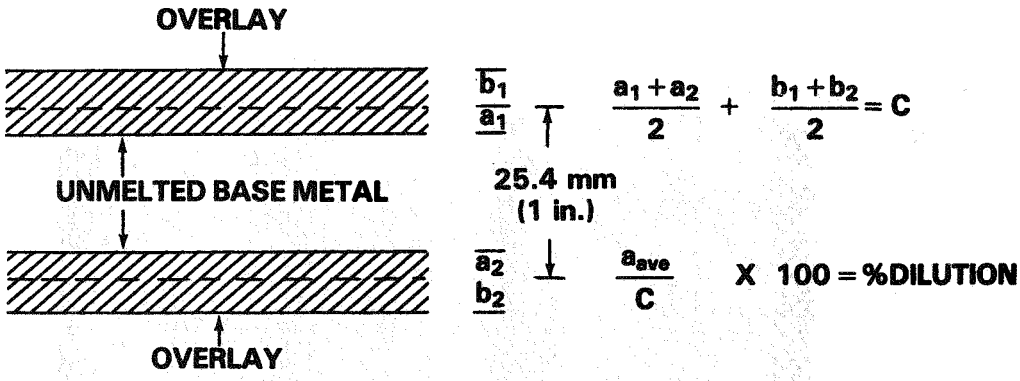


FIG. 22A

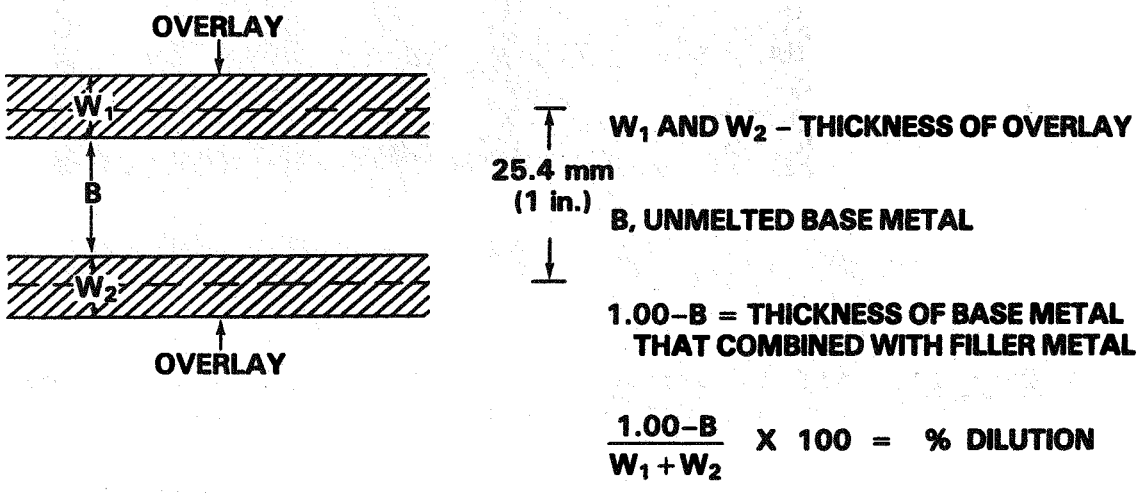


FIG. 22B

FIGURE 22 – METHODS OF CALCULATING PERCENT BASE METAL DILUTION

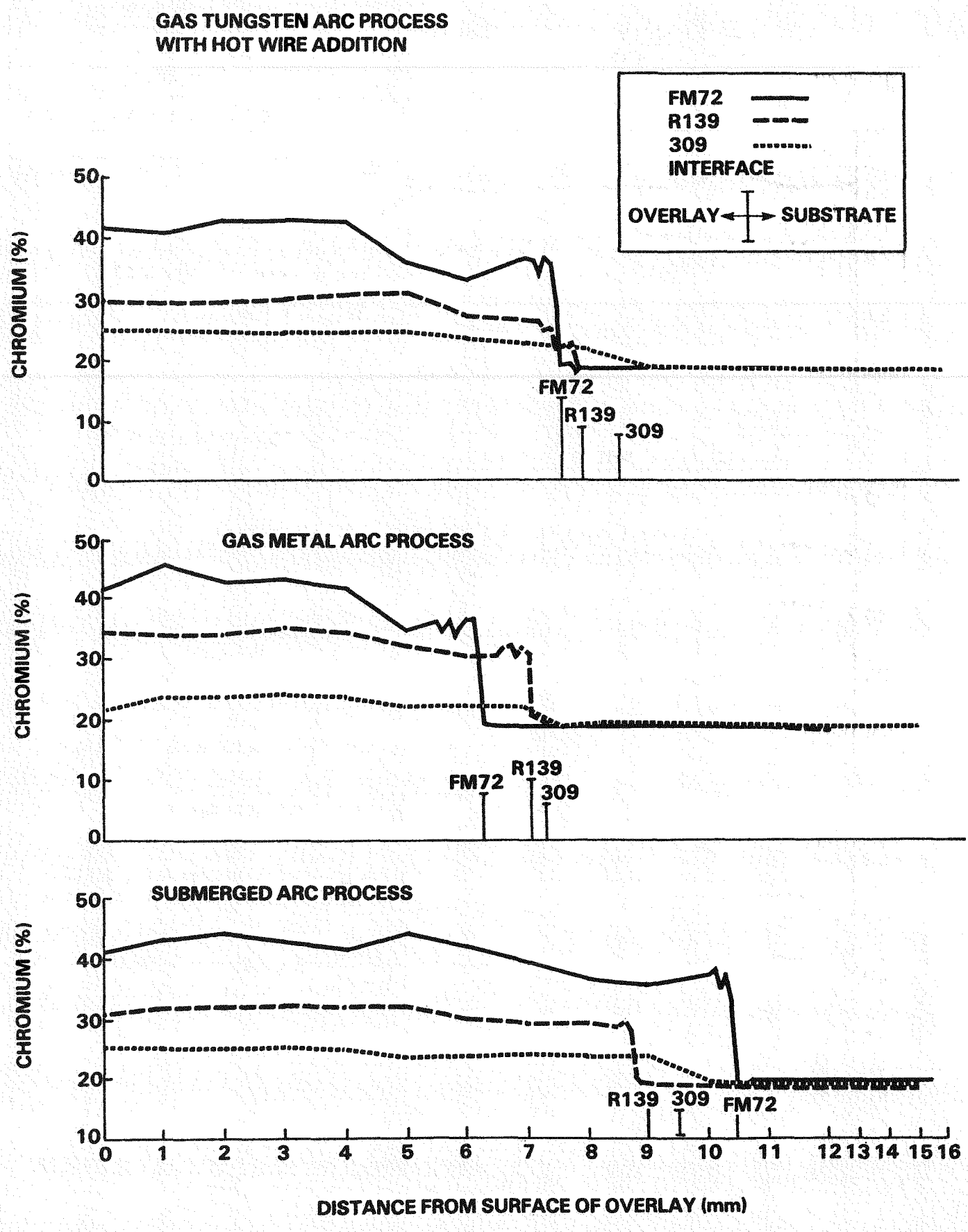


FIGURE 23. EFFECT OF FILLER METAL ON CHROMIUM DISTRIBUTION IN 304L WELDMENTS, DOUBLE LAYERS, AS WELDED.

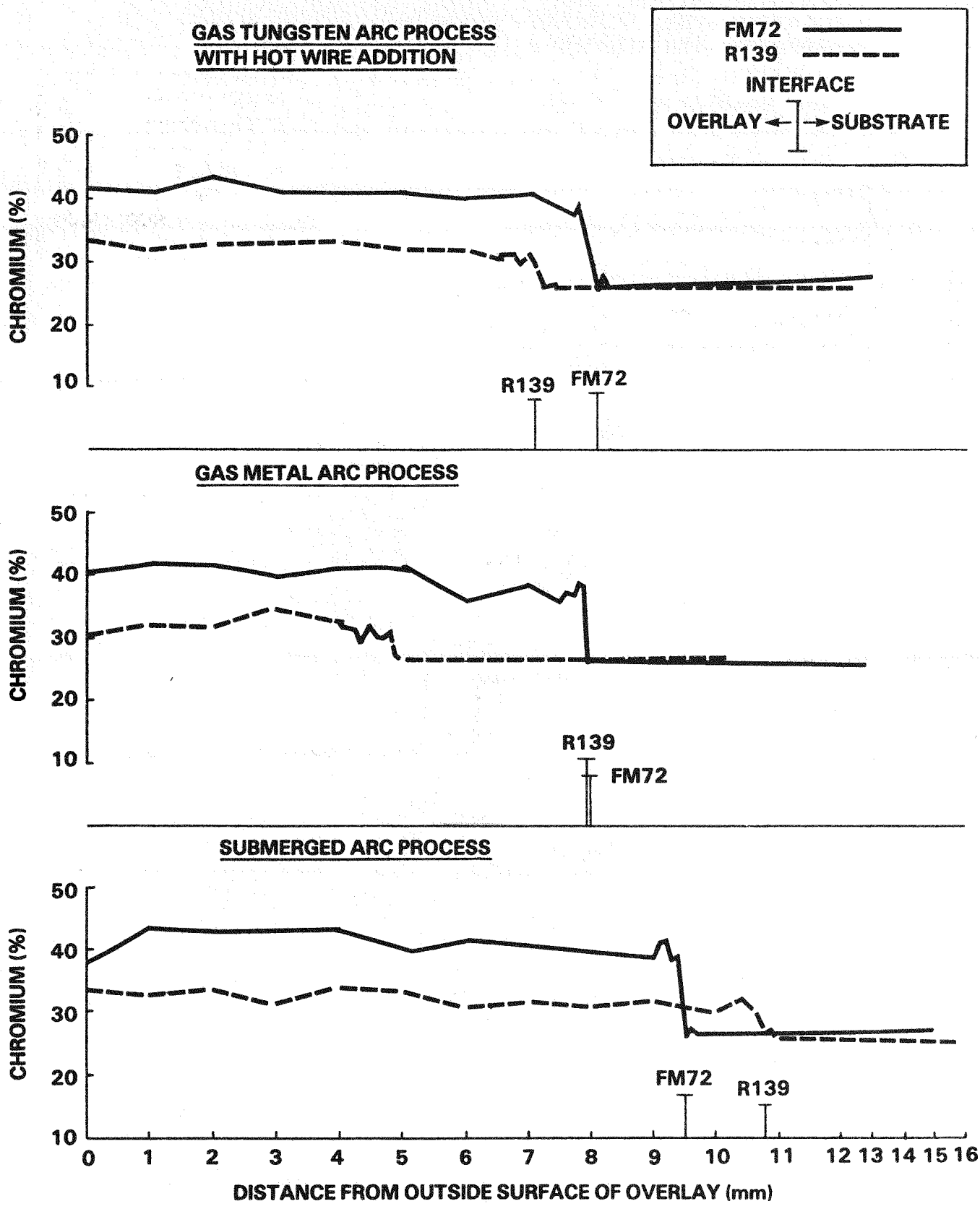


FIGURE 24. EFFECT OF FILLER METAL ON CHROMIUM DISTRIBUTION IN 310SS WELDMENTS, DOUBLE LAYERS, AS WELDED.

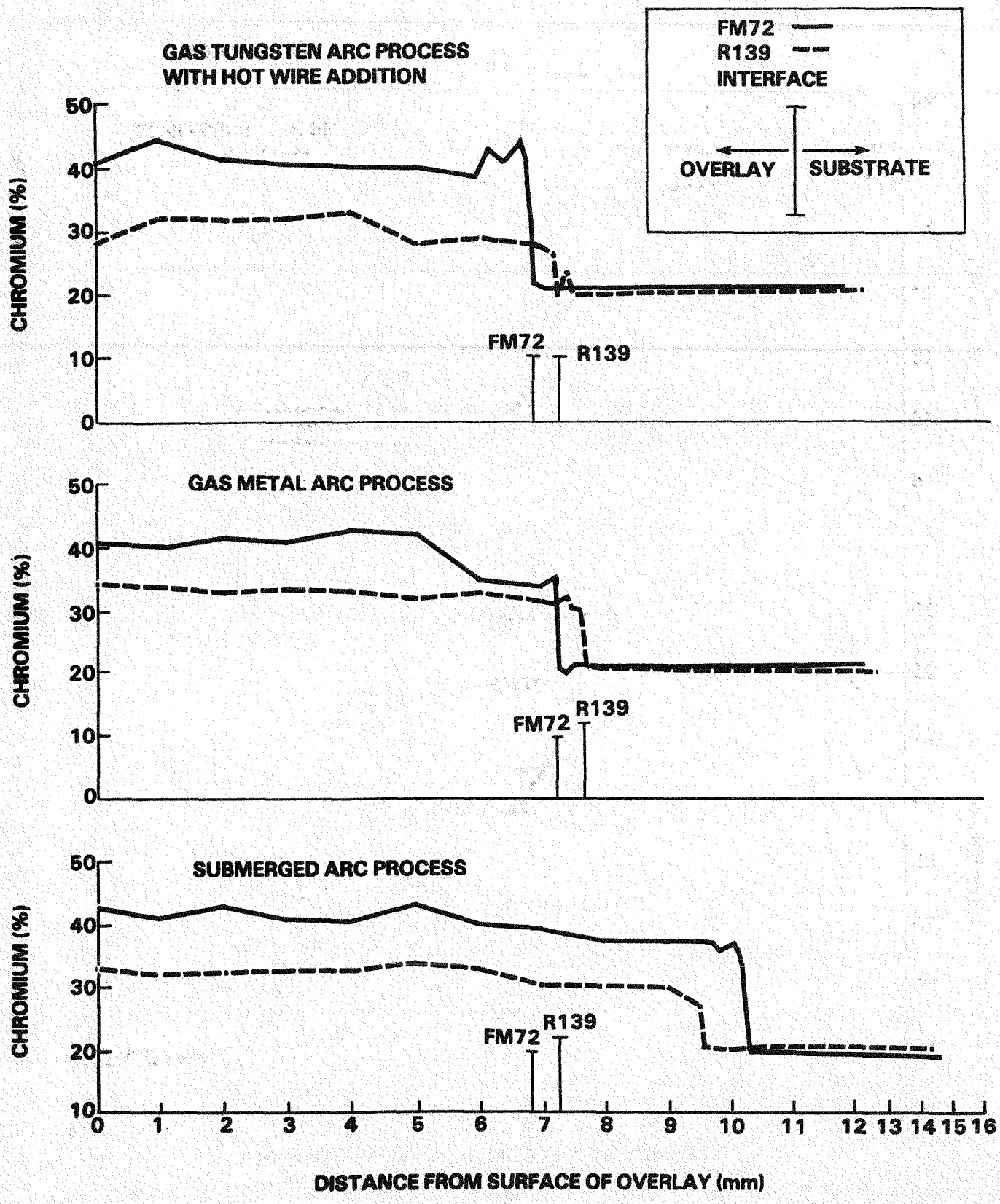


FIGURE 25. EFFECT OF FILLER METAL ON CHROMIUM DISTRIBUTION IN INCOLOY ALLOY 800H WELDMENTS, DOUBLE LAYERS, AS WELDED.

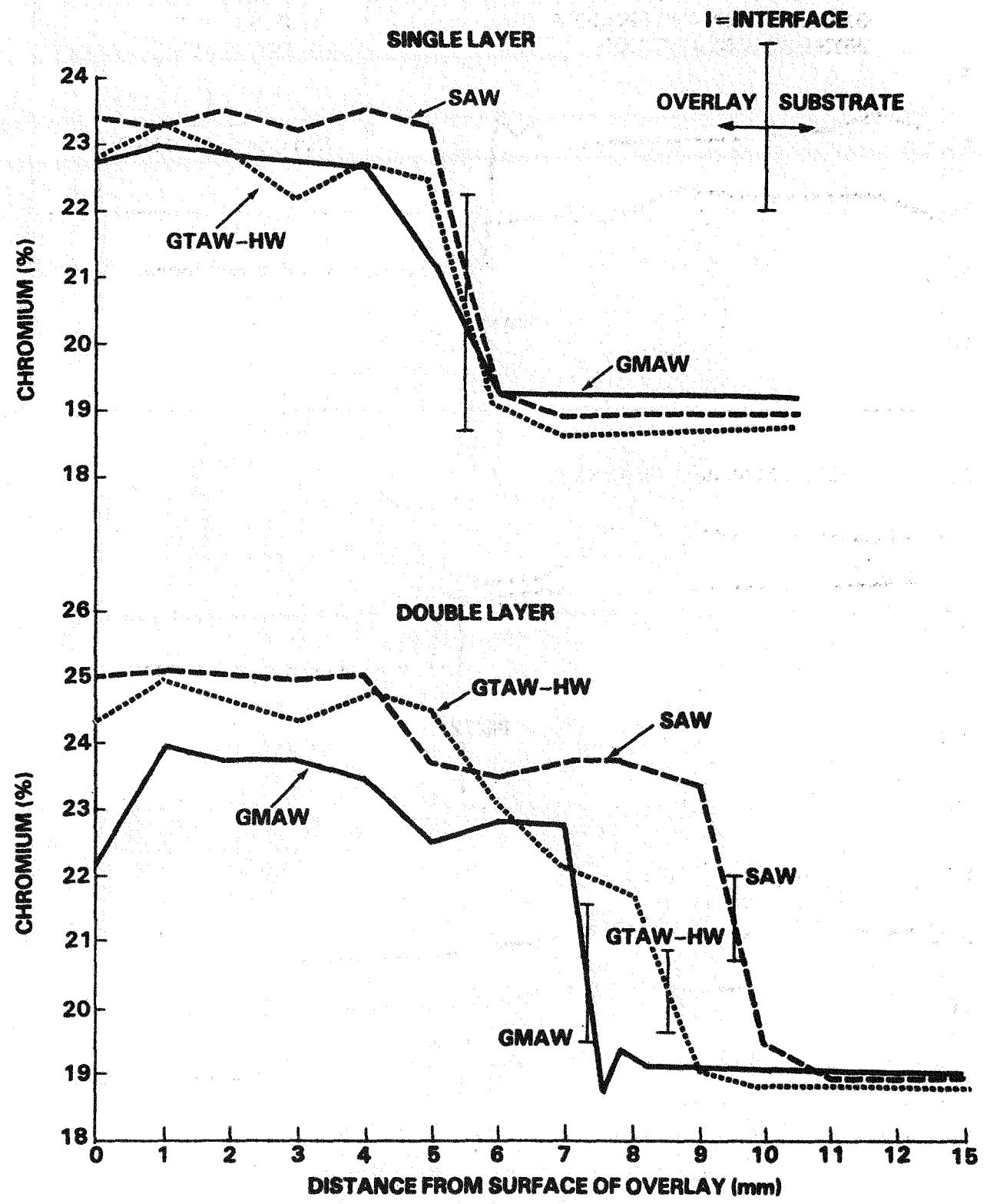


FIGURE 26. – EFFECT OF WELDING PROCESS ON CHROMIUM DISTRIBUTION – AWS-ER 309 ON 304L

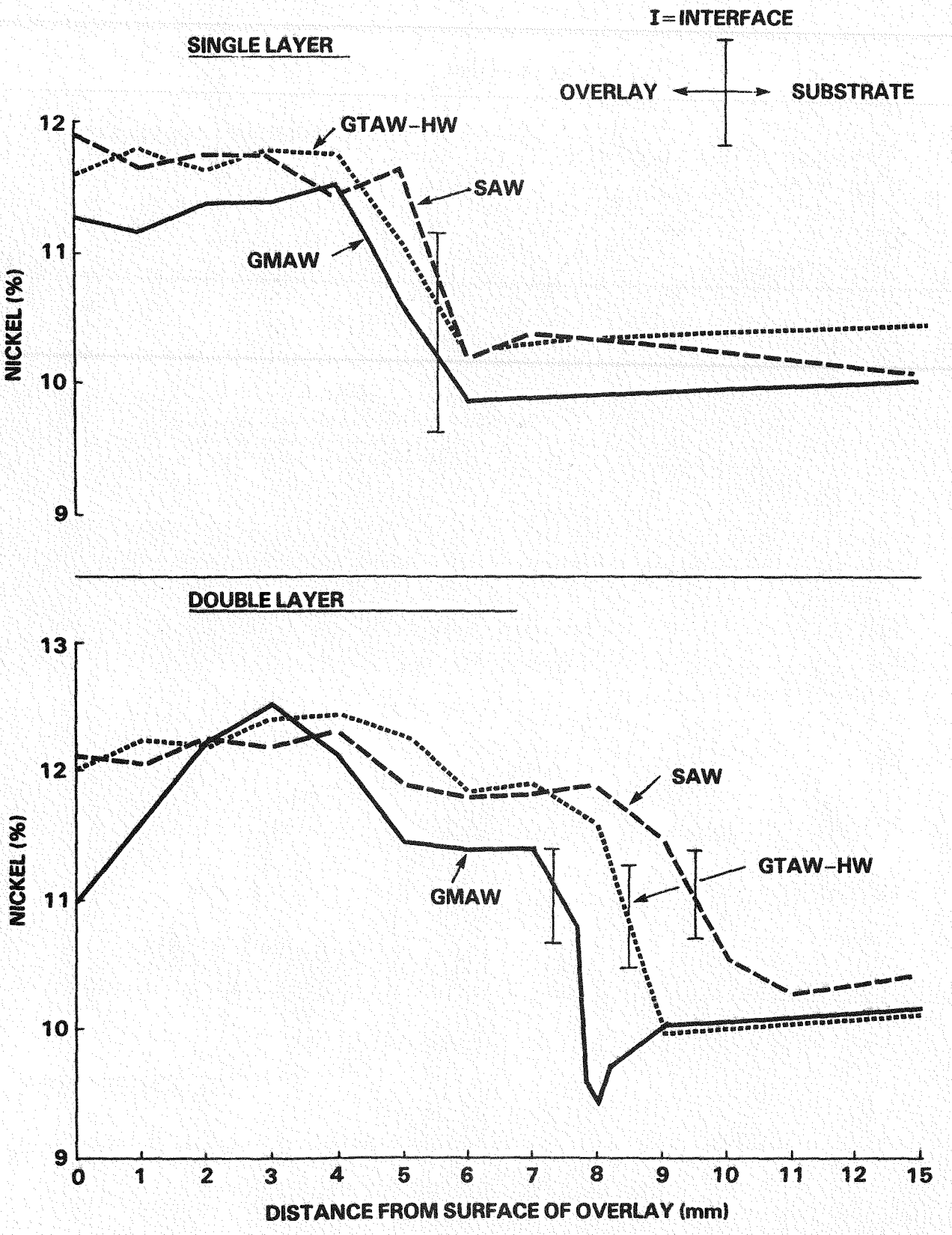


FIGURE 27. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF NICKEL – AWS-ER 309 ON 304L, AS WELDED.

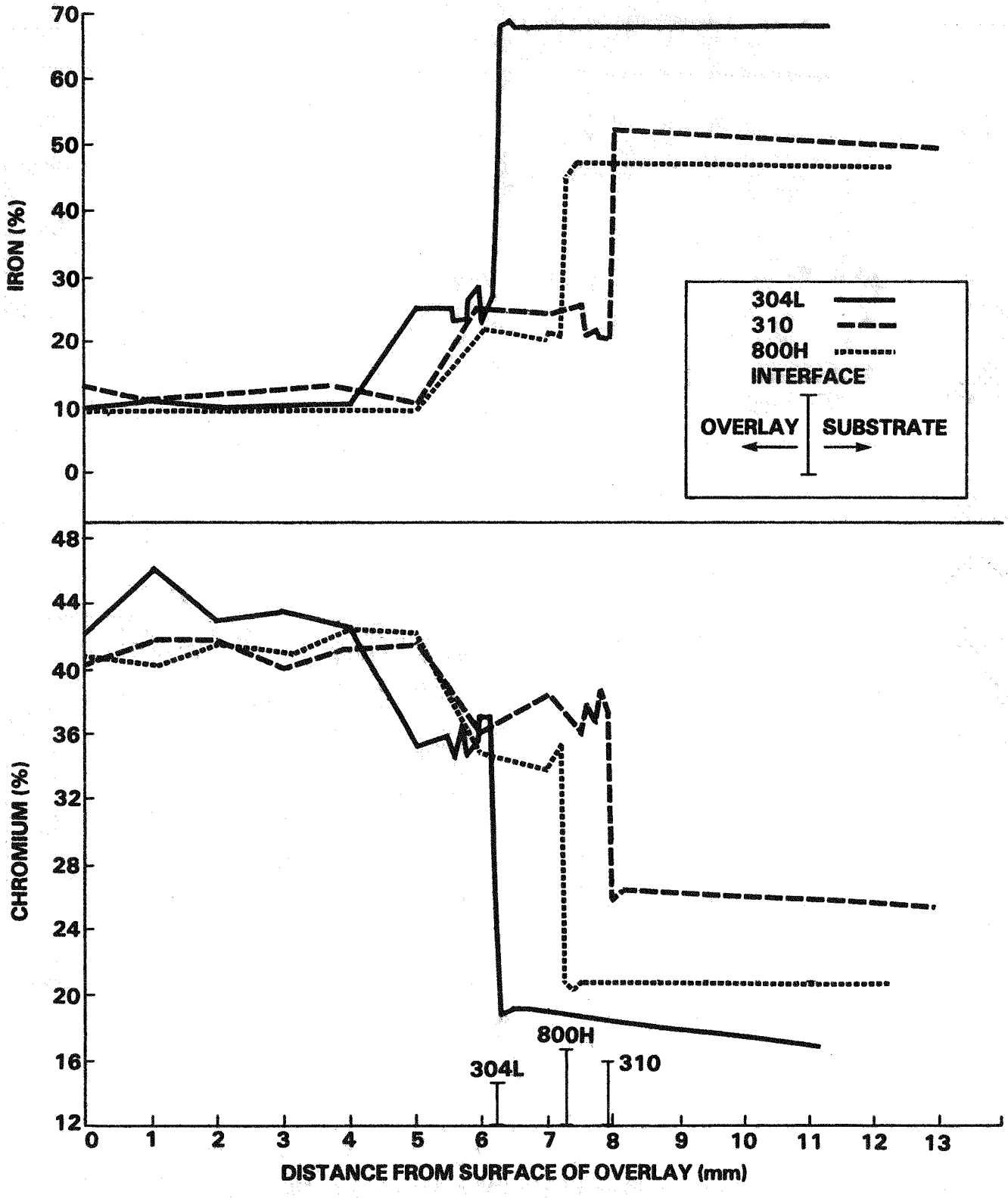


FIGURE 28. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS – GMAW PROCESS – DOUBLE LAYERS, AS WELDED.

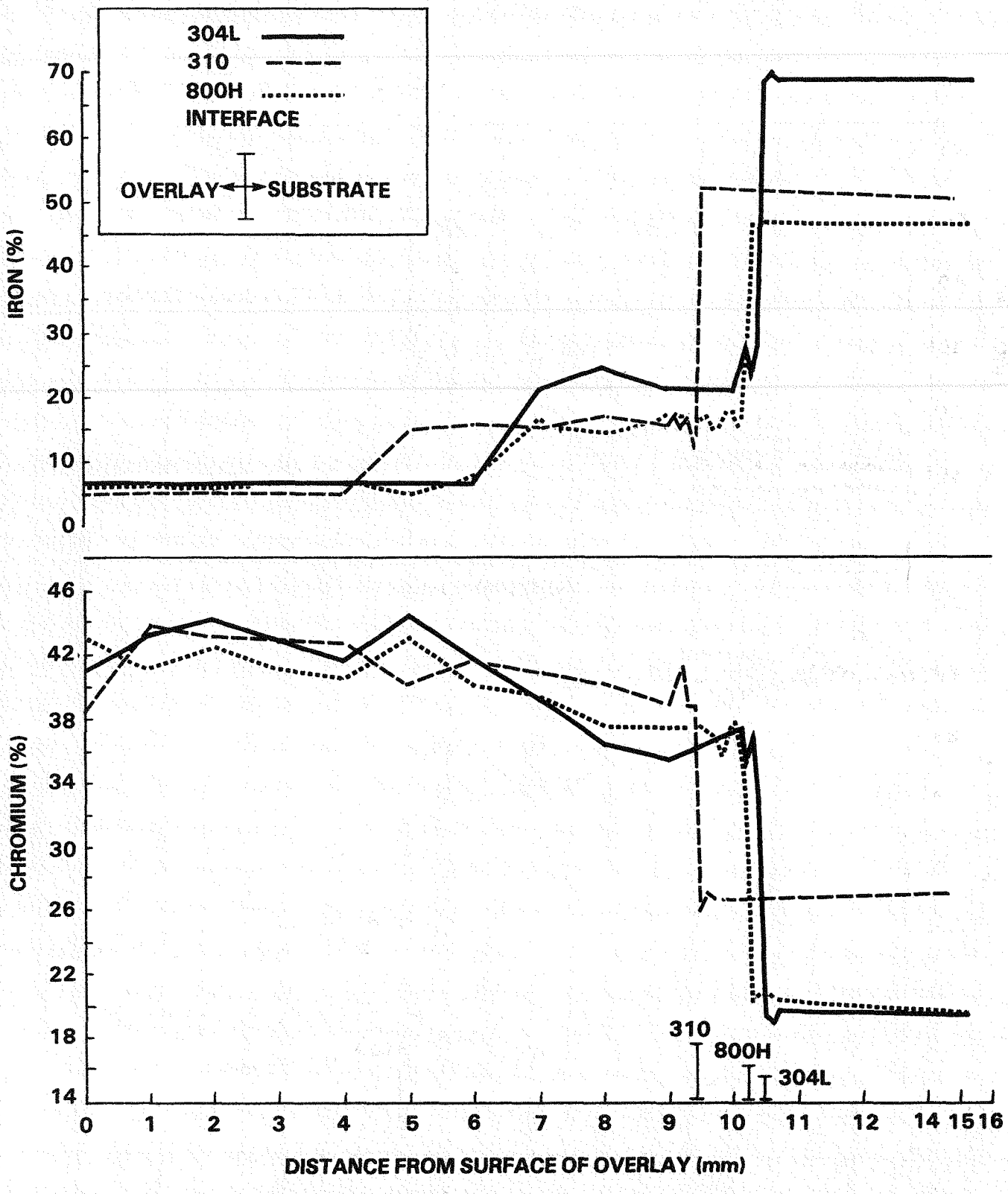


FIGURE 29. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS, SAW PROCESS – DOUBLE LAYERS, AS WELDED.

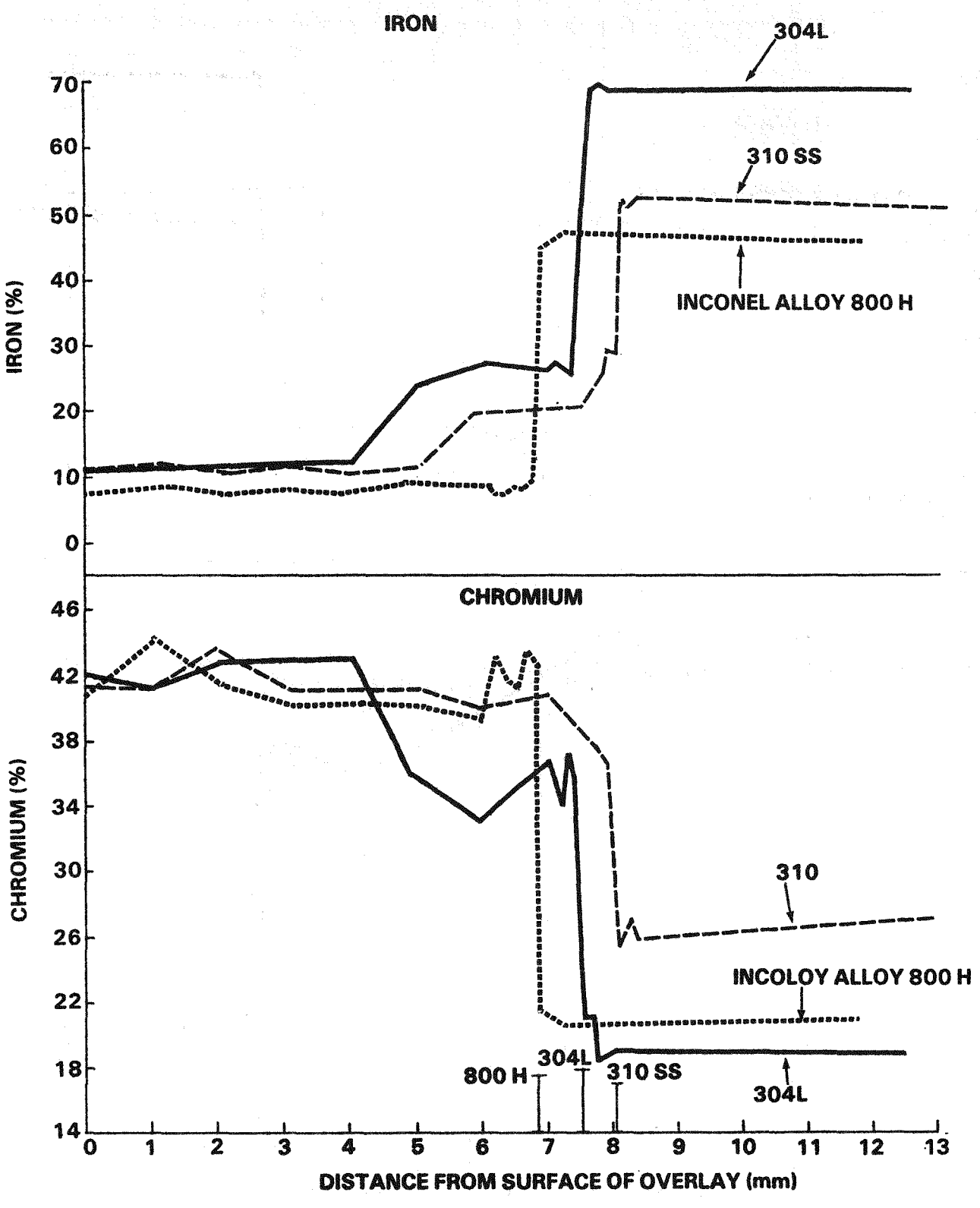


FIGURE 30 EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS, GTAW-HW PROCESS, DOUBLE LAYERS, AS WELDED.

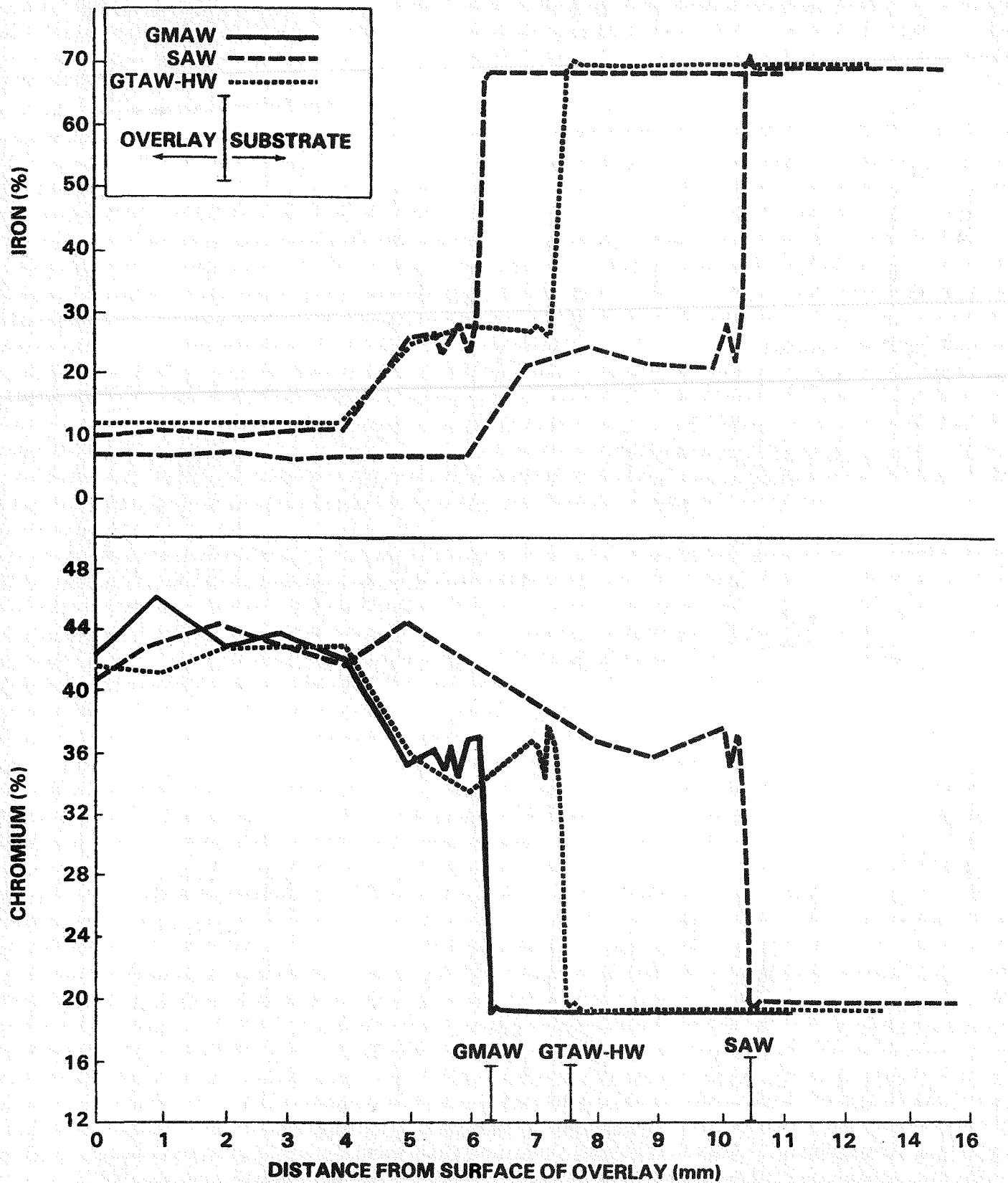


FIGURE 31 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON — INCONEL FILLER METAL 72 ON 304L — DOUBLE LAYERS, AS WELDED.

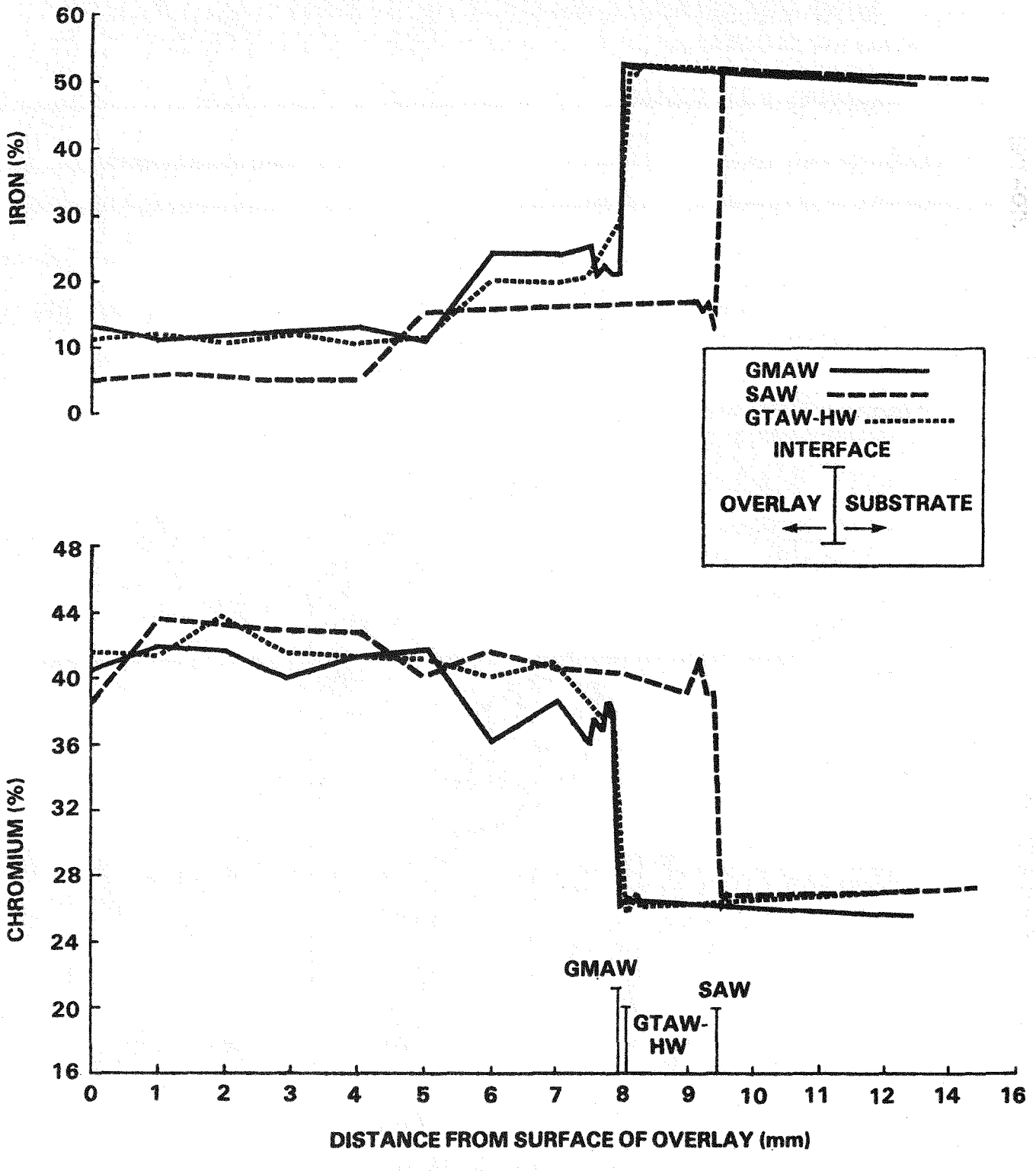


FIGURE 32 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON — INCONEL FILLER METAL 72 ON 310 SS — DOUBLE LAYERS, AS WELDED.

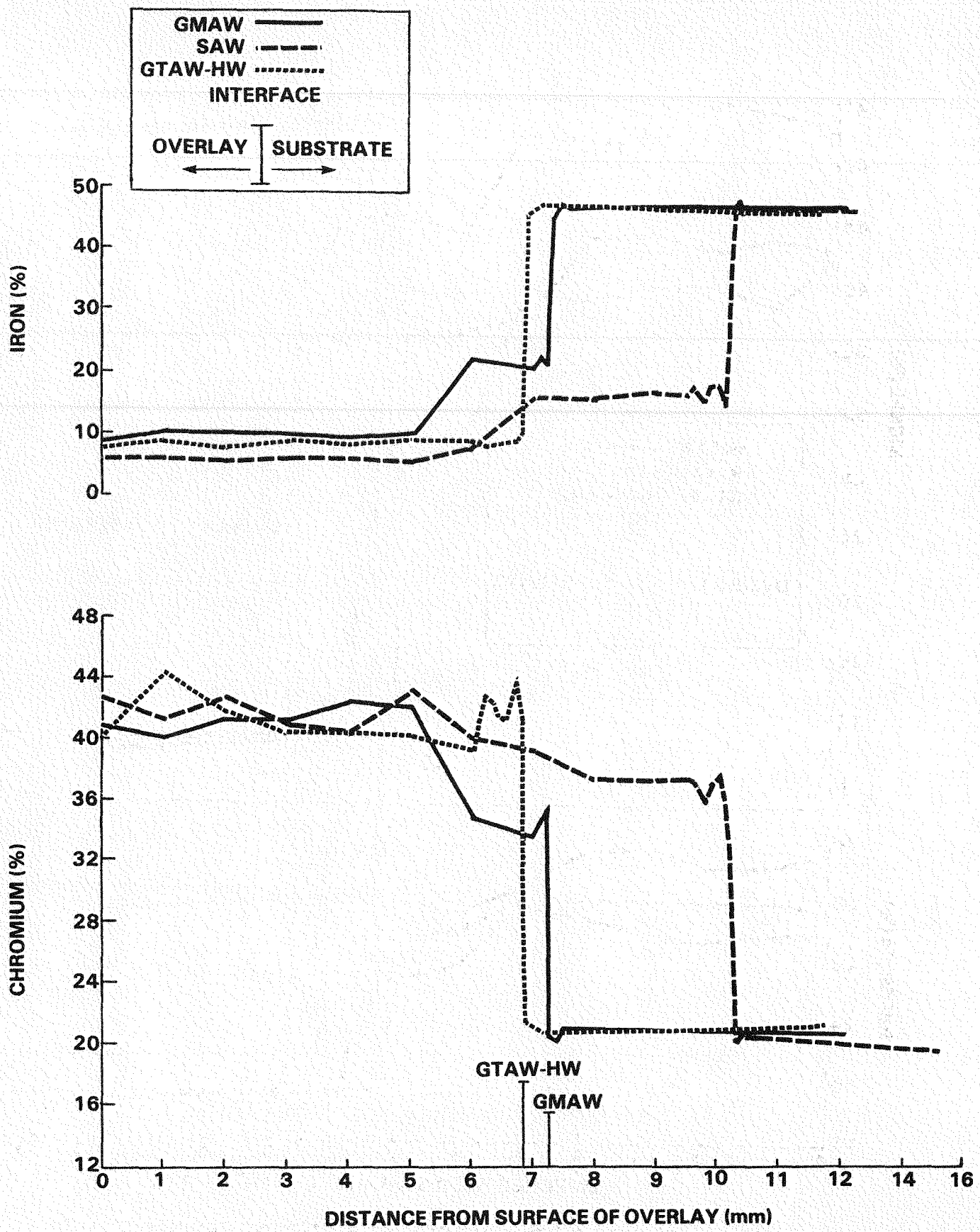


FIGURE 33 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON — INCONEL FILLER METAL 72 ON INCOLOY ALLOY 800 H — DOUBLE LAYERS, AS WELDED.

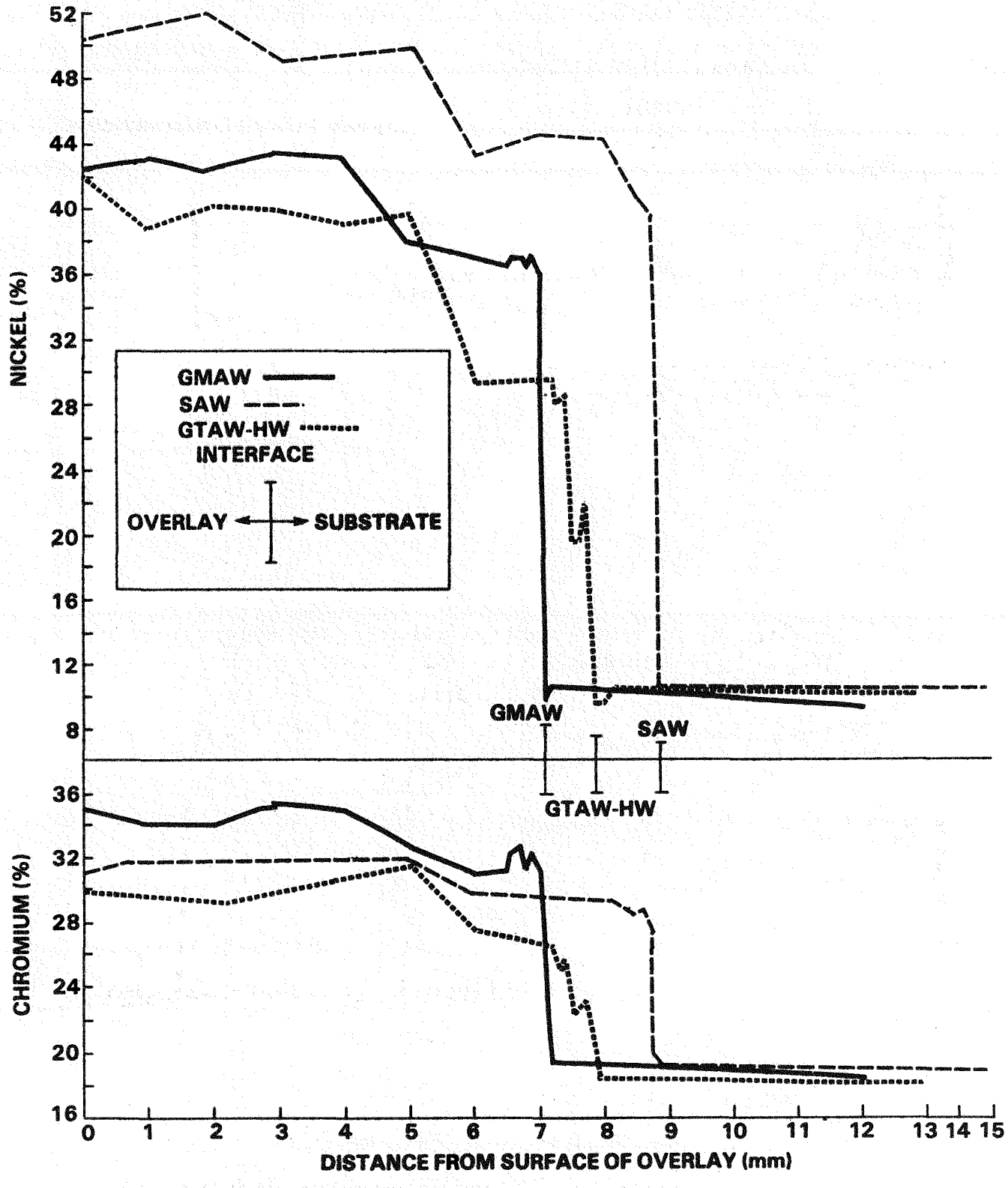


FIGURE 34 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL — R139 ON 304L — DOUBLE LAYERS, AS WELDED.

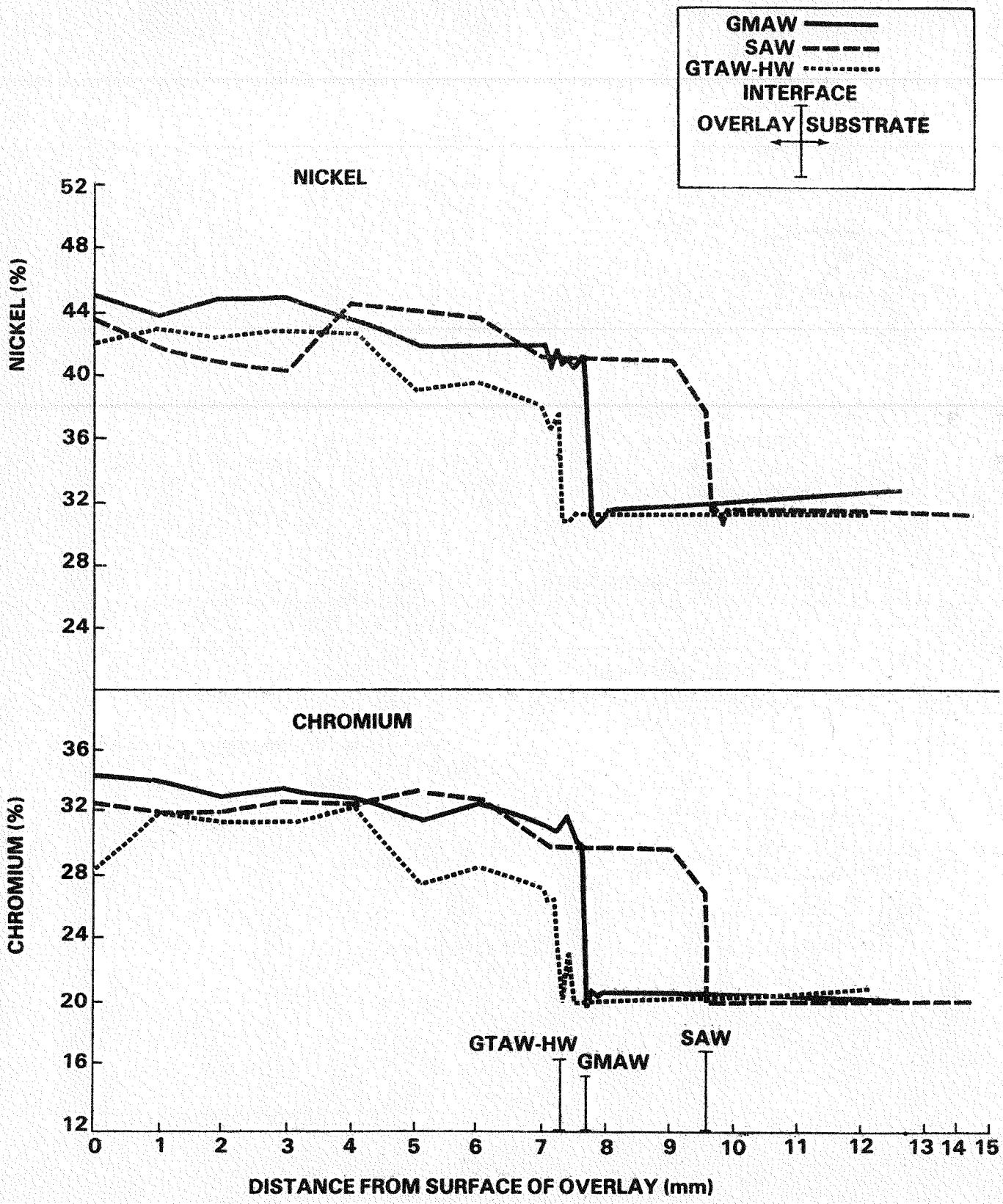


FIGURE 35 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 – INCOLOY ALLOY 800 H WELDMENTS, DOUBLE LAYERS, AS WELDED.

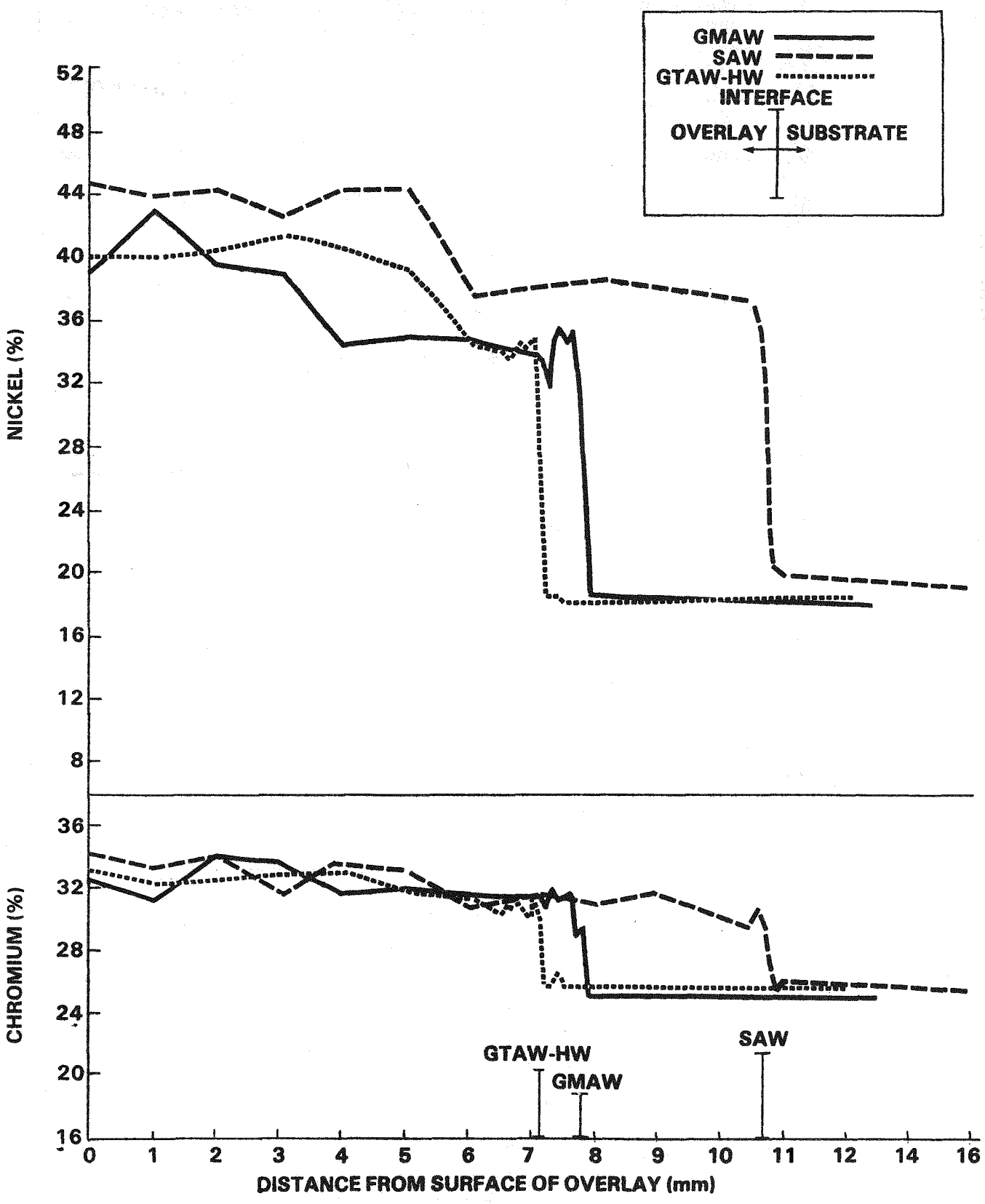


FIGURE 36 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 – 310 SS WELDMENTS, DOUBLE LAYERS, AS WELDED.

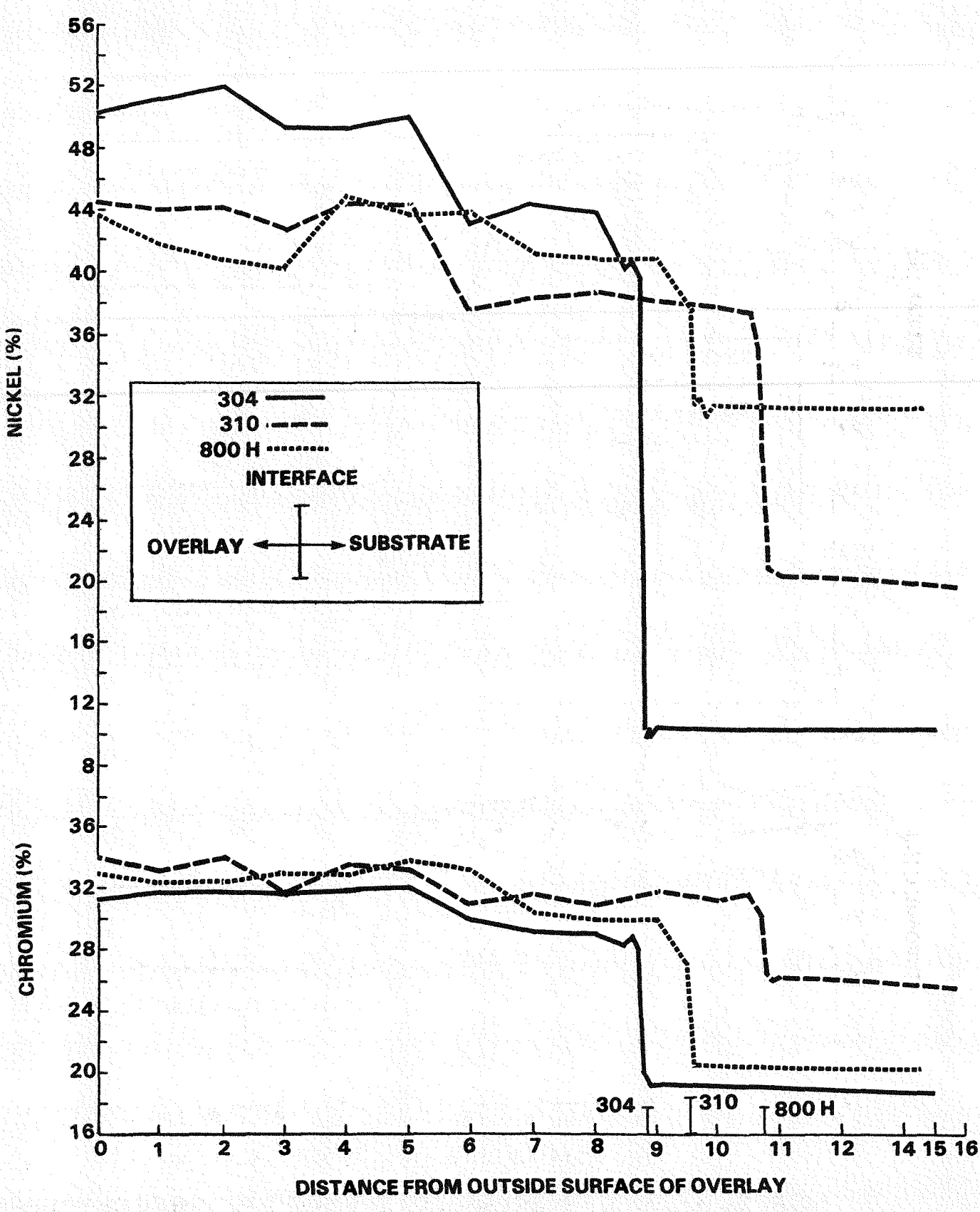


FIGURE 37 EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS, SAW PROCESS, DOUBLE LAYERS, AS WELDED.

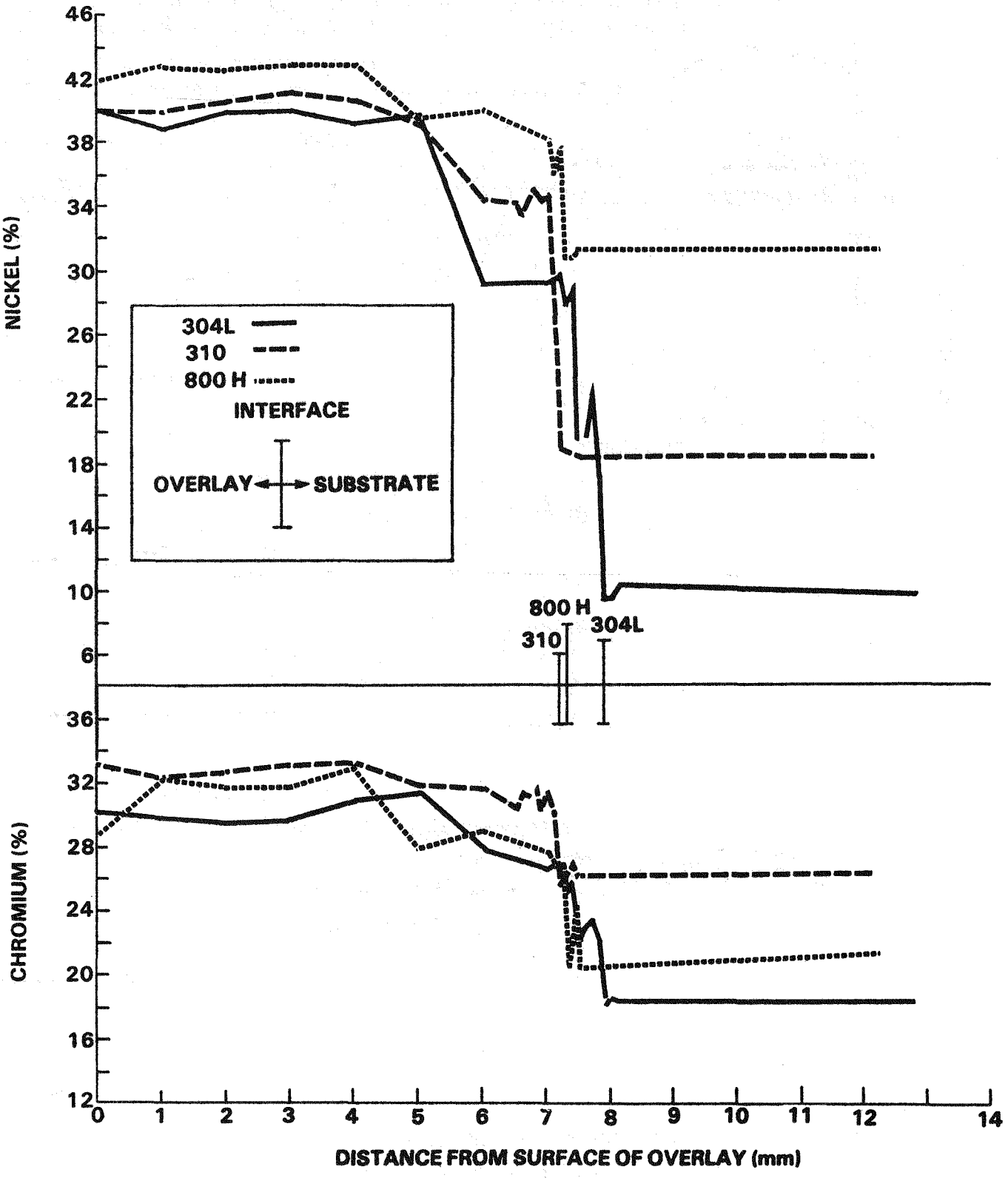


FIGURE 38 EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS, GTAW-HW PROCESS, DOUBLE LAYERS, AS WELDED.

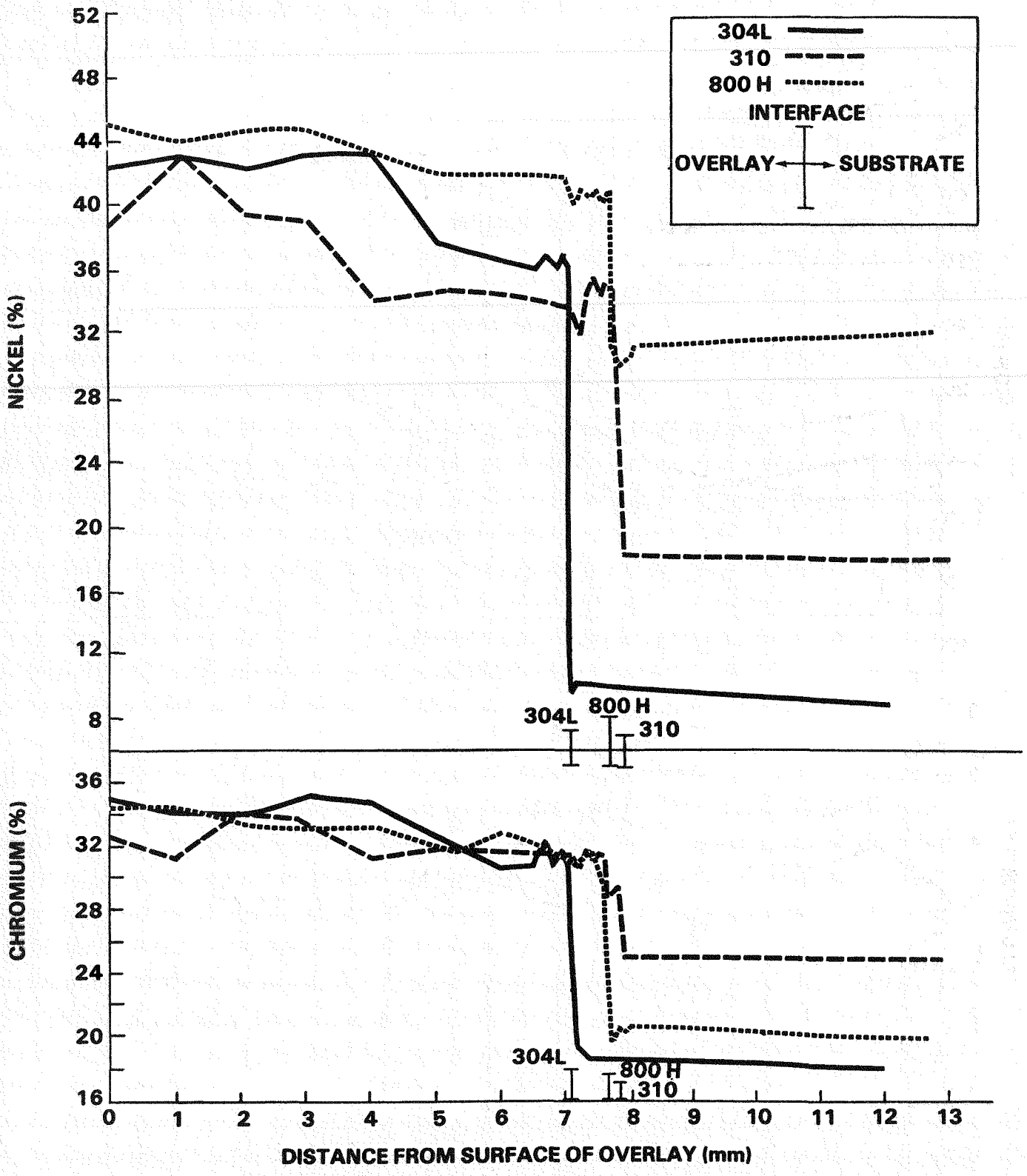


FIGURE 39 EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS, GMAW PROCESS, DOUBLE LAYERS, AS WELDED.

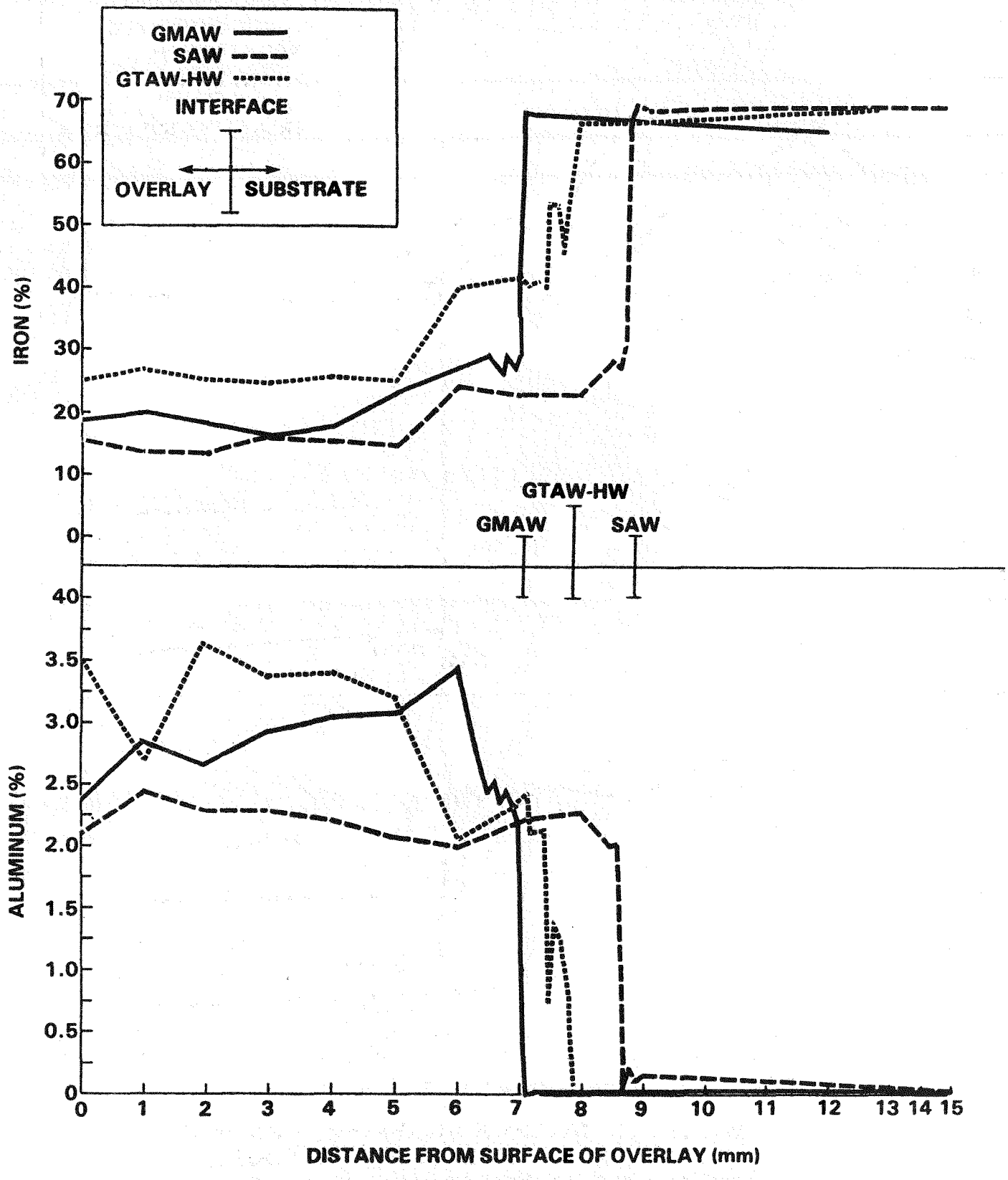


FIGURE 40 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 – 304L WELDMENTS, DOUBLE LAYERS, AS WELDED.

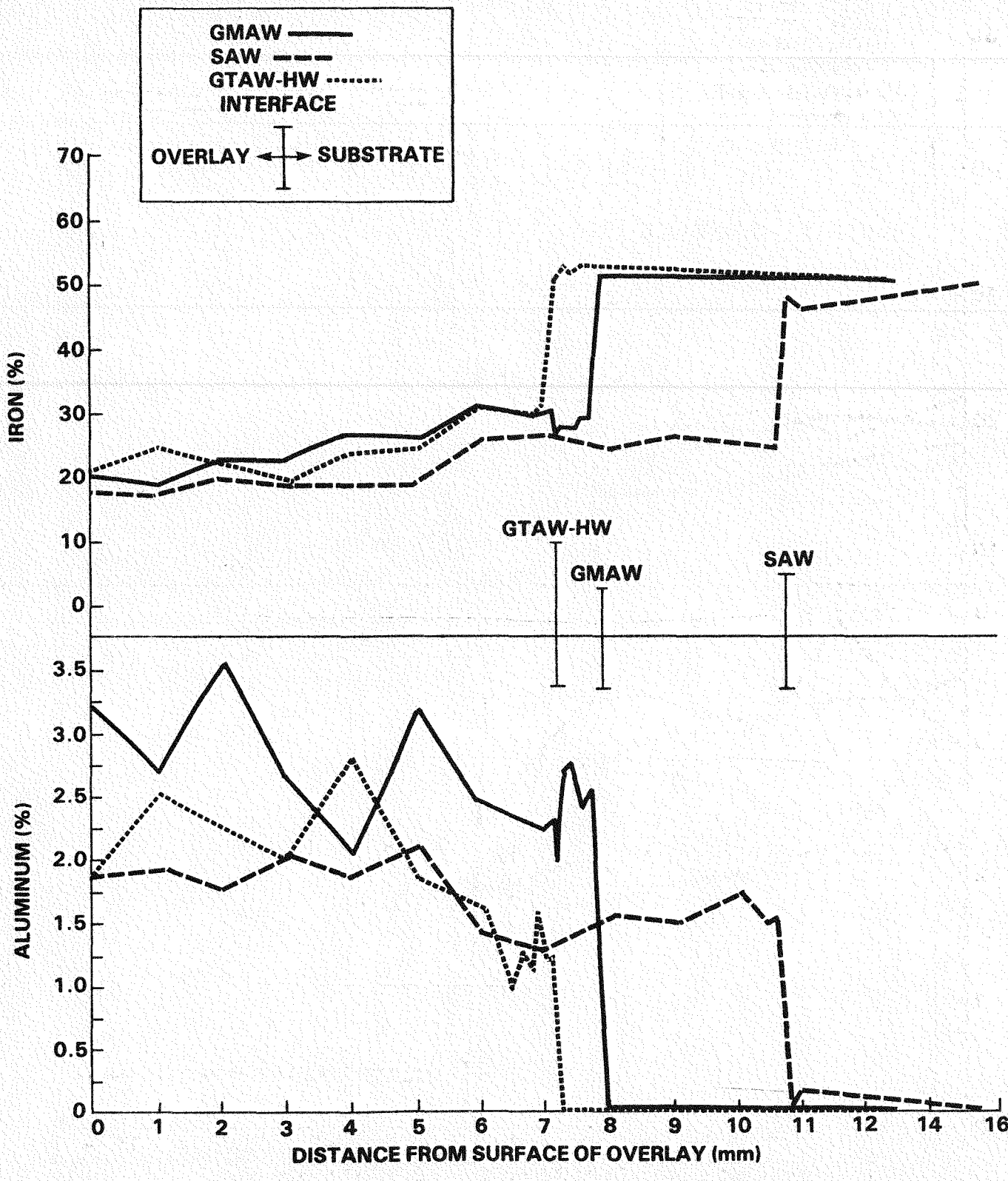


FIGURE 41 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 – 310 SS WELDMENTS, DOUBLE LAYERS, AS WELDED.

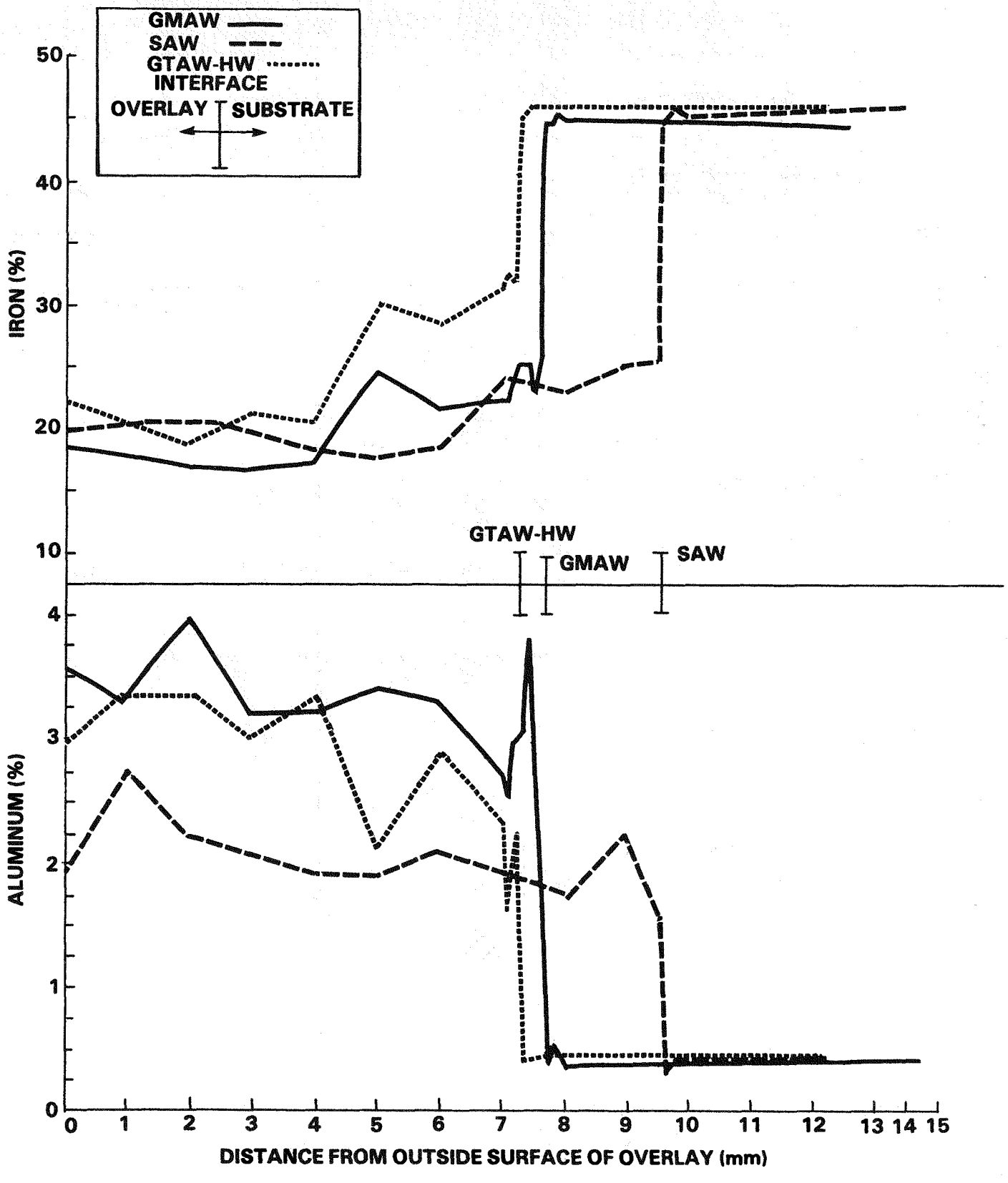


FIGURE 42 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 – INCOLOY ALLOY 800 H WELDMENTS, DOUBLE LAYERS, AS WELDED.

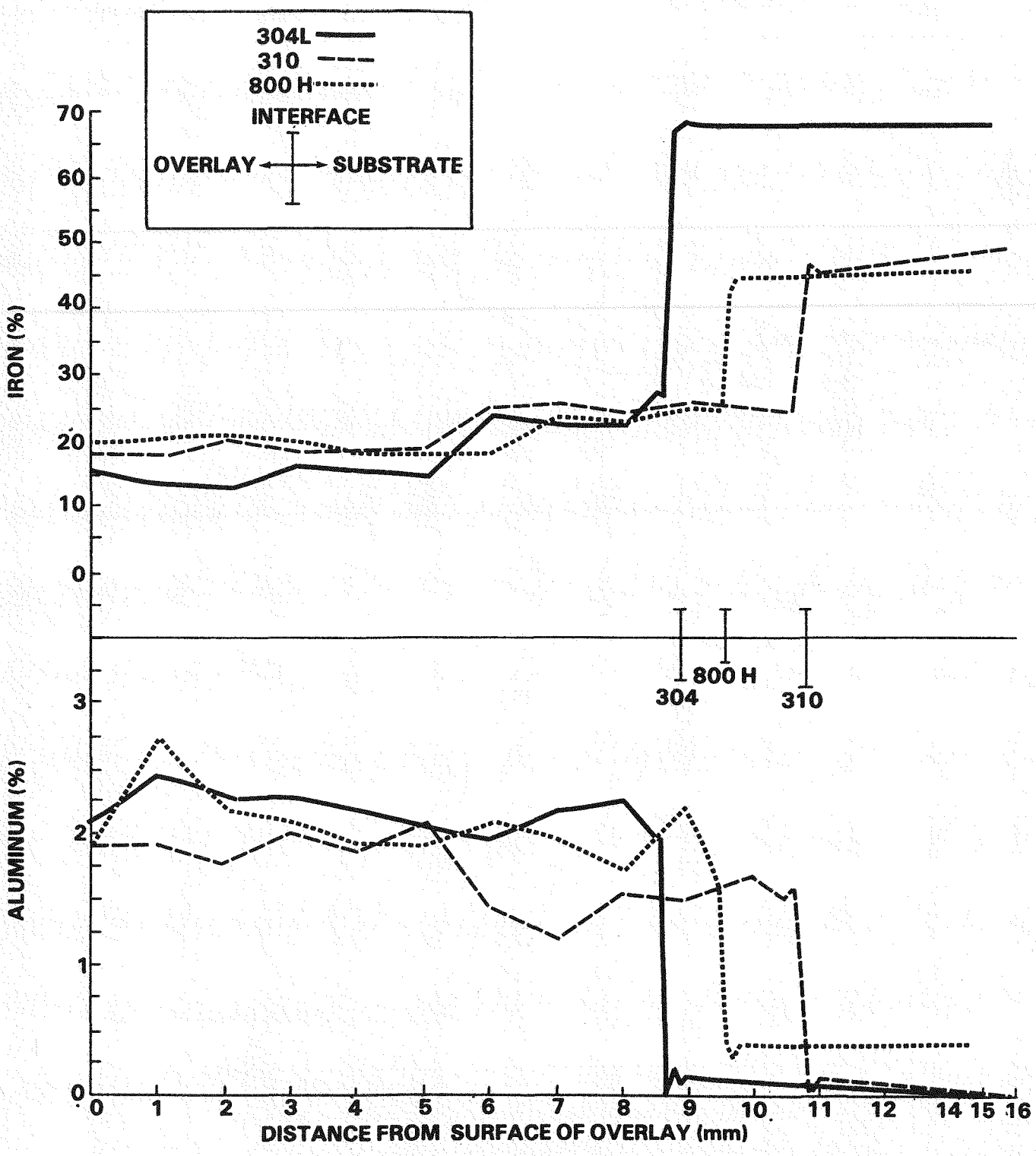


FIGURE 43 EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 OVERLAYS, SAW PROCESS, DOUBLE LAYERS, AS WELDED.

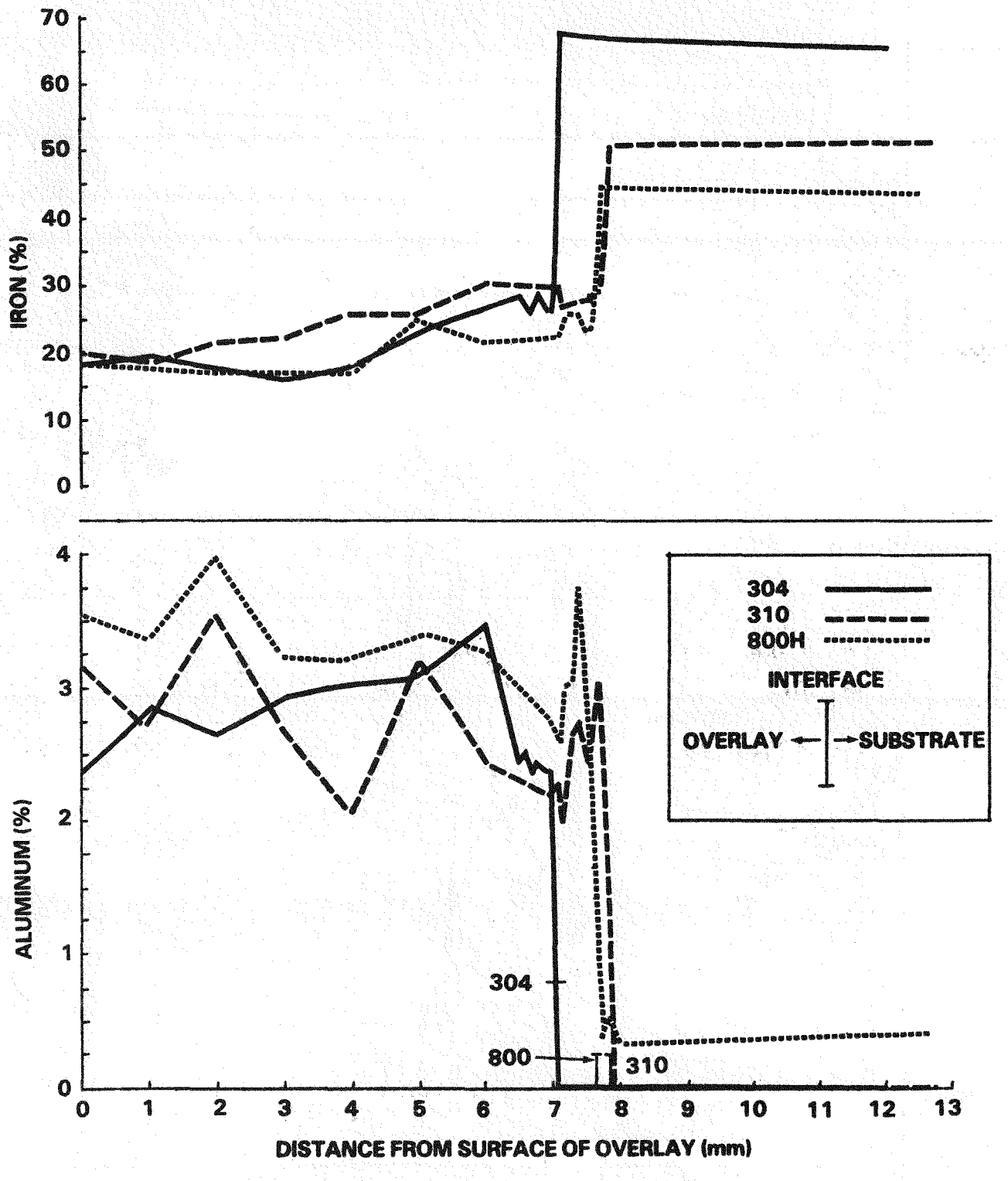


FIGURE 44. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 OVERLAYS, GMAW PROCESS, DOUBLE LAYERS, AS WELDED

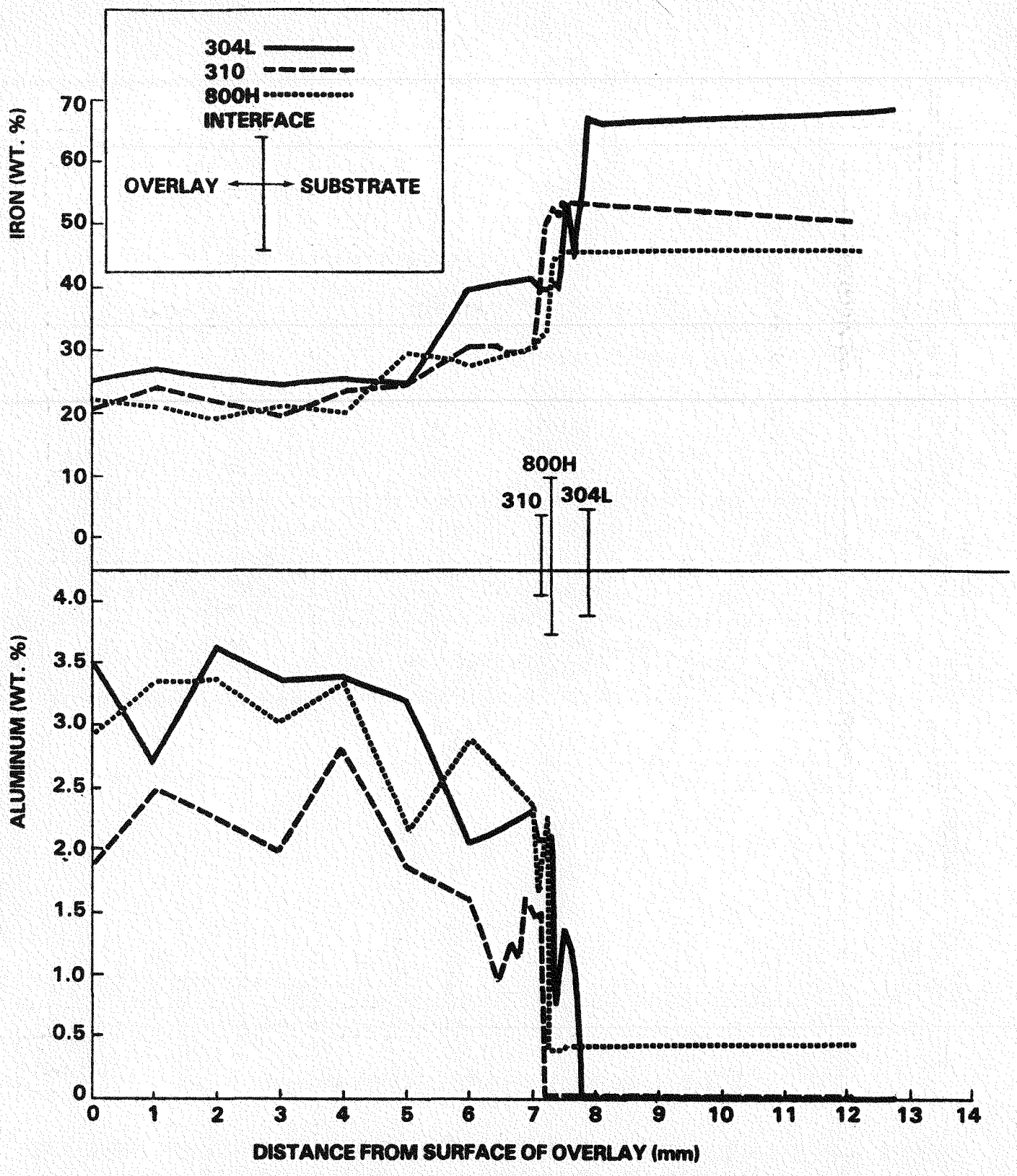


FIGURE 45. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 WELDMENTS, GTAW-HW PROCESS, DOUBLE LAYERS AS WELDED

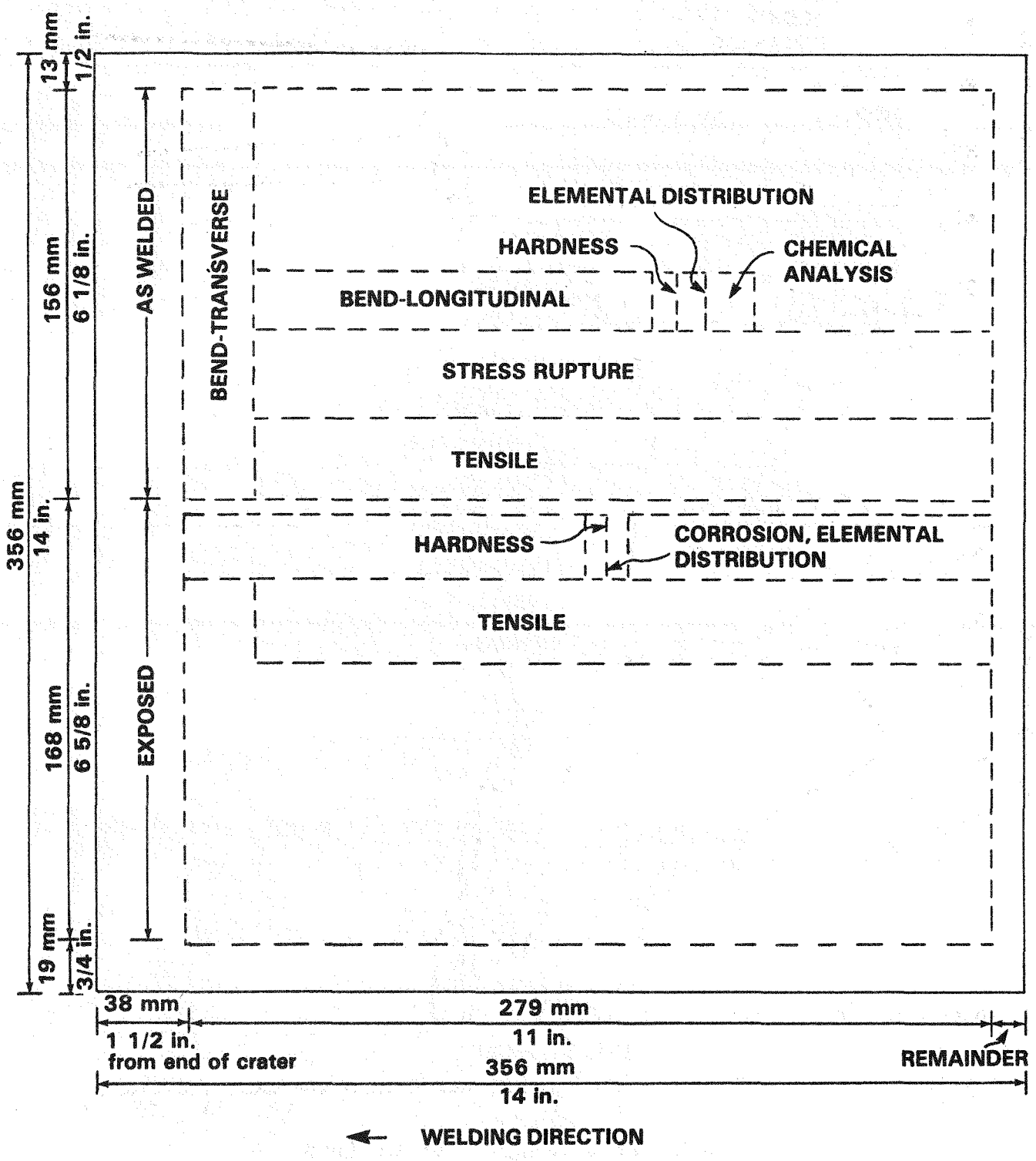


FIGURE 46 LOCATION OF TEST SPECIMENS

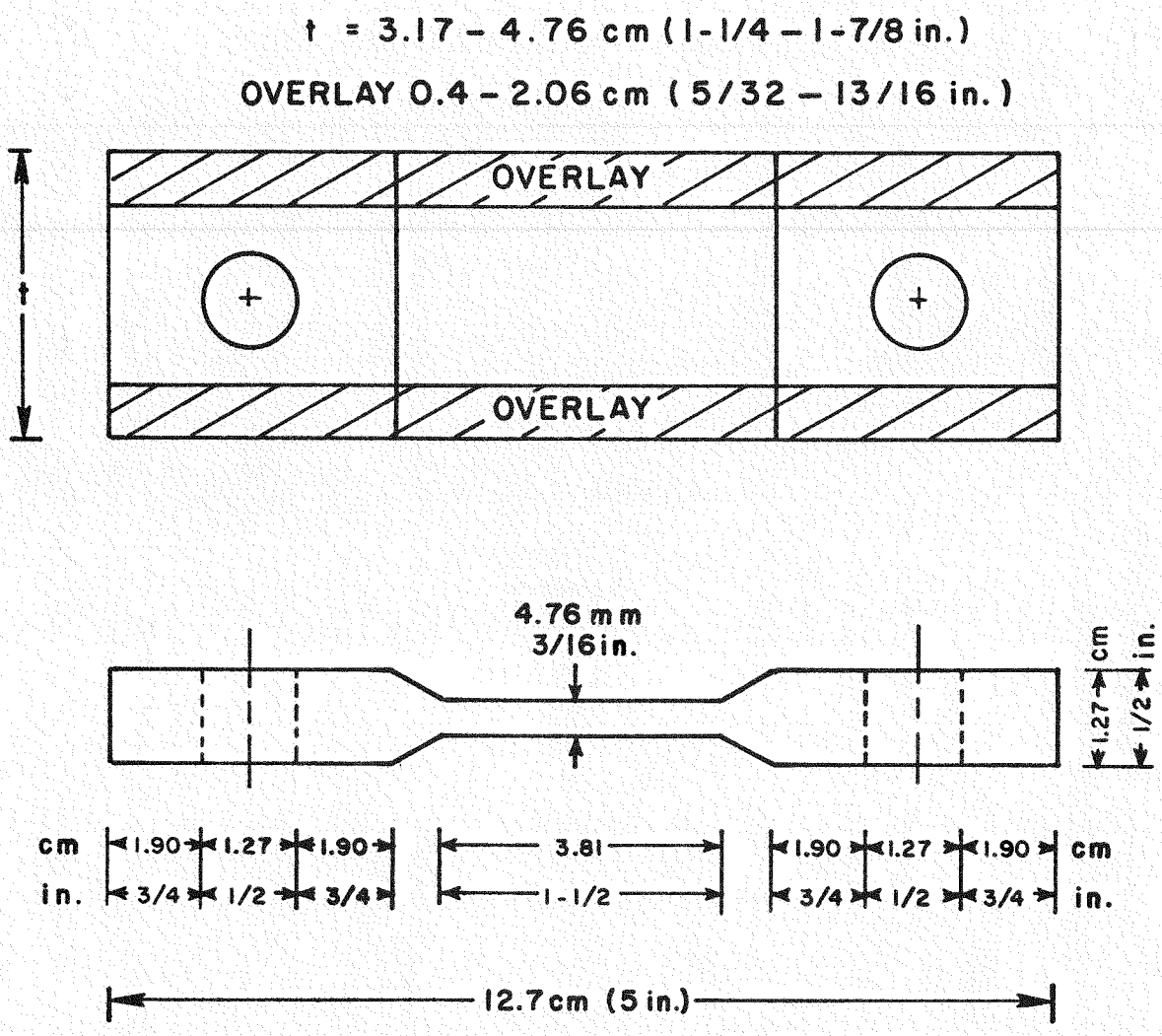


FIGURE 47- STRESS RUPTURE SPECIMEN.

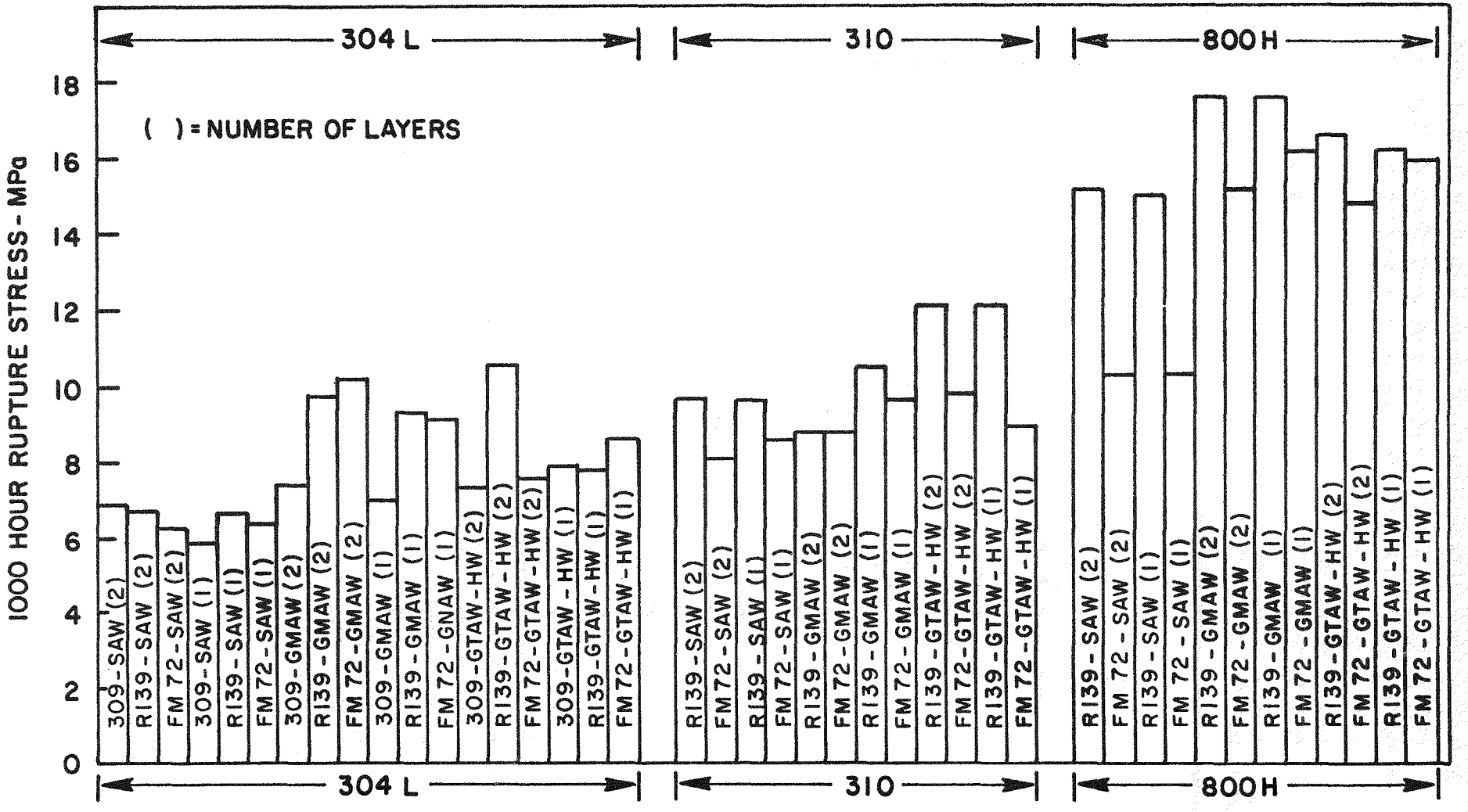


FIGURE 48 EFFECT OF SUBSTRATE ON 1000 HOUR RUPTURE STRESS AT 982 °C (1800 °F)

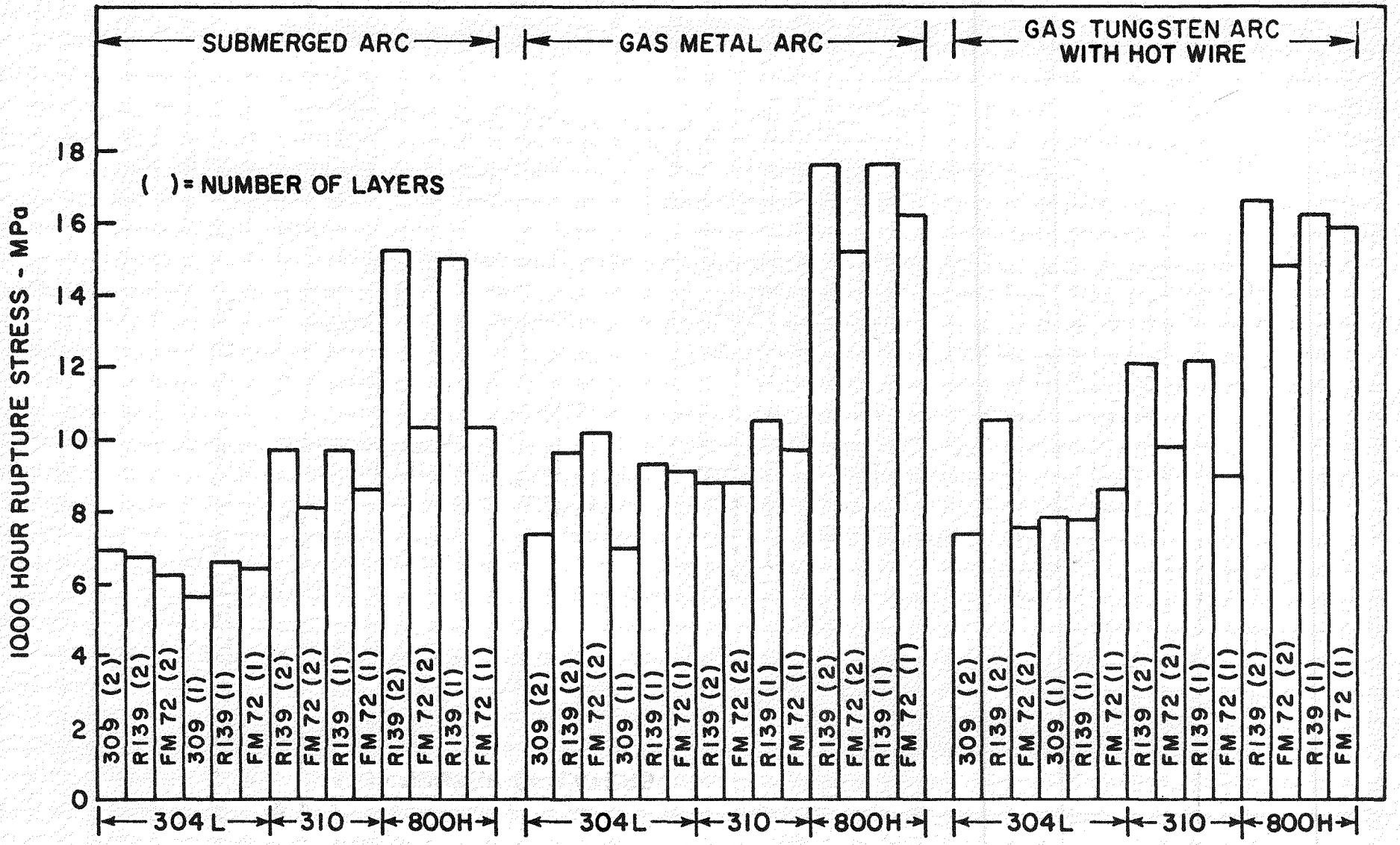


FIGURE 49-EFFECT OF WELDING PROCESS ON 1000 HOUR RUPTURE STRESS AT 982°C (1800°F).

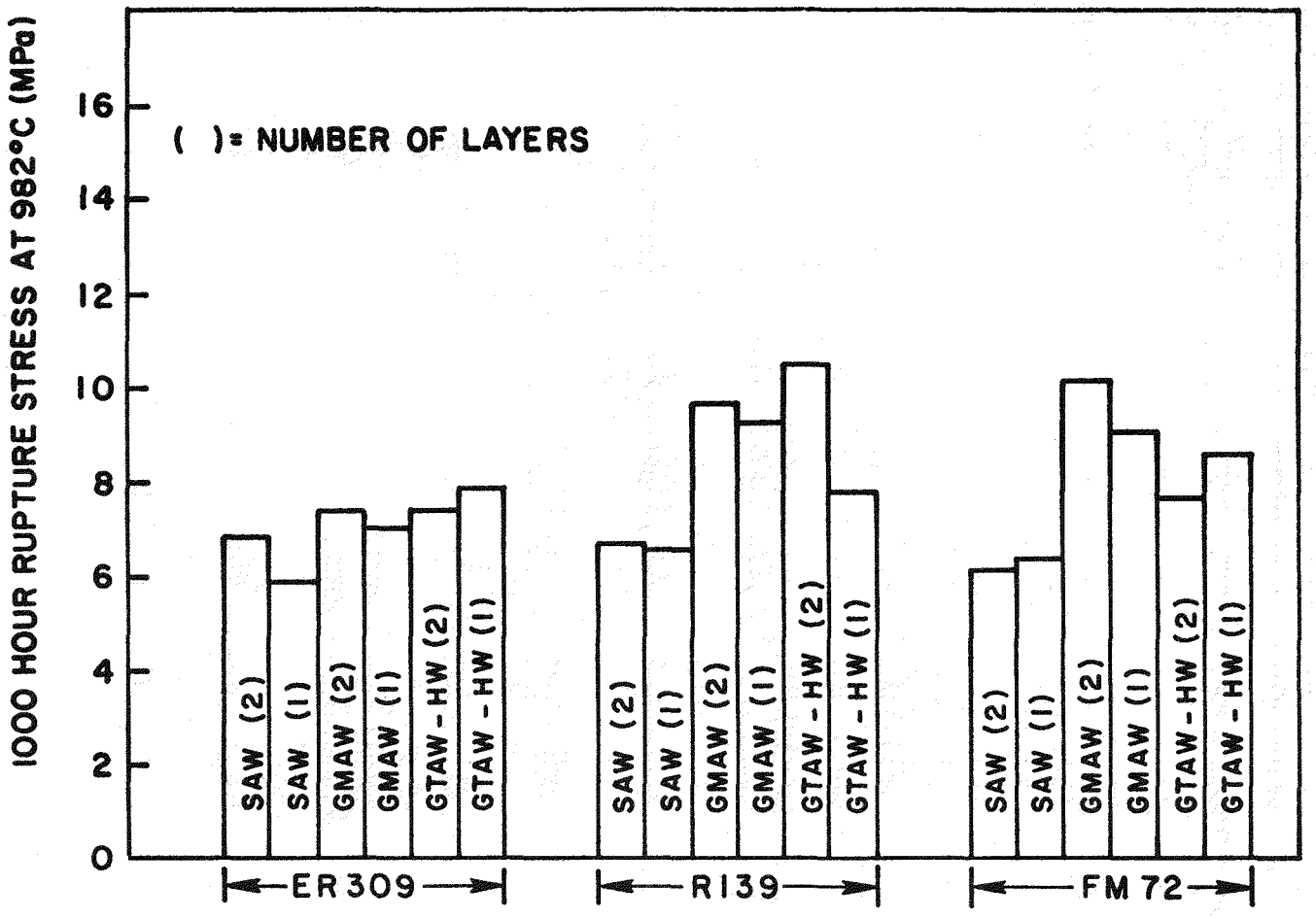


FIGURE 50-EFFECT OF OVERLAY COMPOSITION ON THE 1000 HOUR STRESS RUPTURE STRENGTH AT 982°C (1800°F) OF 304L SUBSTRATE.

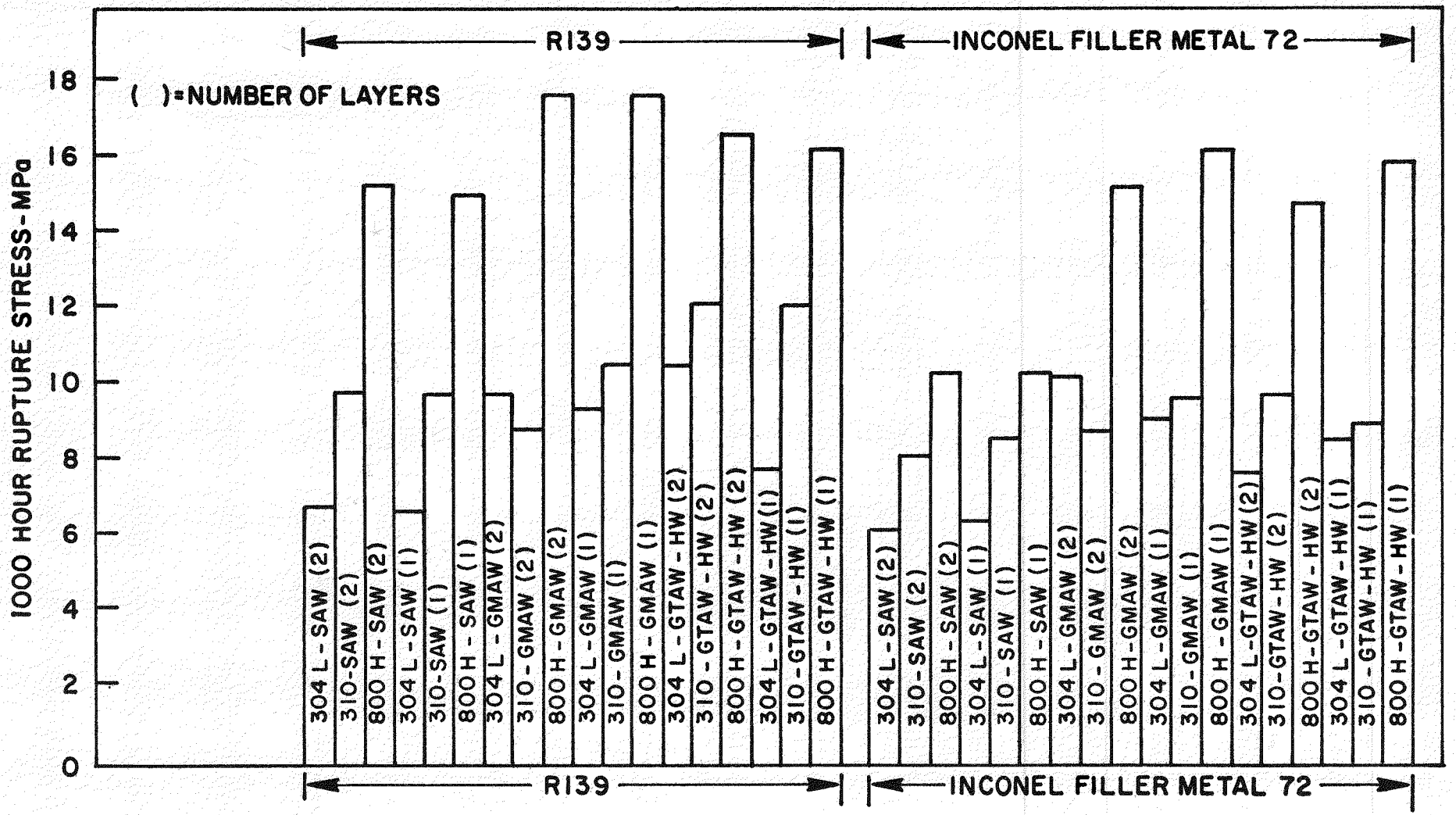


FIGURE 51 - EFFECT OF FILLER METAL COMPOSITION ON 1000 HOUR RUPTURE STRESS AT 982°C (1800°F) - ALL SUBSTRATES AND WELD PROCESSES.

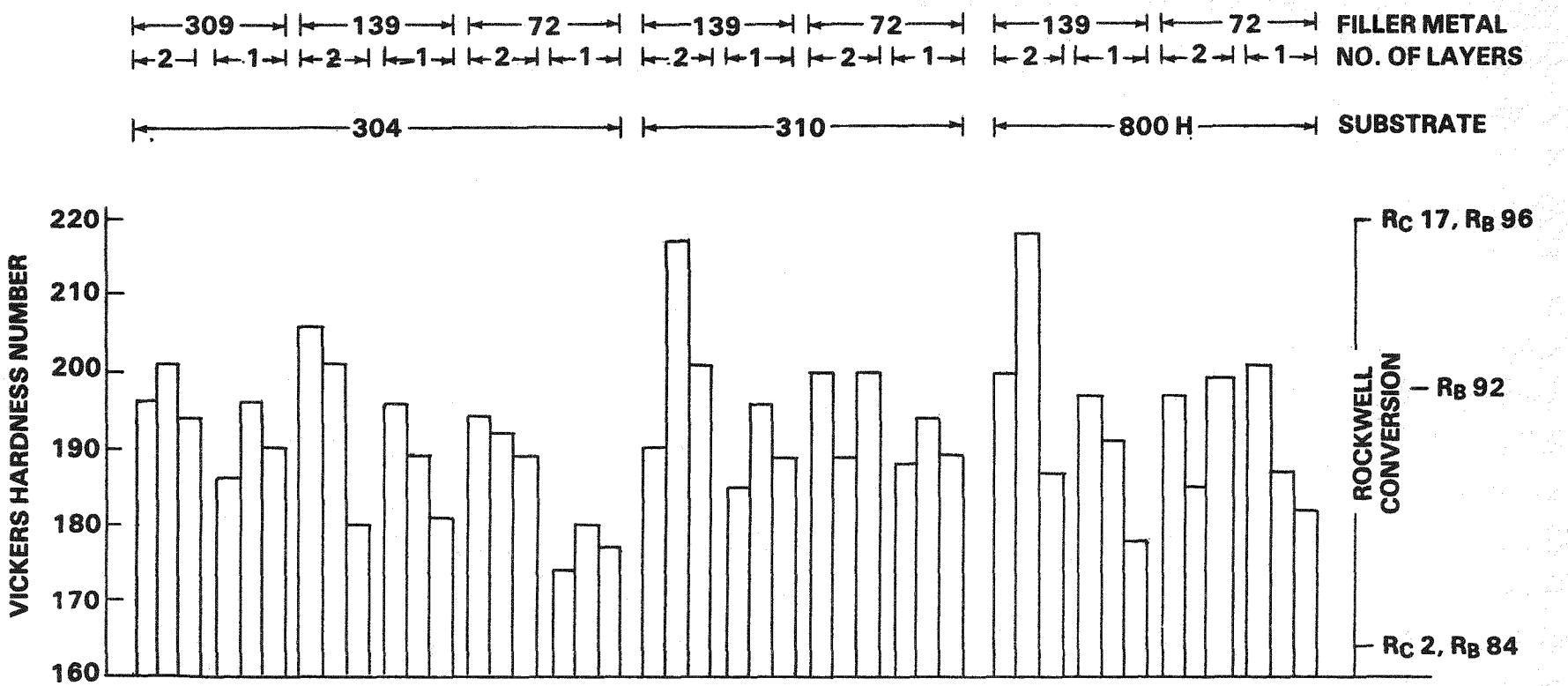


FIGURE 52 EFFECT OF SUBSTRATE AND NUMBER OF LAYERS ON THE HARDNESS OF OVERLAYS, AS WELDED.

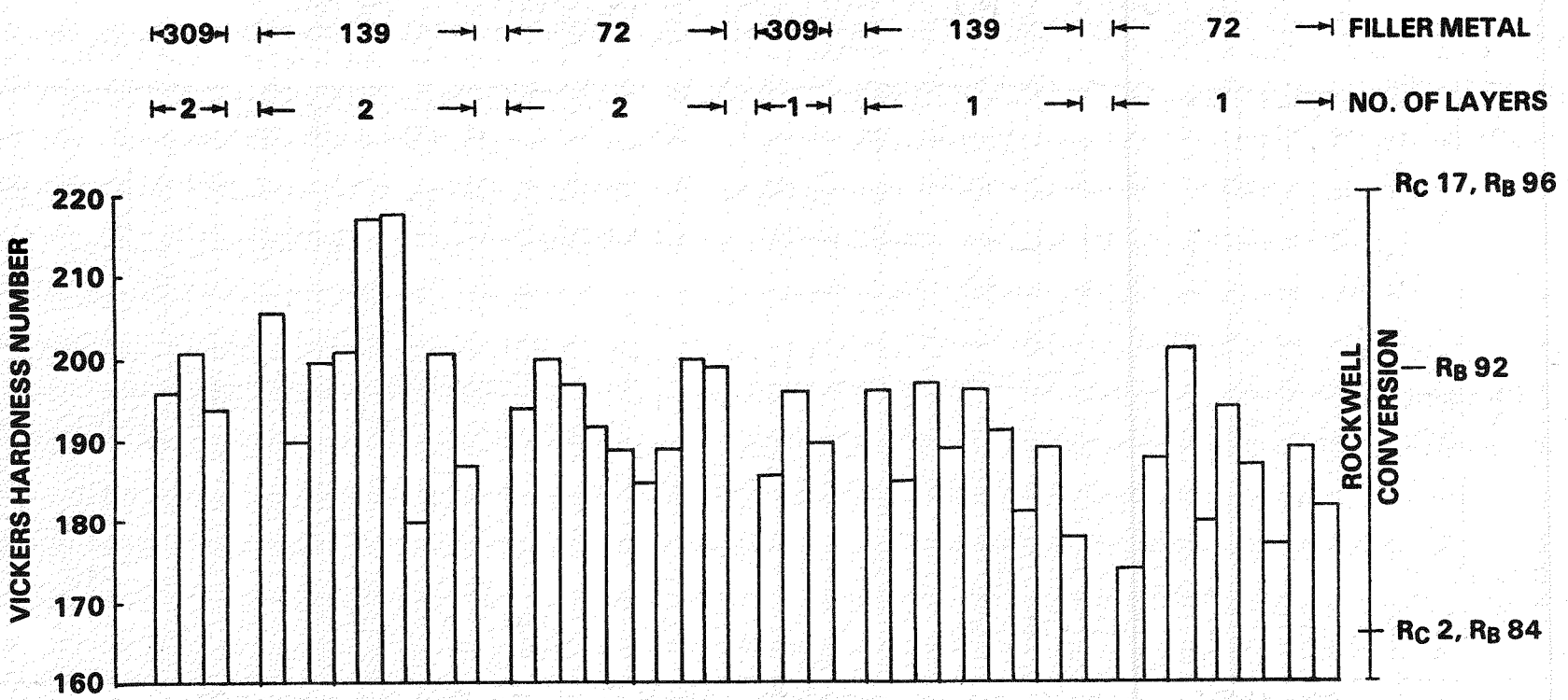


FIGURE 53 EFFECT OF FILLER METAL ON THE HARDNESS OF OVERLAYS, AS WELDED.

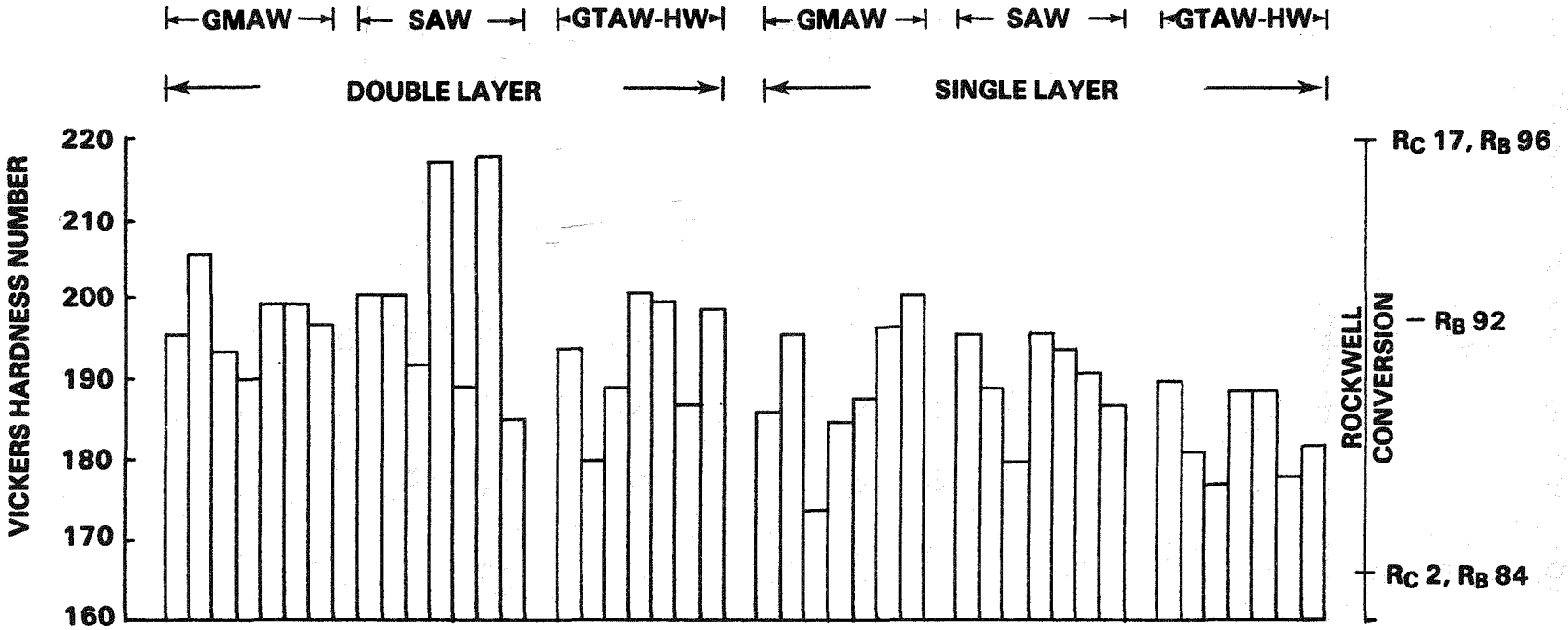


FIGURE 54 EFFECT OF THE WELDING PROCESS ON THE HARDNESS OF OVERLAYS, AS WELDED.

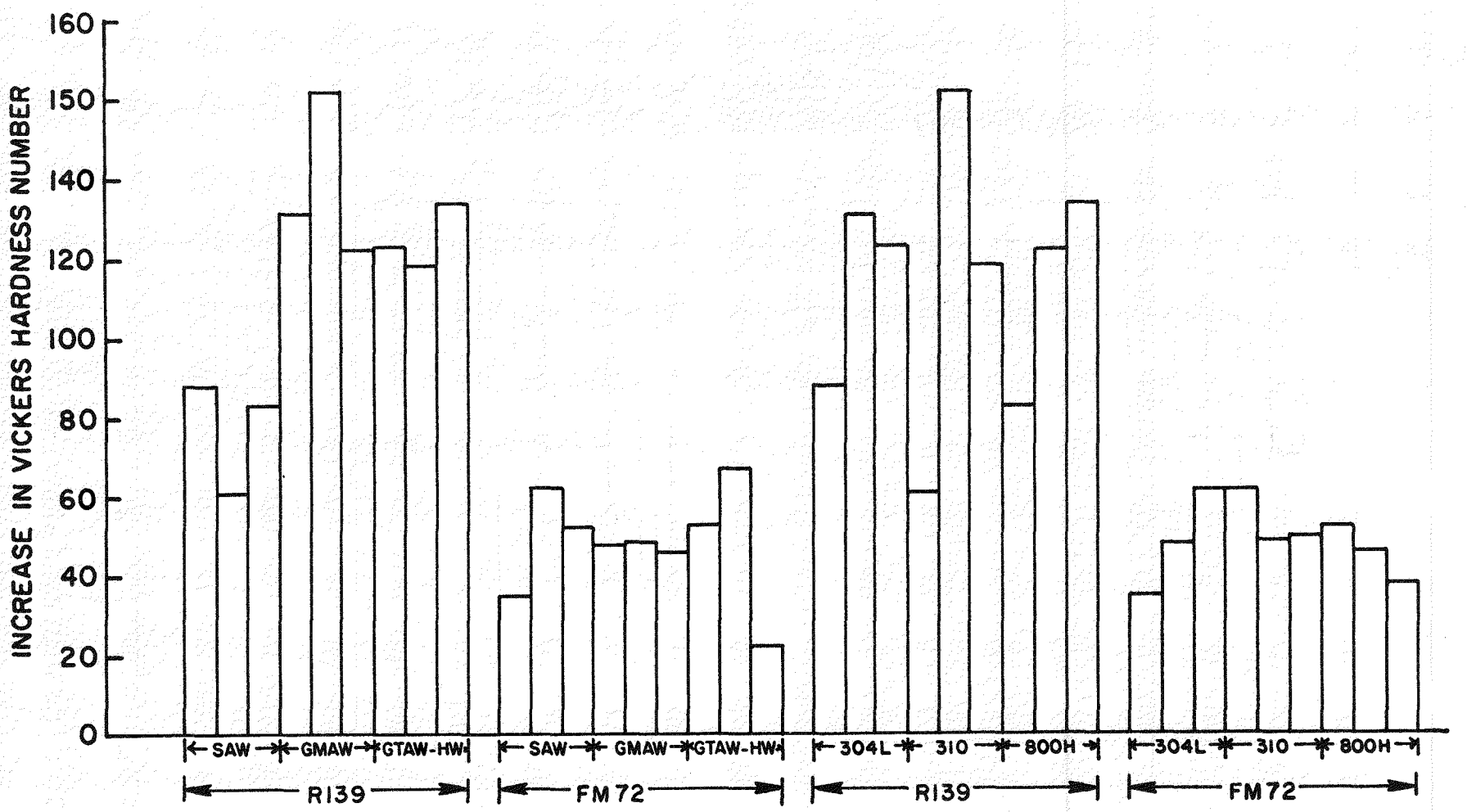


FIGURE 55- EFFECT OF FILLER METAL, WELD PROCESS AND SUBSTRATE ON INCREASE IN HARDNESS OF UPPER LAYER OF DOUBLE LAYER OVERLAYS AFTER EXPOSURE IN A COAL GASIFICATION ATMOSPHERE.

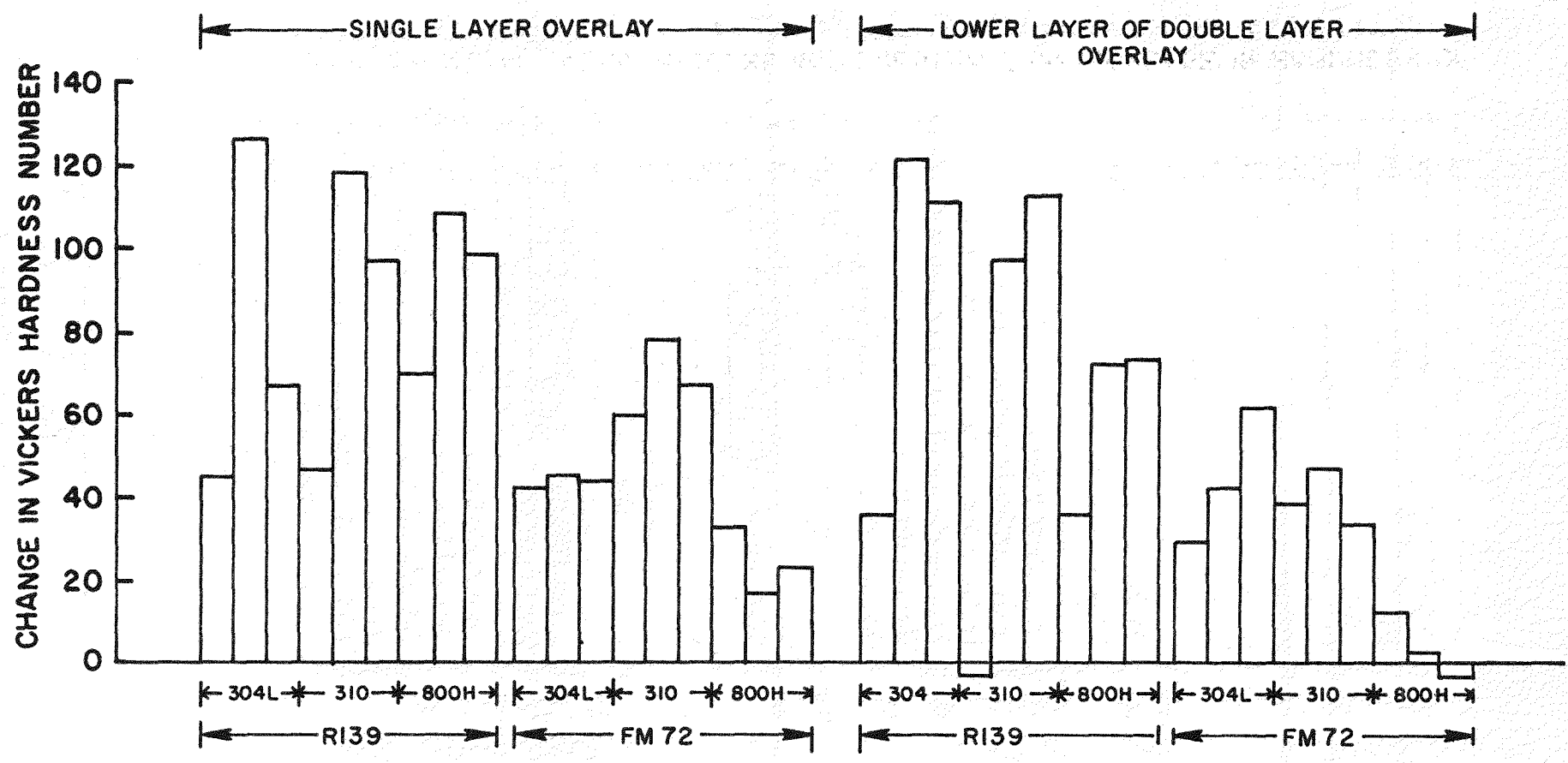


FIGURE 56-EFFECT OF FILLER METAL AND SUBSTRATE ON CHANGE IN OVERLAY HARDNESS AFTER EXPOSURE IN A COAL GASIFICATION ATMOSPHERE.

t = 1 1/4 – 1 3/4" (32–44 mm)

OVERLAY = ~1/8–3/8" (3–10 mm)

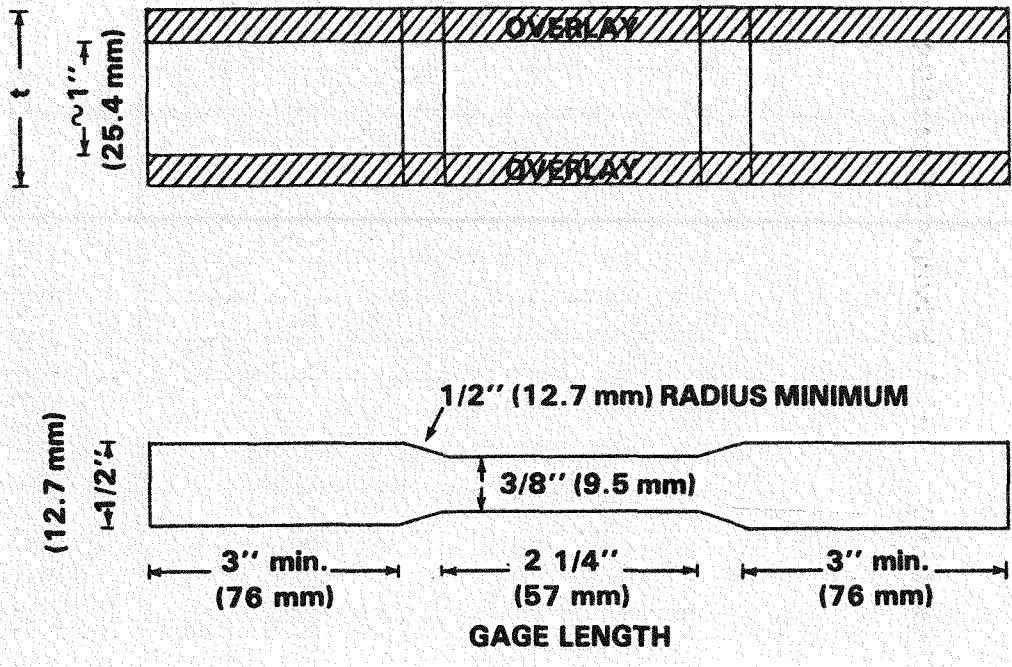


FIGURE 57–DIMENSIONS OF TENSILE SPECIMEN

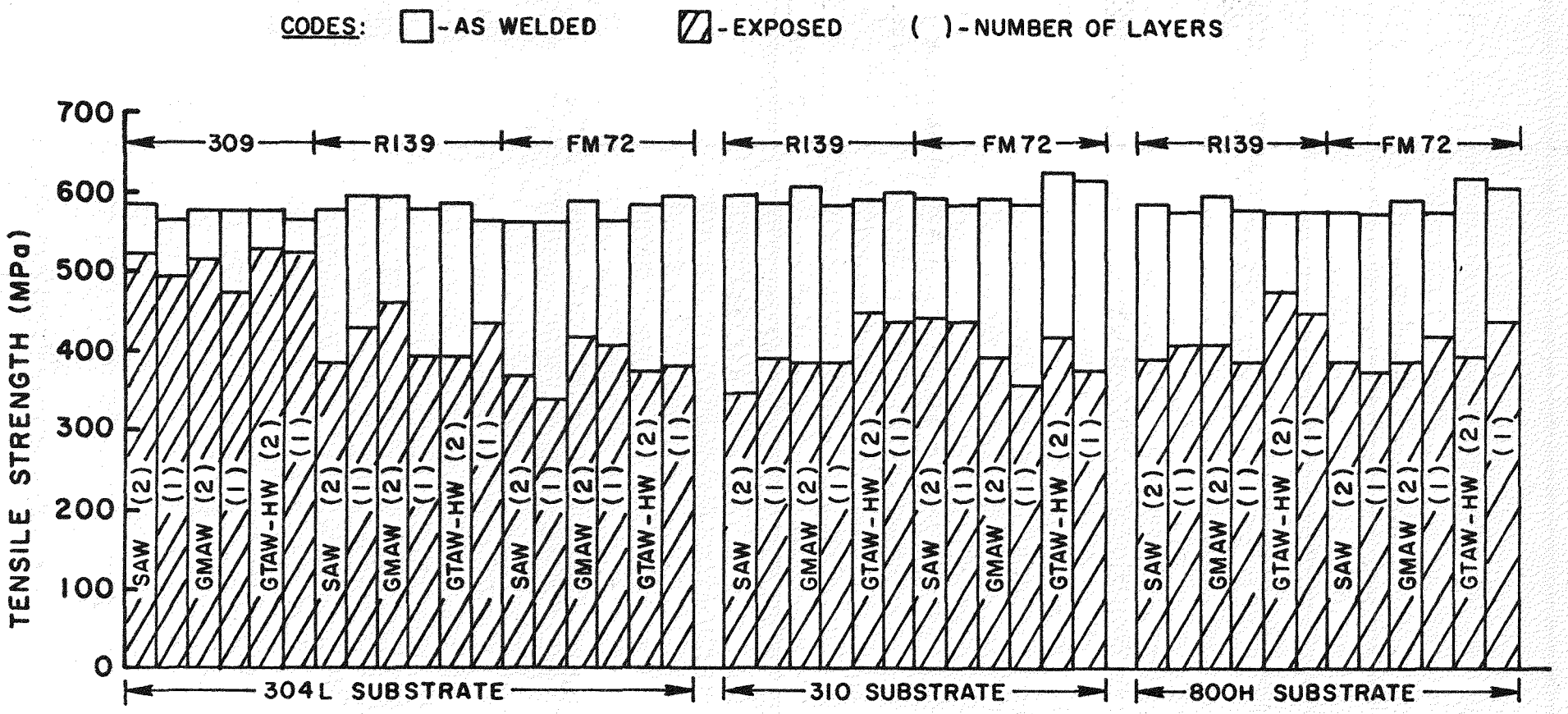


FIGURE 58-EFFECT OF SUBSTRATE AND EXPOSURE IN A COAL GASIFICATION ATMOSPHERE ON ROOM TEMPERATURE TENSILE STRENGTH.

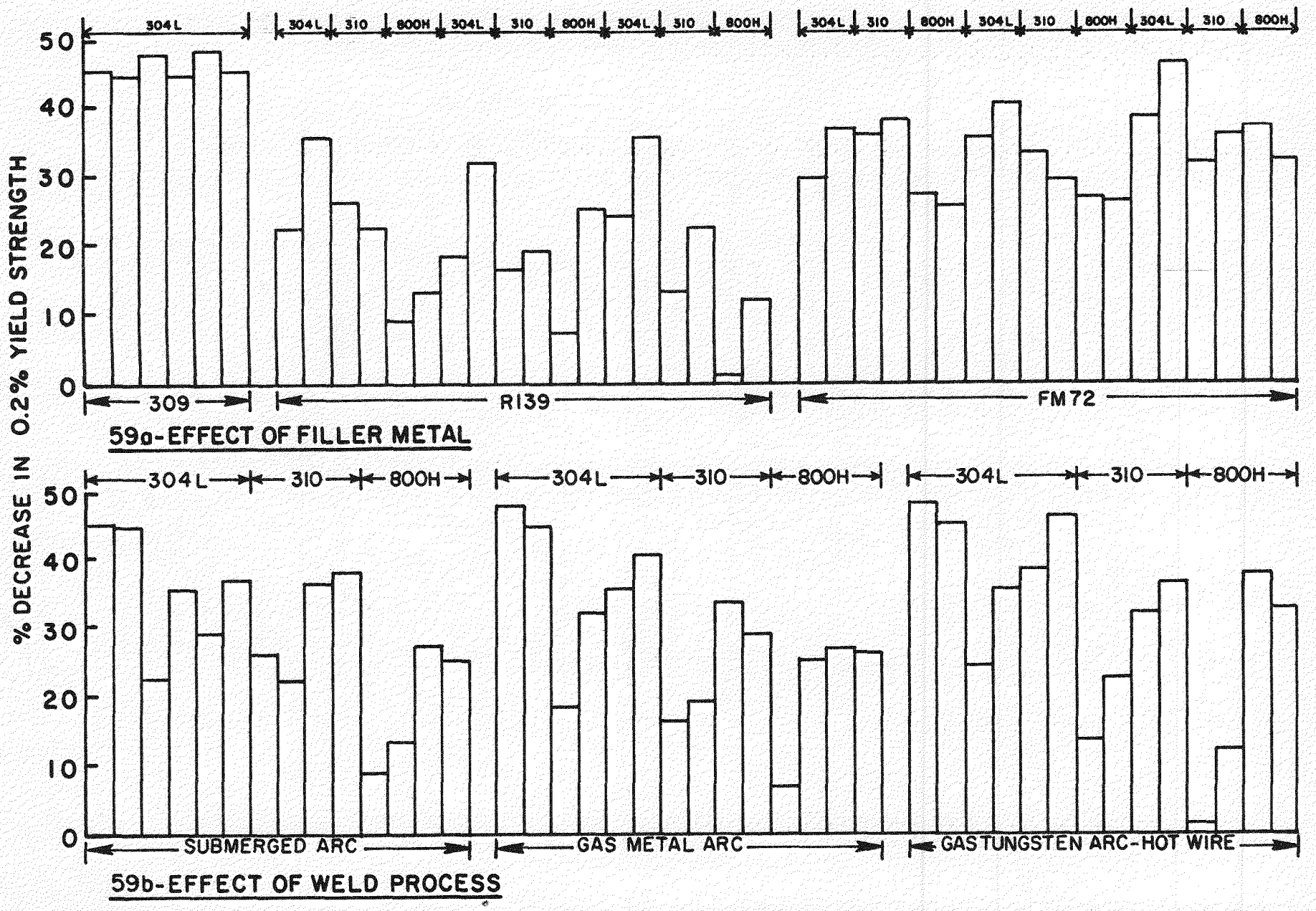


FIGURE 59-EFFECT OF FILLER METAL AND WELD PROCESS ON PERCENT DECREASE IN ROOM TEMPERATURE YIELD STRENGTH AFTER EXPOSURE IN A CGA.

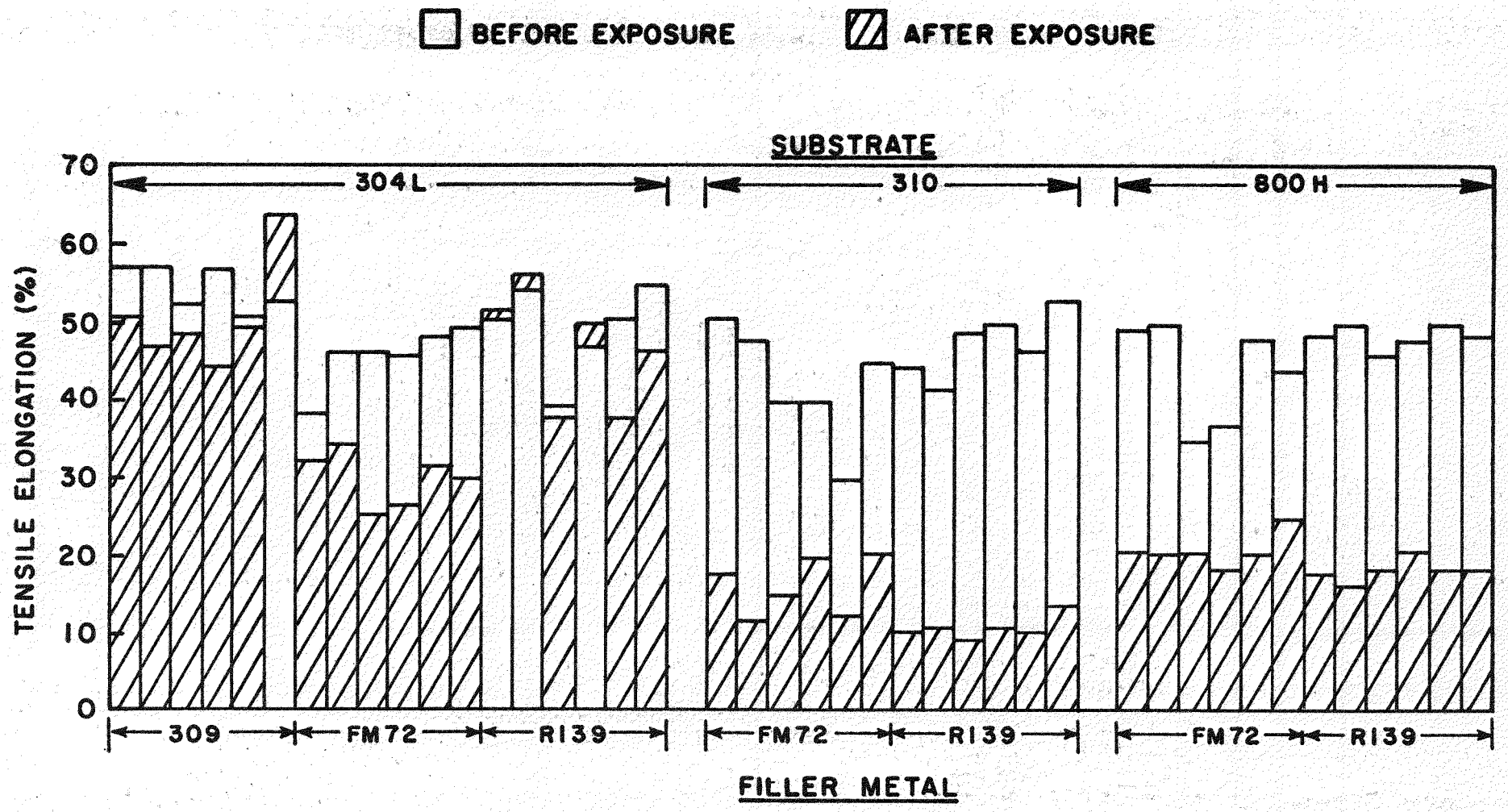


FIGURE 60- EFFECT OF FILLER METAL, SUBSTRATE AND EXPOSURE IN CGA ON THE ROOM TEMPERATURE TENSILE DUCTILITY OF SURFACED SPECIMENS.

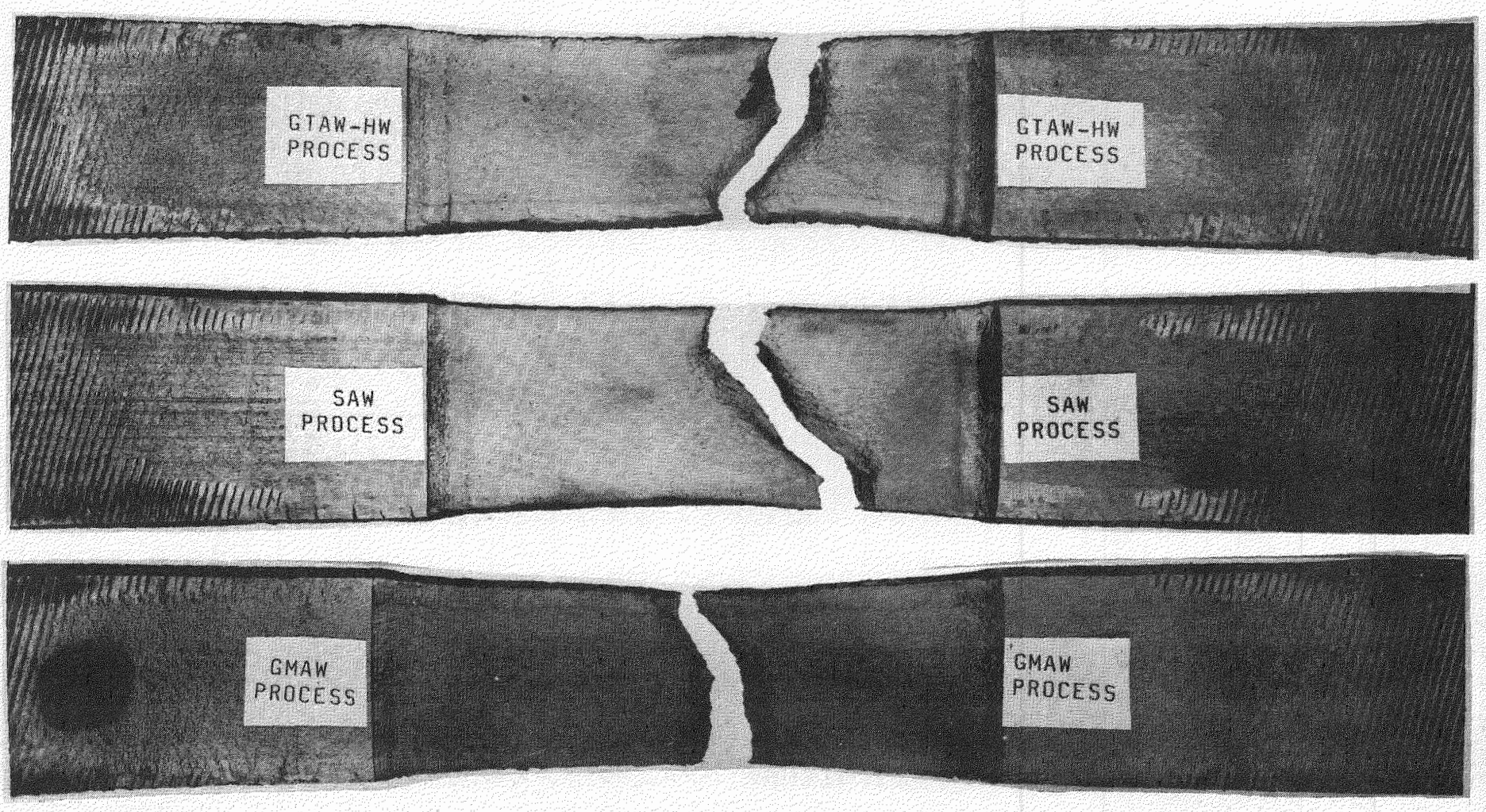


FIGURE 61: Effect of welding process on the fracture appearance of tensile specimens tested after exposure in a CGA, AWS-ER309 on 304L, double layers. (Approx. 1X)

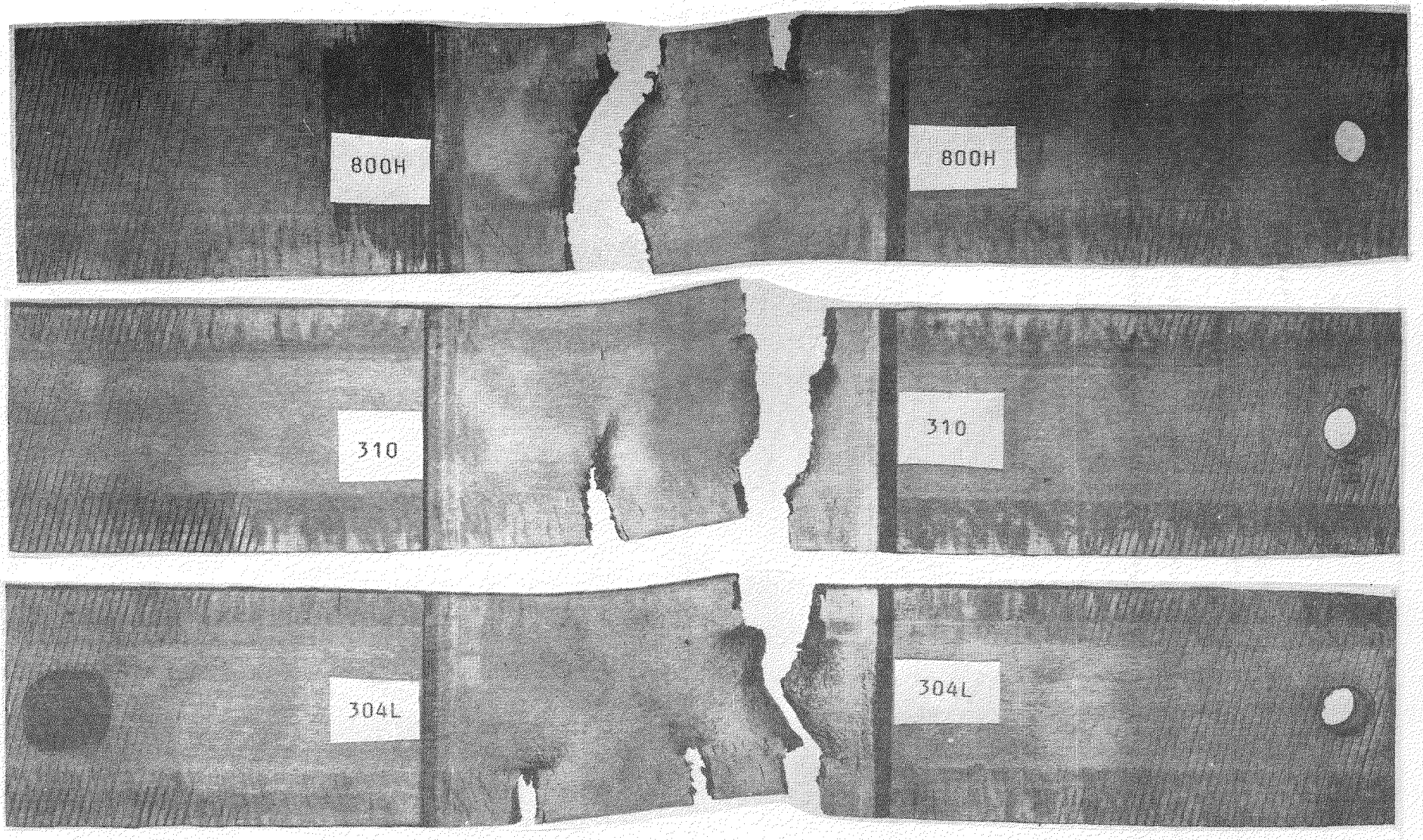


FIGURE 62: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, INCONEL Filler Metal 72 overlays, SAW process double layers.

(Approx. 1X)

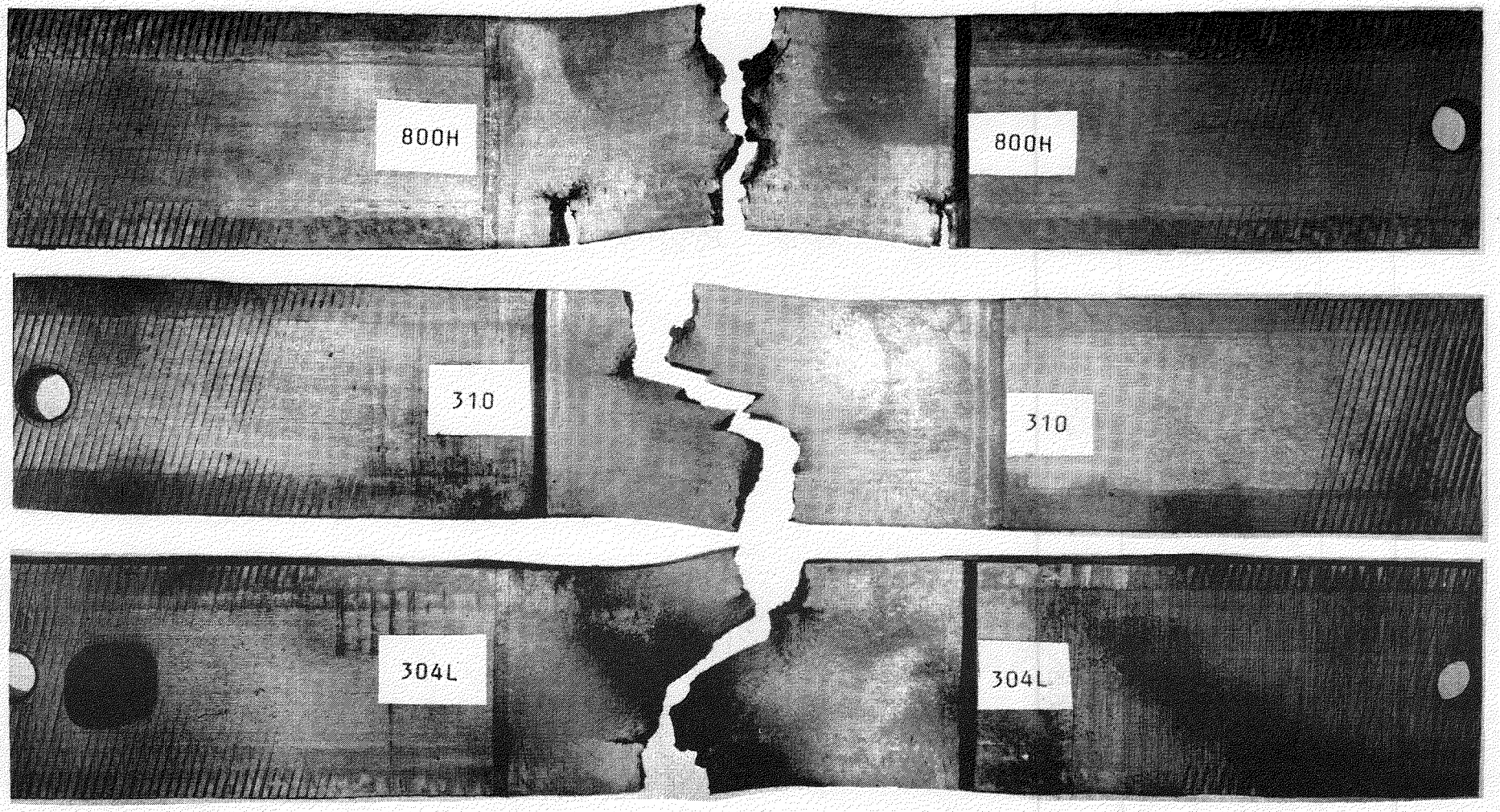


FIGURE 63: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, INCONEL Filler Metal 72 overlays, GMAW process, double layers.

(Approx. 1X)

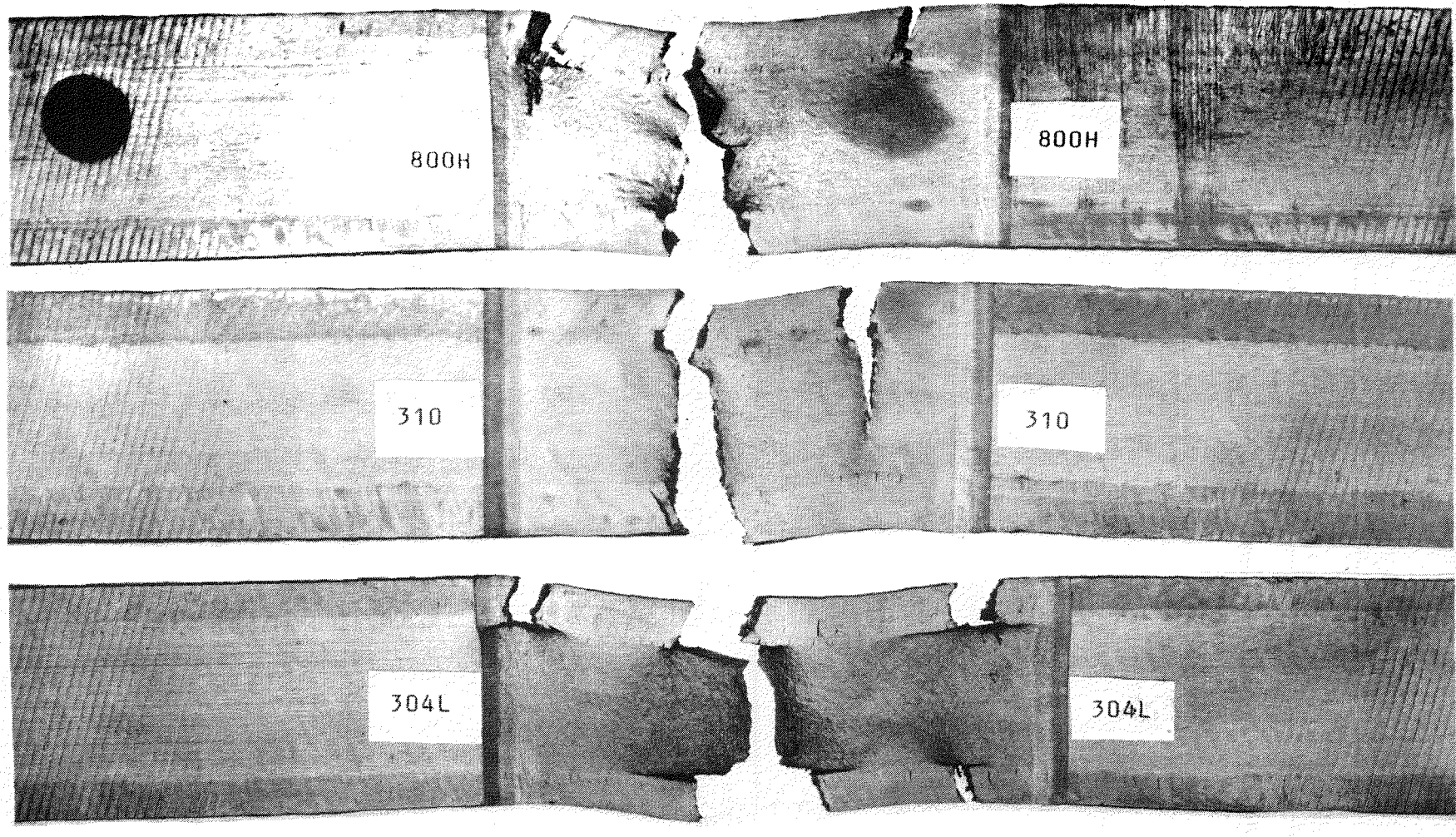


FIGURE 64: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, INCONEL Filler Metal 72 overlays, GTAW-HW process, double layers.

(Approx. 1X)

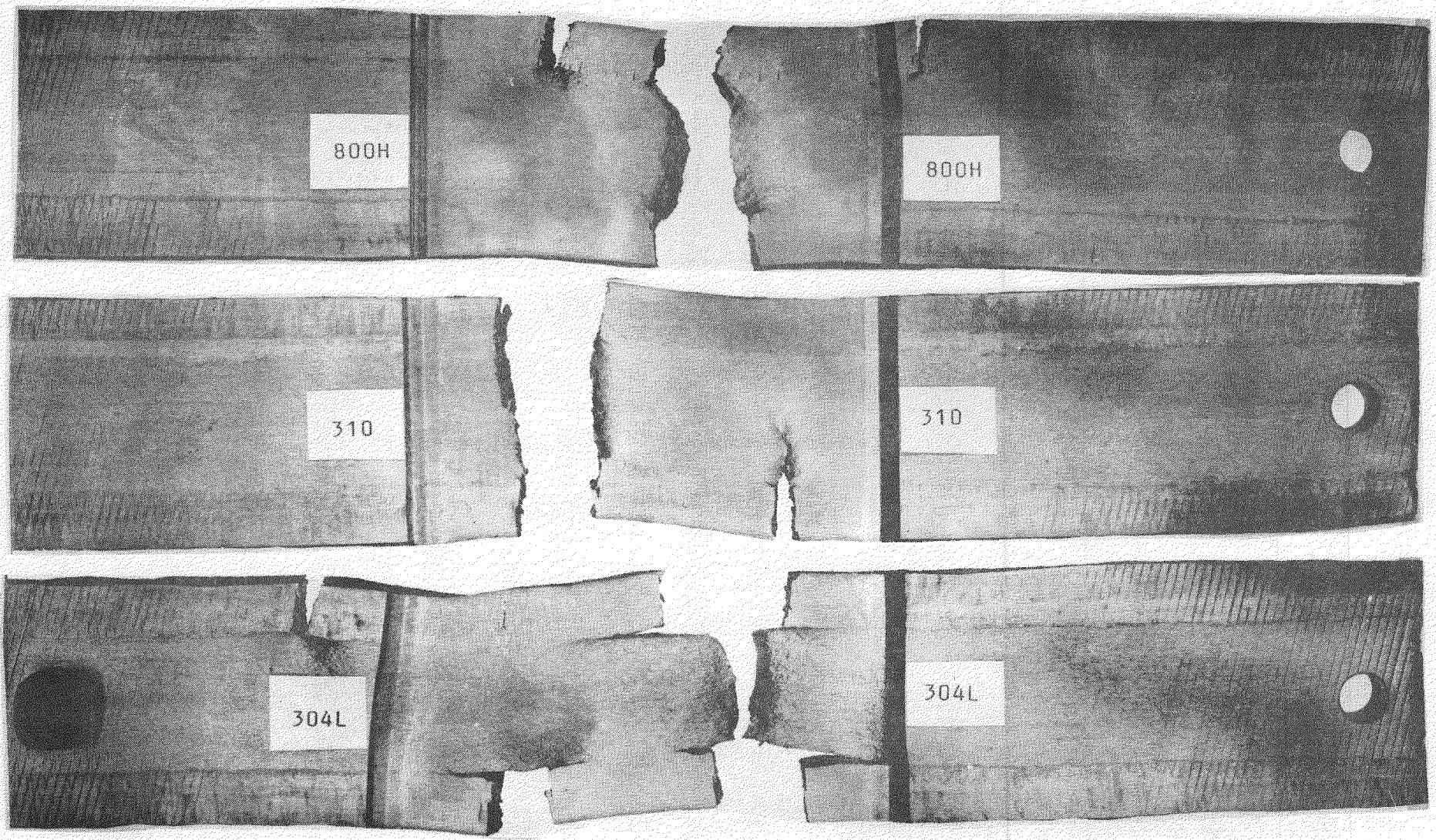


FIGURE 65: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, R139 overlays, SAW process, double layers. (Approx. 1X)

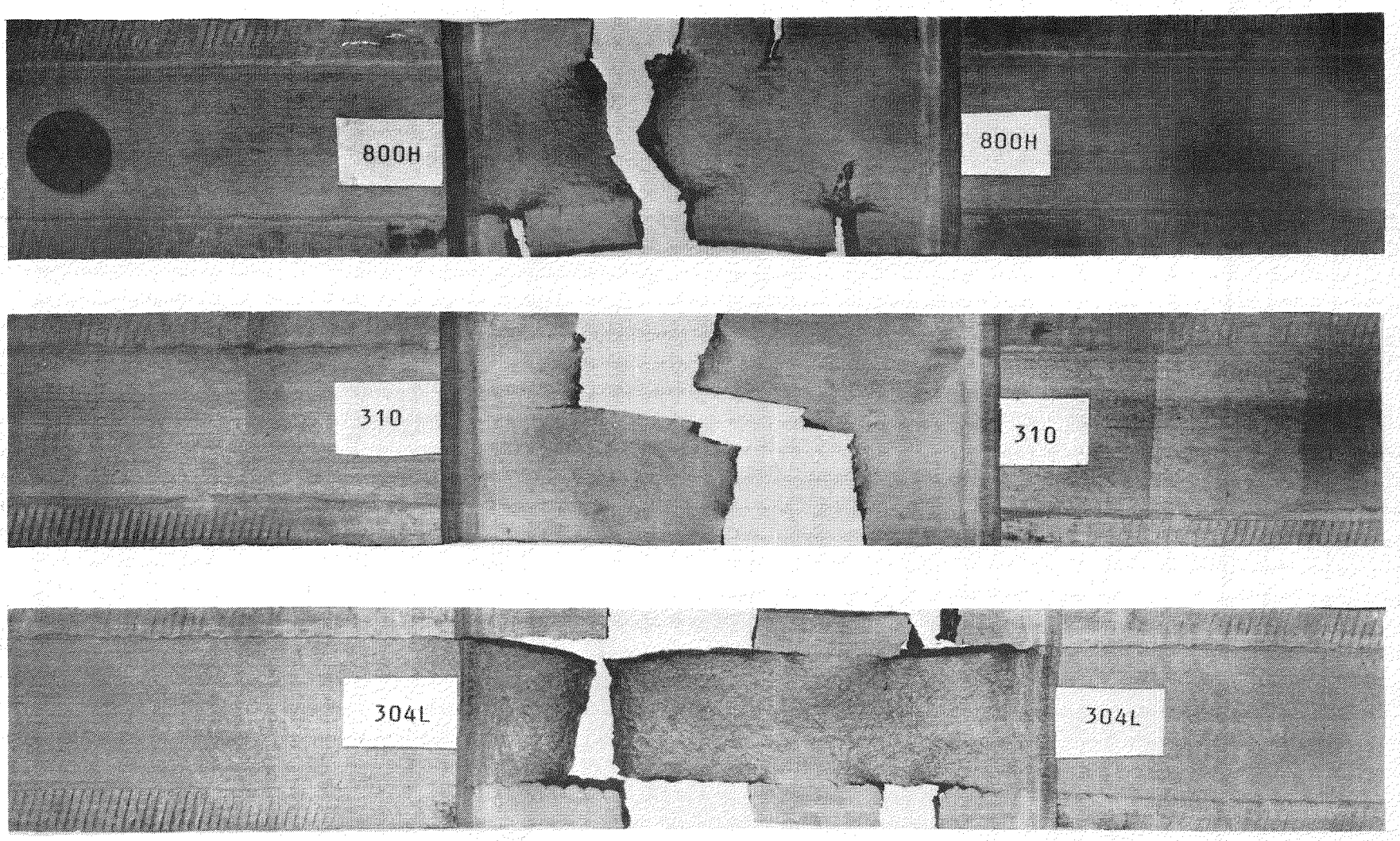


FIGURE 66: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, R139 overlays, GMAW process, double layers. (Approx. 1X)

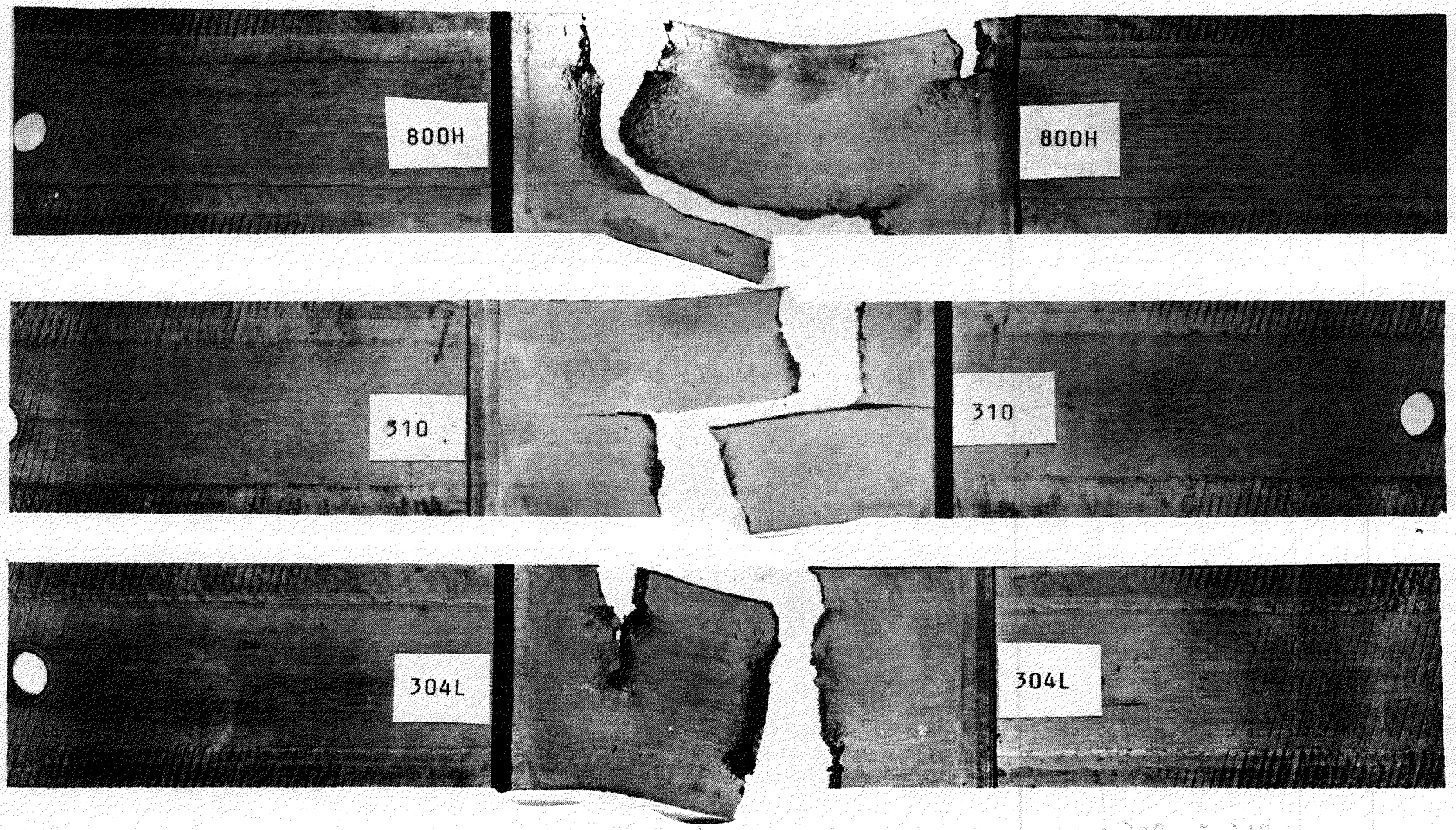
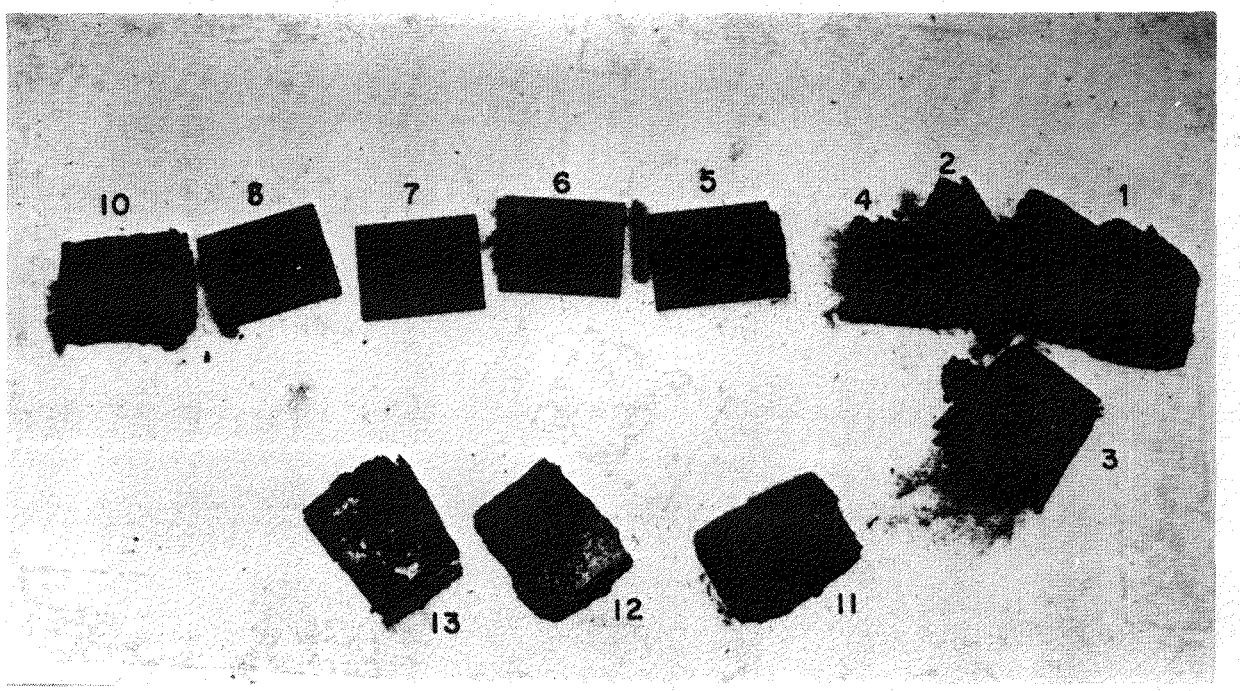


FIGURE 67: Effect of substrate on the fracture appearance of tensile specimens tested after exposure in a CGA, R139 overlays, GTAW-HW process, double layers. (Approx. 1X)

1-4 = 304L

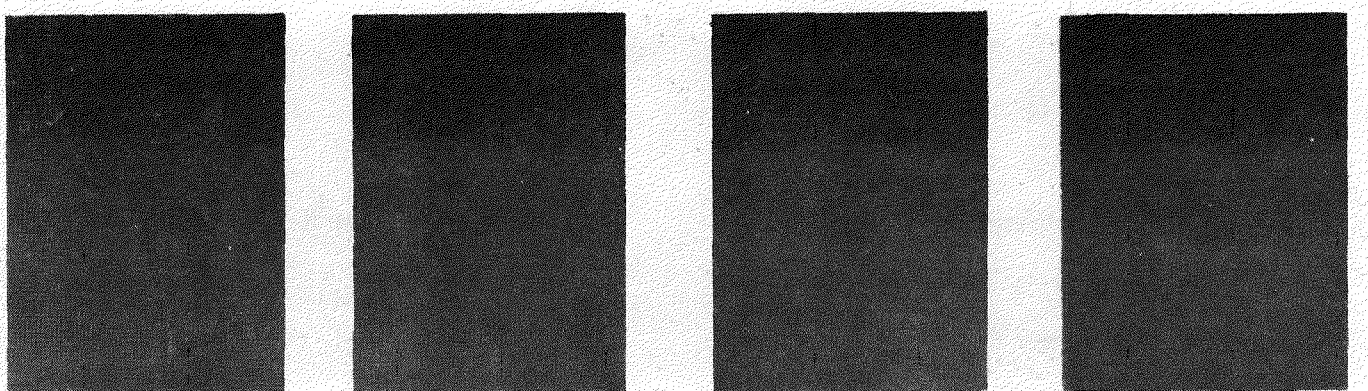
5-8 = 310

10-13 = 800H



Approx. 5/8X

FIGURE 68: Appearance of unwelded test coupons after removal from test cell.



Approx. 1.5X

FIGURE 69: Appearance of type 310 stainless steel samples after exposure to coal gasifier atmosphere; samples 5 through 8, left to right.

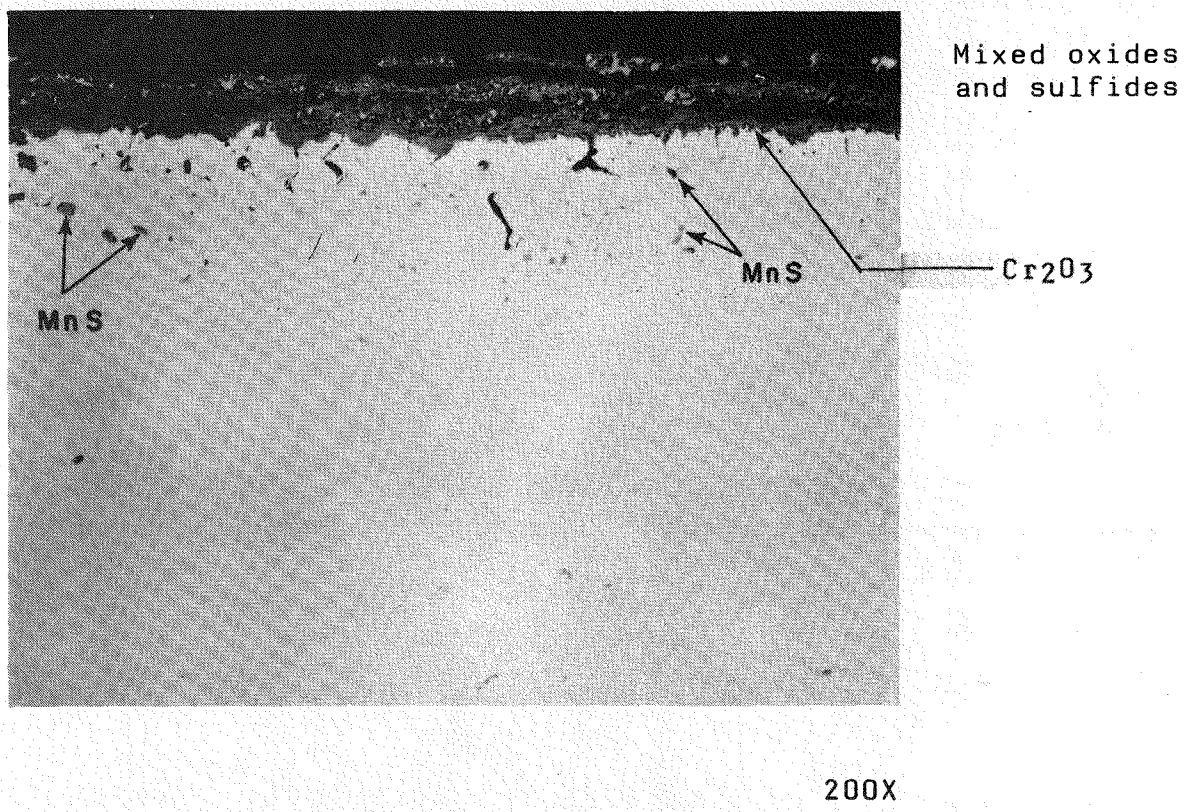
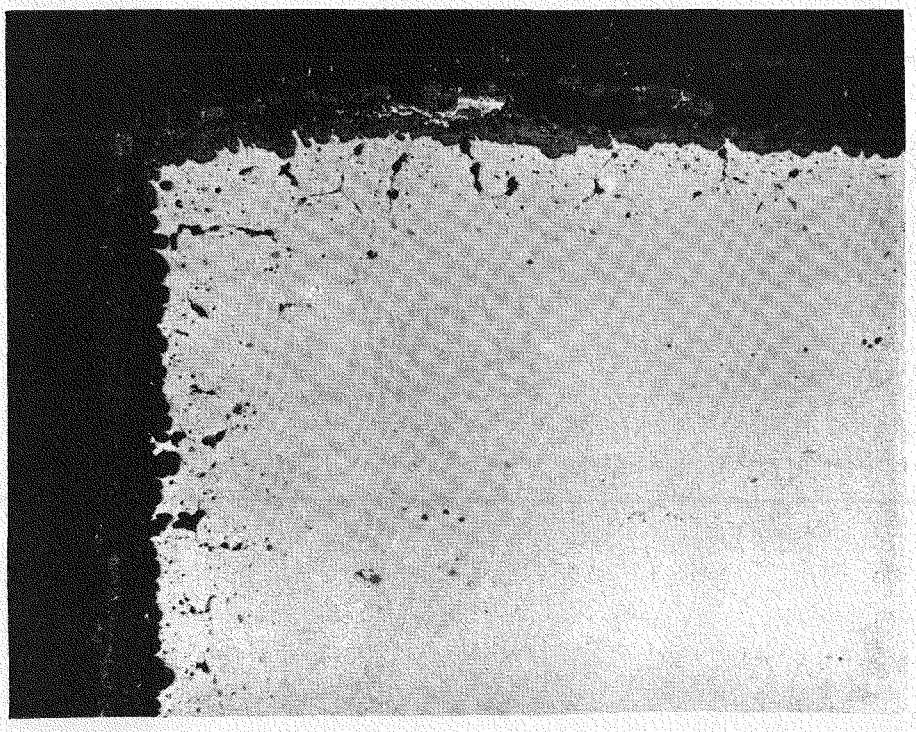
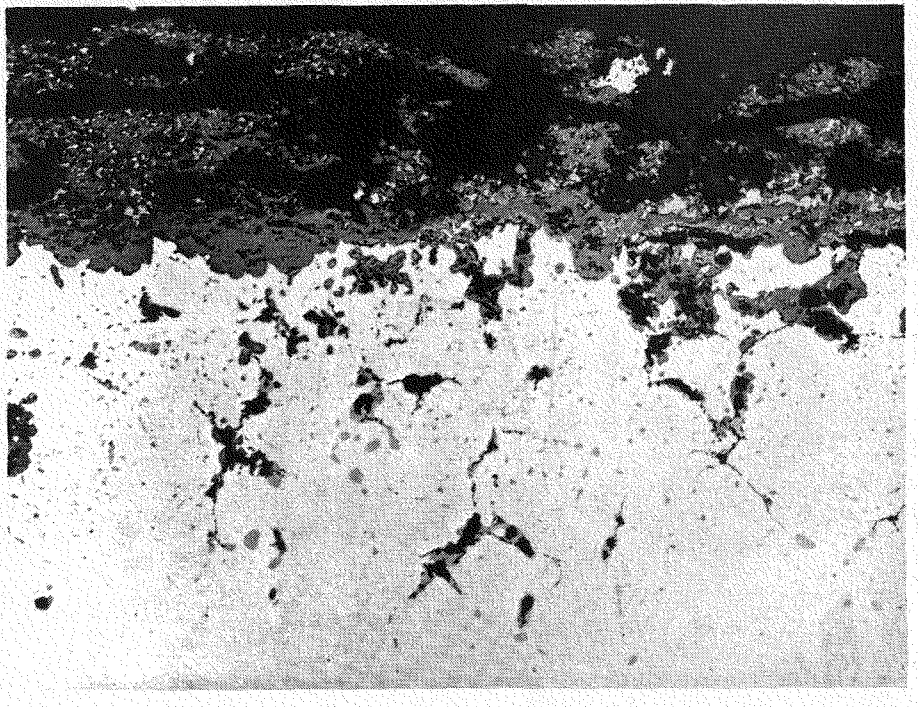


FIGURE 70: Structure of CGA exposed type 310 stainless steel sample 7.
Unetched

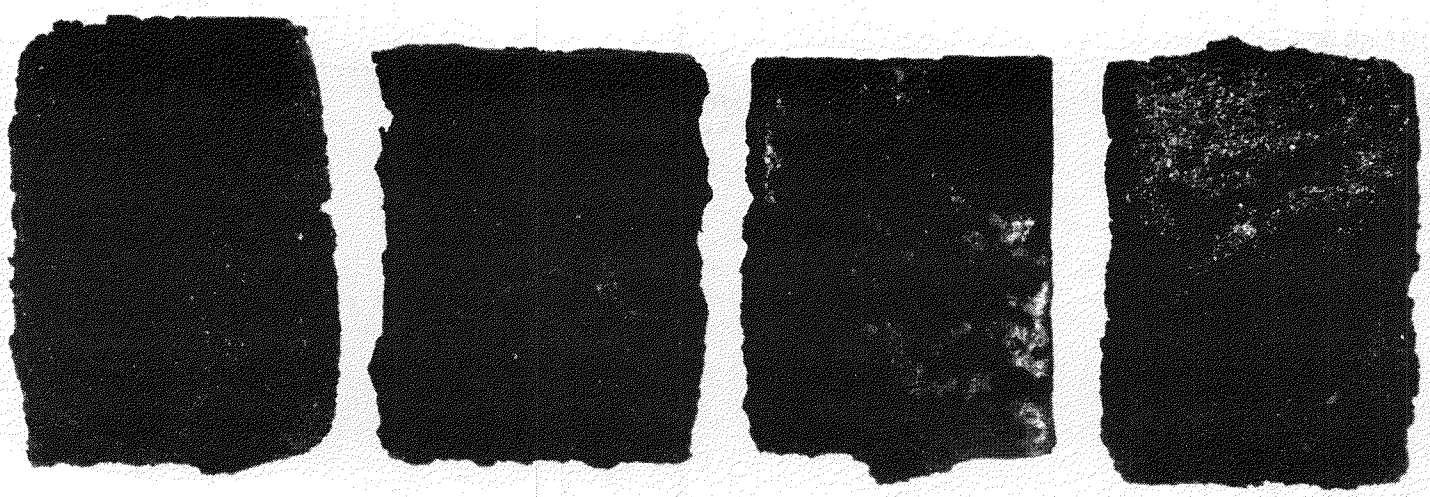


(a) 100X



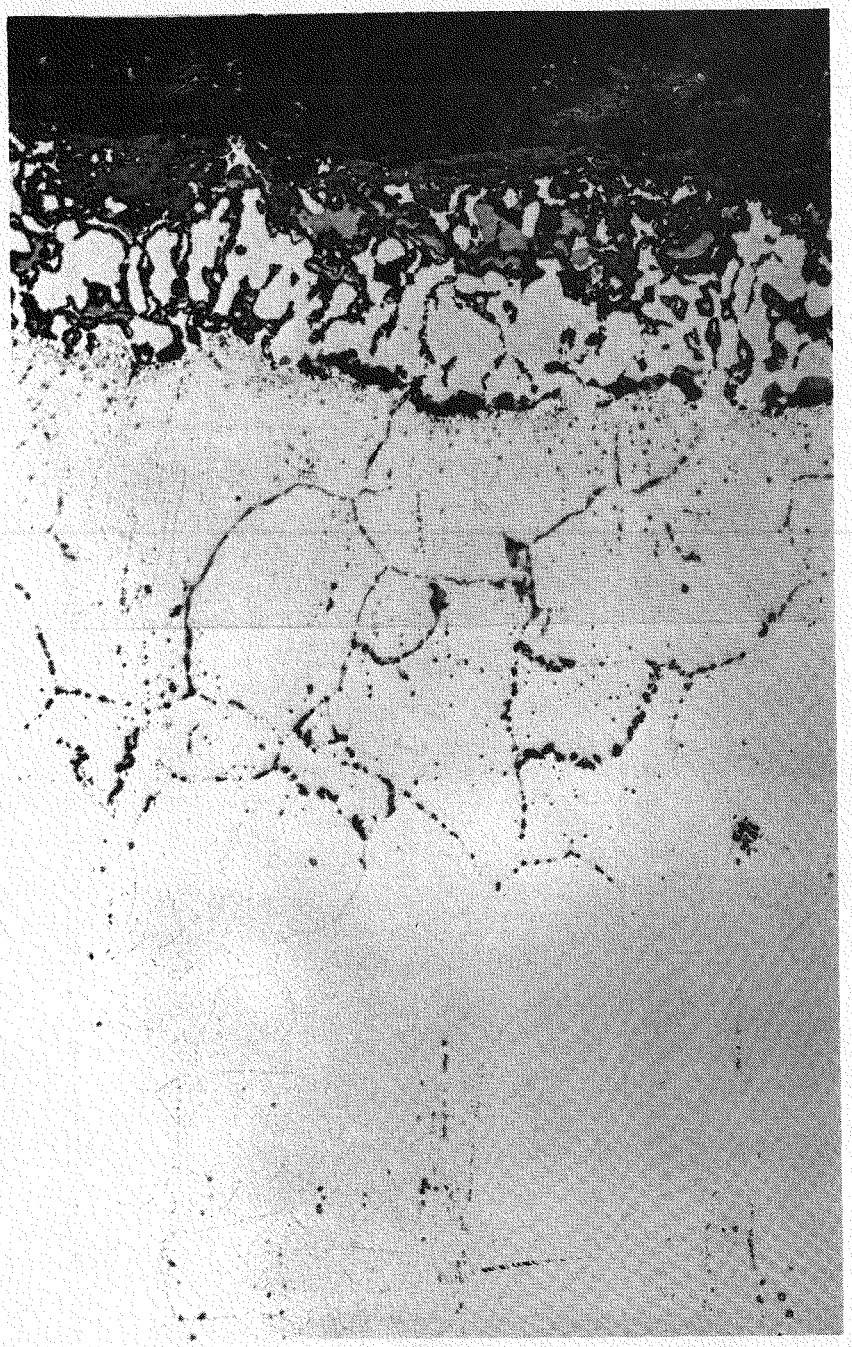
(b) 200X

FIGURE 71: Structures of sample 310-5. Continuous chromia has not formed. Note solid subscale sulfides and delta ferrite.



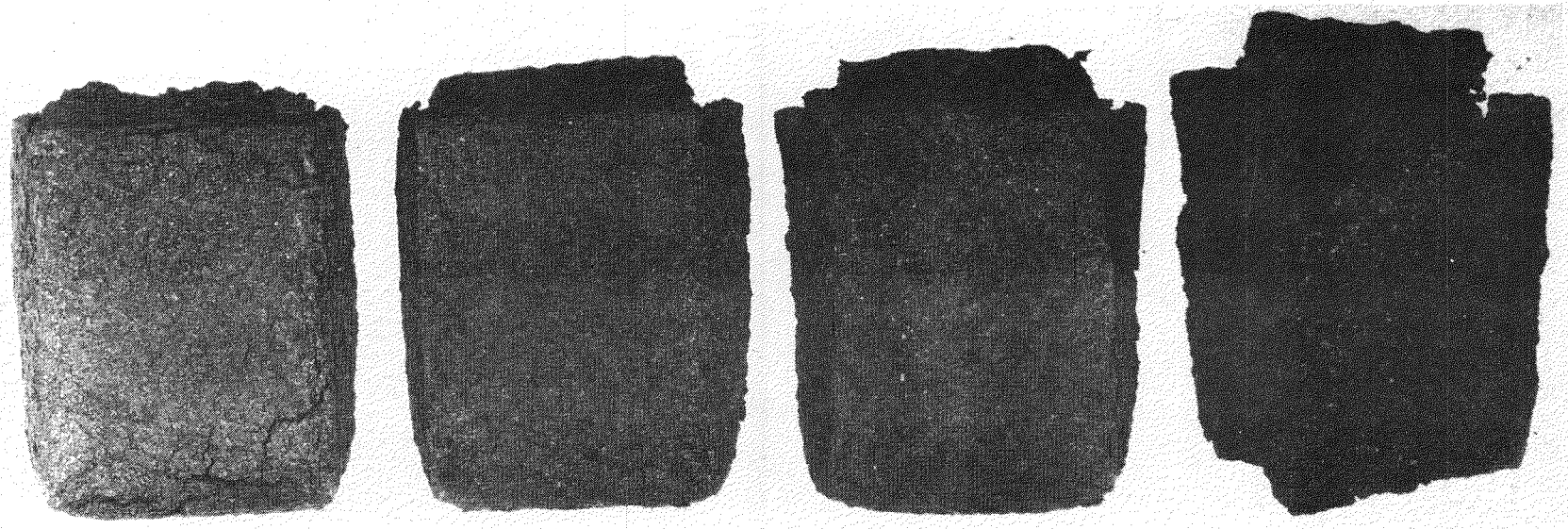
Approx. 1.5X

FIGURE 72: Appearance of CGA exposed samples of INCOLOY alloy 800H.



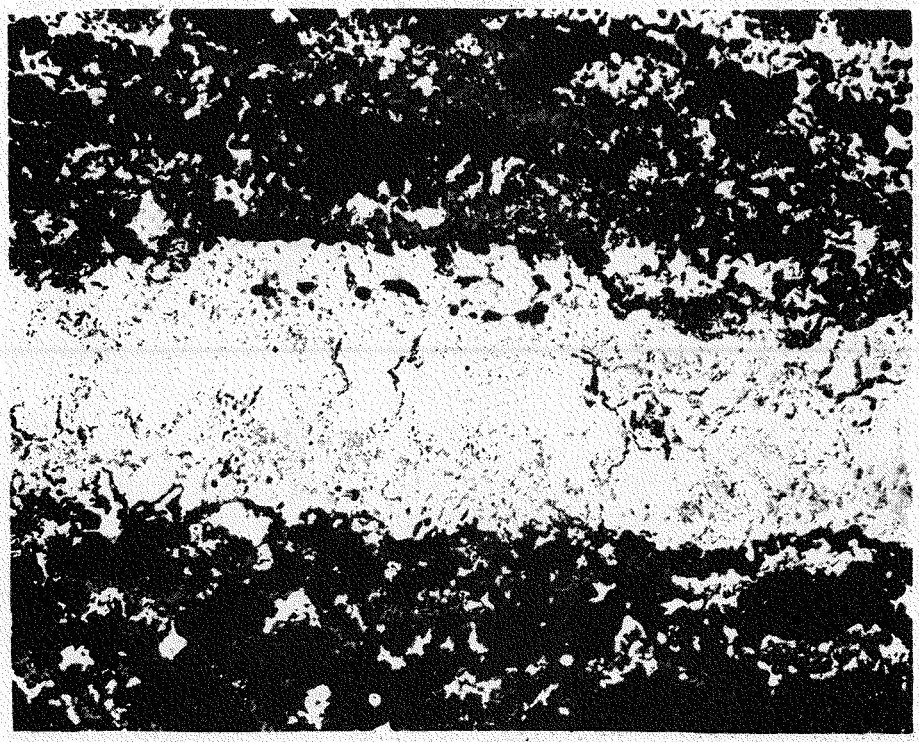
50X

FIGURE 73: Microstructure of sample 10, INCOLOY alloy 800H after exposure in CGA.
Unetched



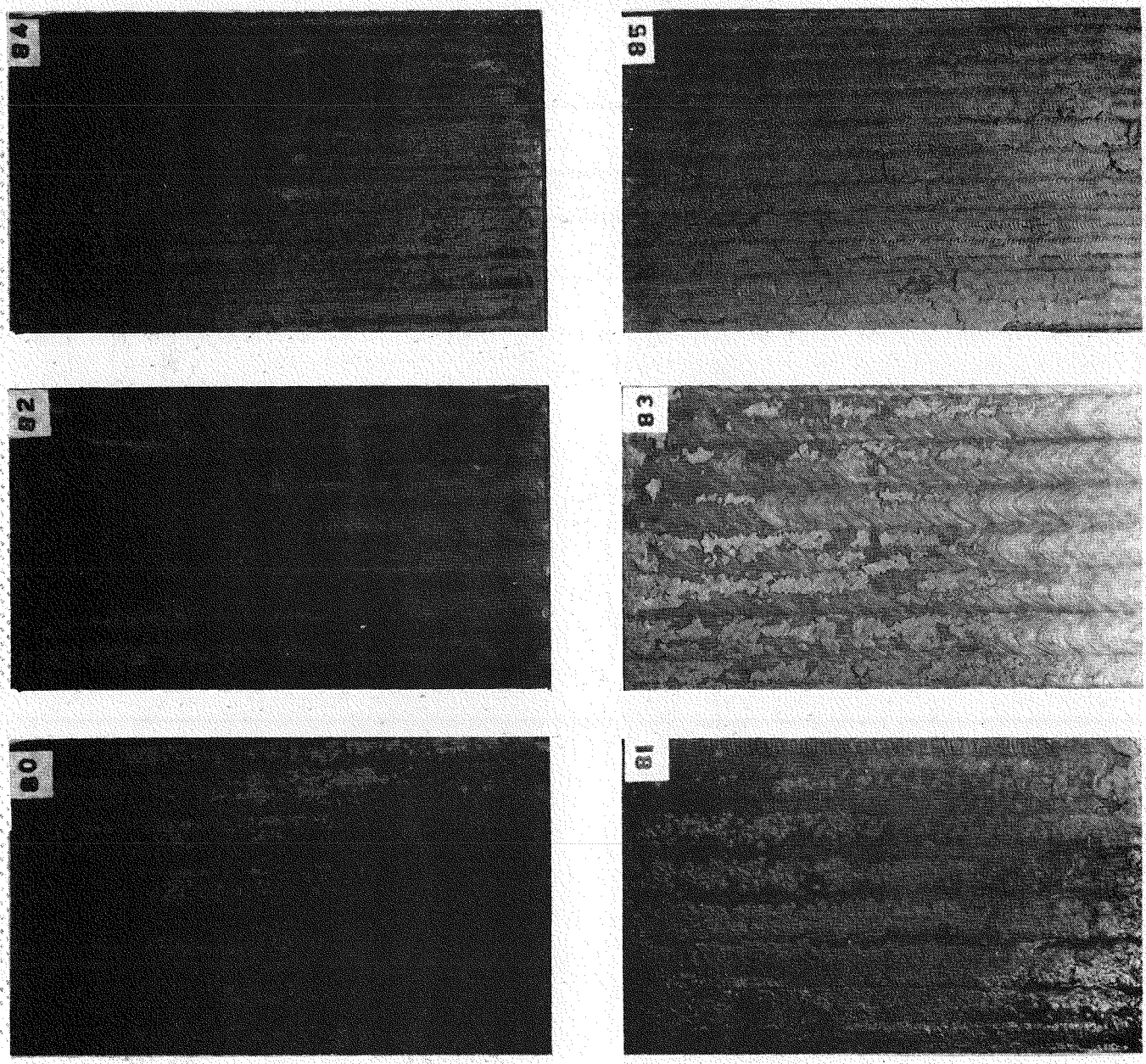
Approx. 1.5X

FIGURE 74: Appearance of type 304L samples exposed to the CGA.



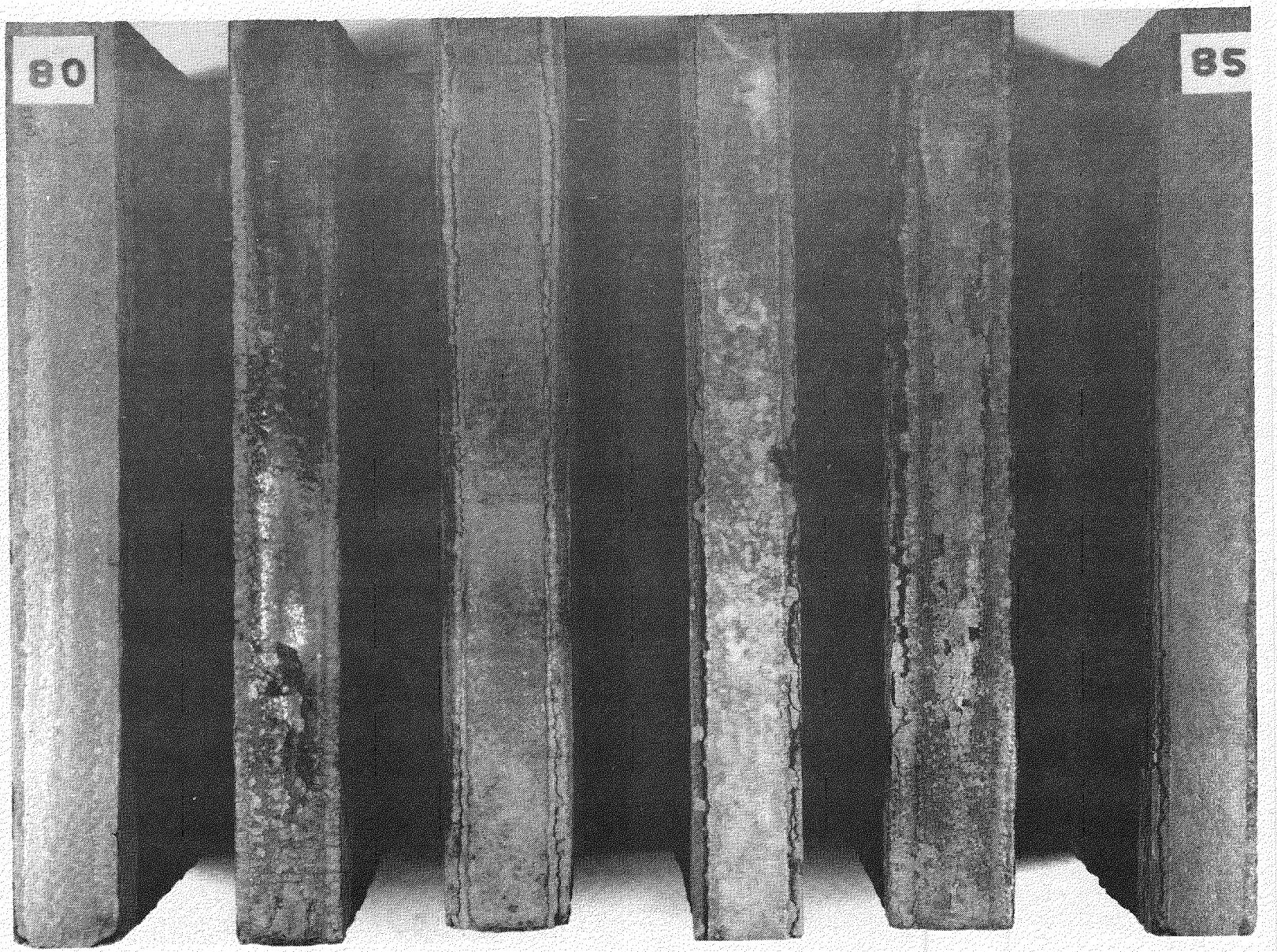
20X

FIGURE 75: Partial section of exposed 304L coupon 304-1. Unetched



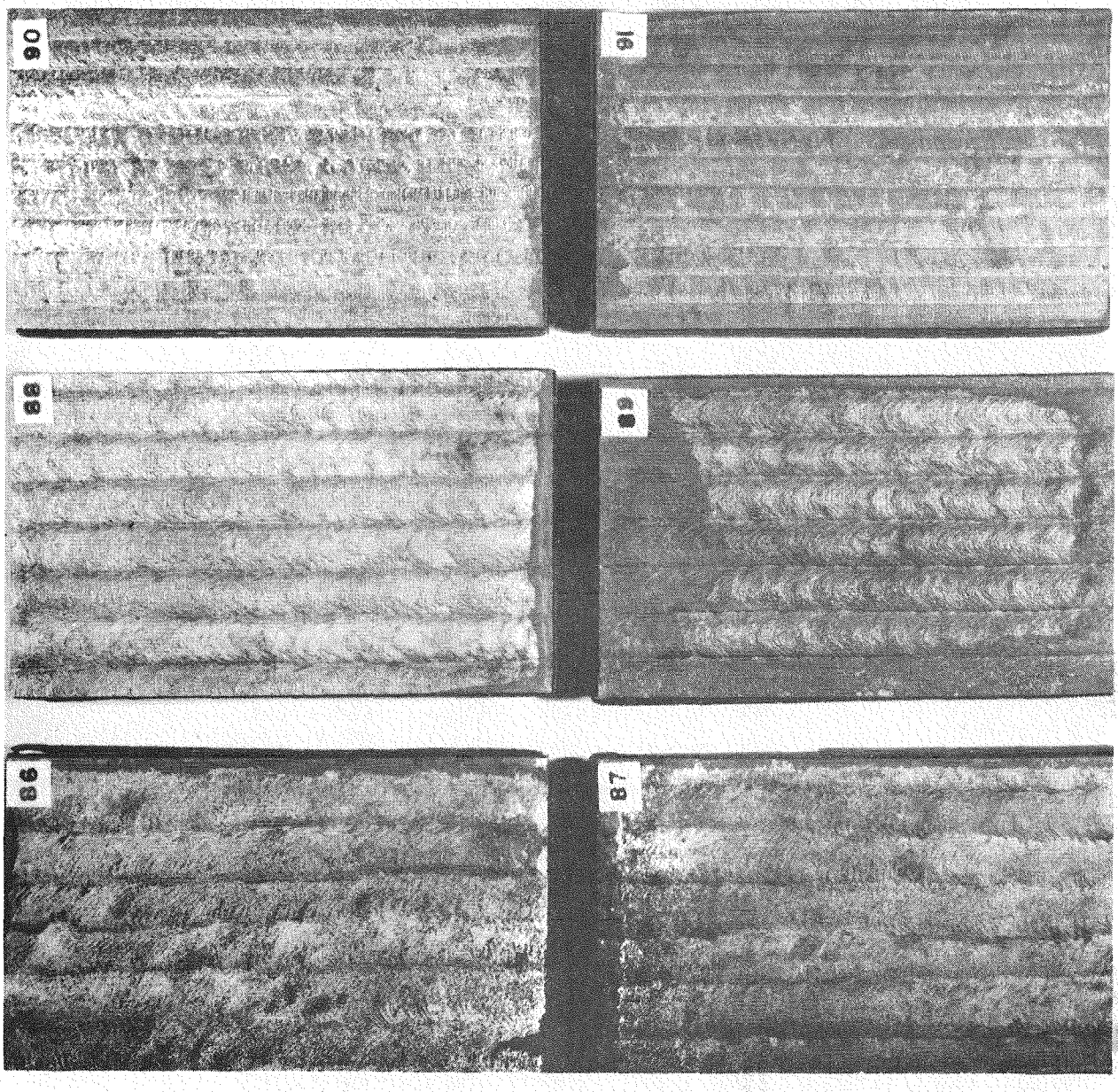
Approx. 3/10X

FIGURE 76: AWS-ER309 overlays on 304L after exposure in a CGA.



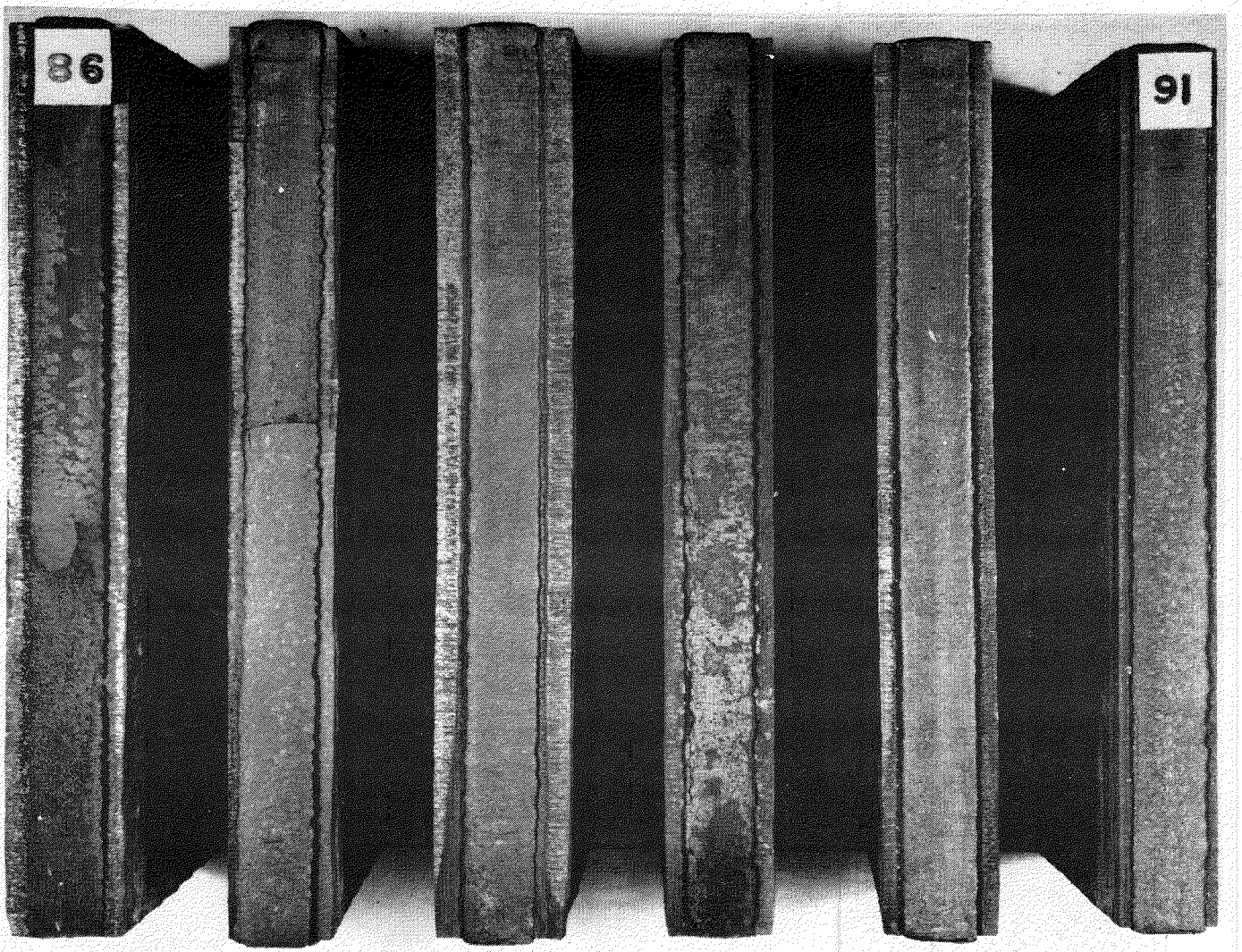
Approx. 1/2X

FIGURE 77: Edge view, of AWS-ER309 - 304L weldments after exposure in a CGA.



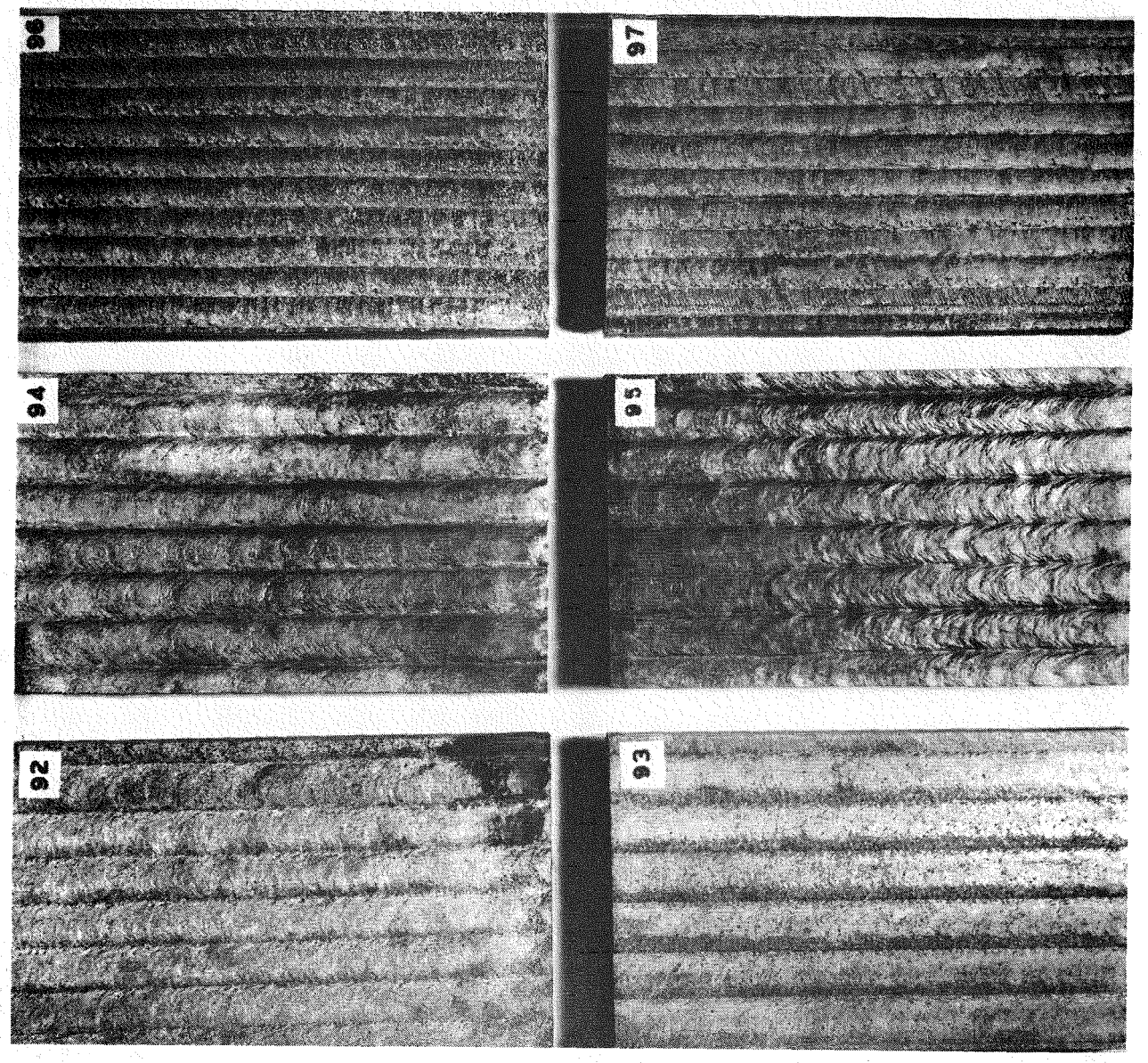
Approx. 3/10X

FIGURE 78: INCONEL Filler Metal 72 overlays on 304L after exposure in a CGA.



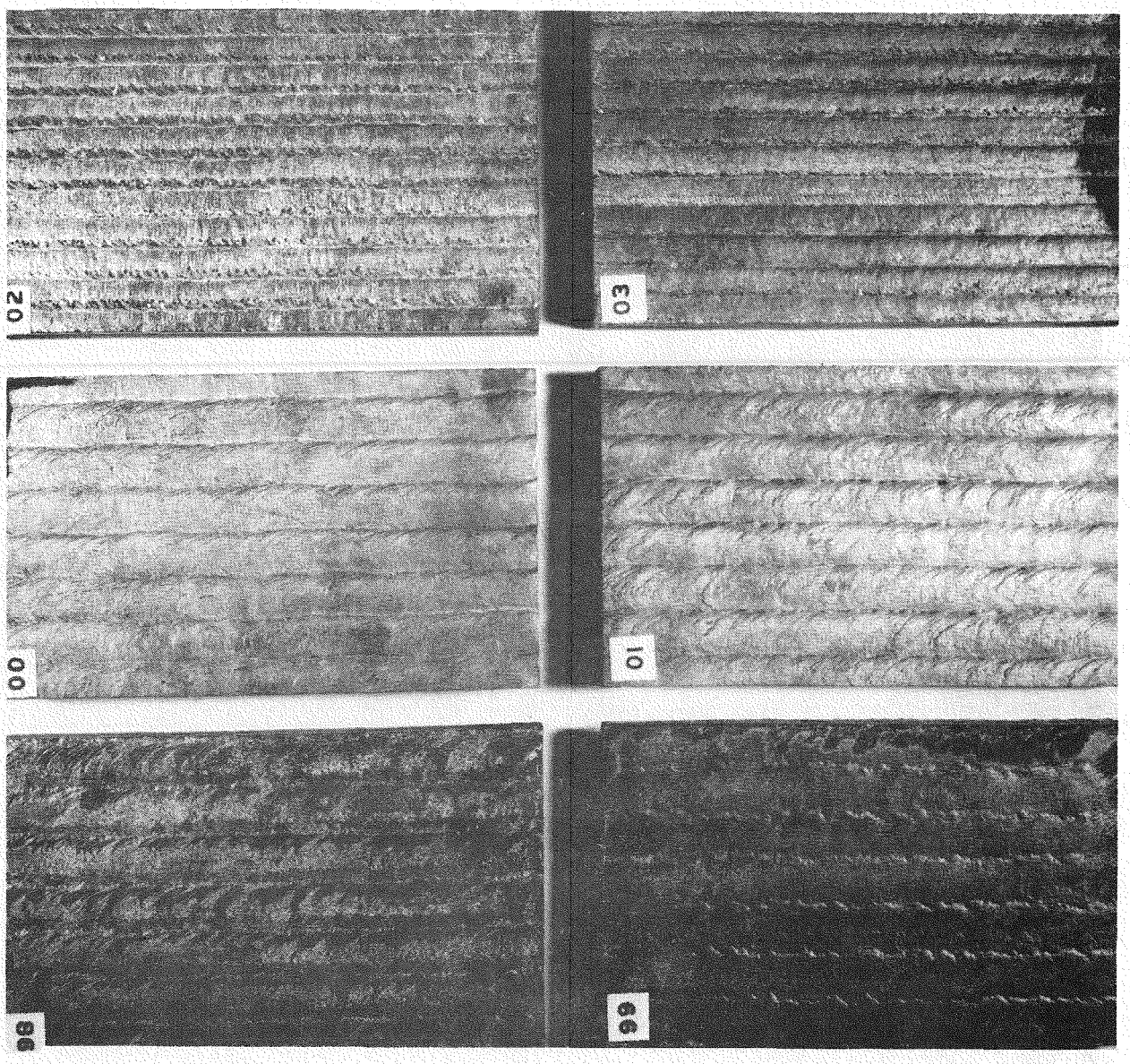
Approx. 1/2X

FIGURE 79: Edge view, INCONEL Filler Metal 72 - 304L weldments after exposure in a CGA.



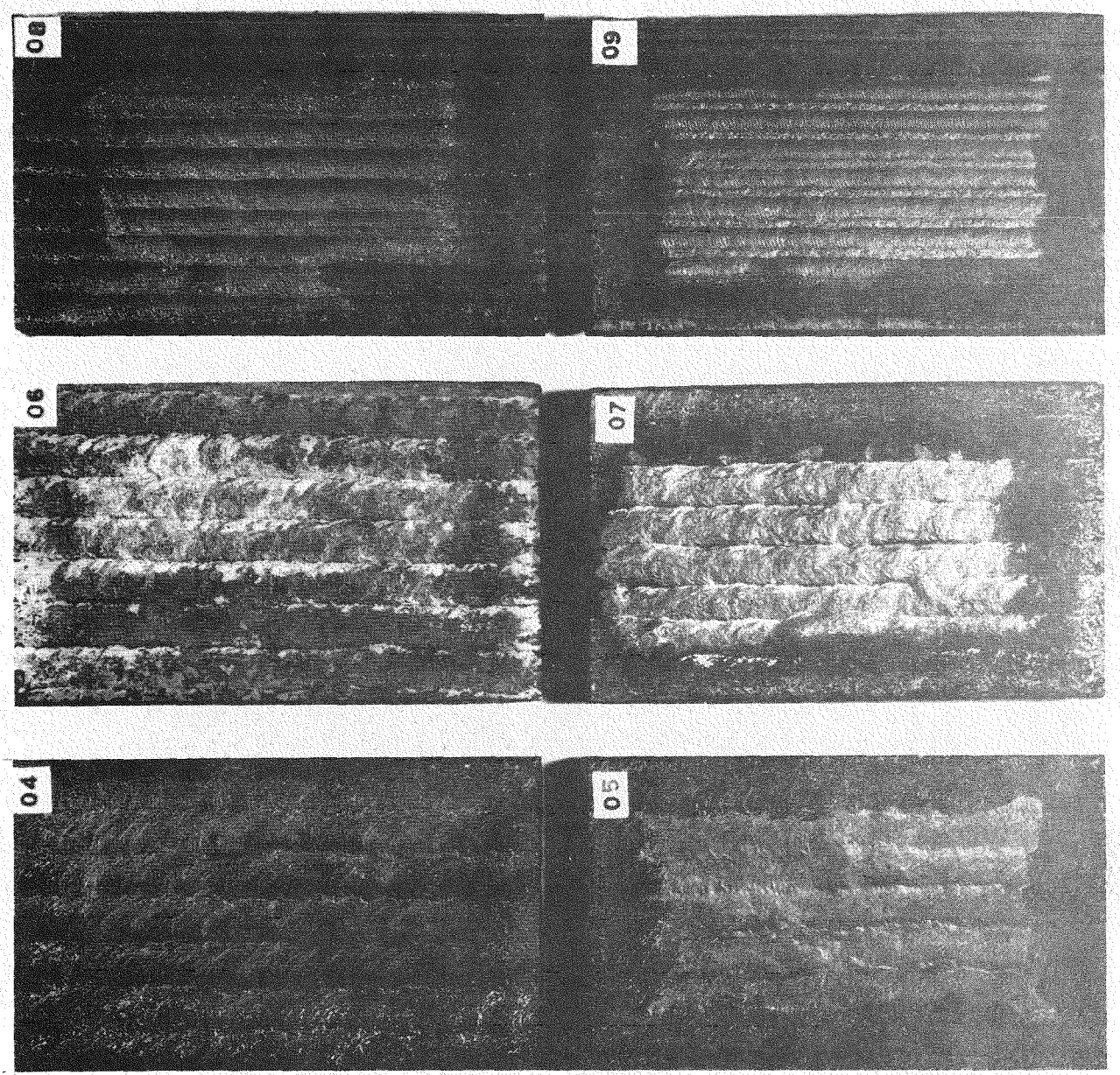
Approx. 3/10X

FIGURE 80: INCONEL Filler Metal 72 overlays on 310SS after exposure in a CGA.



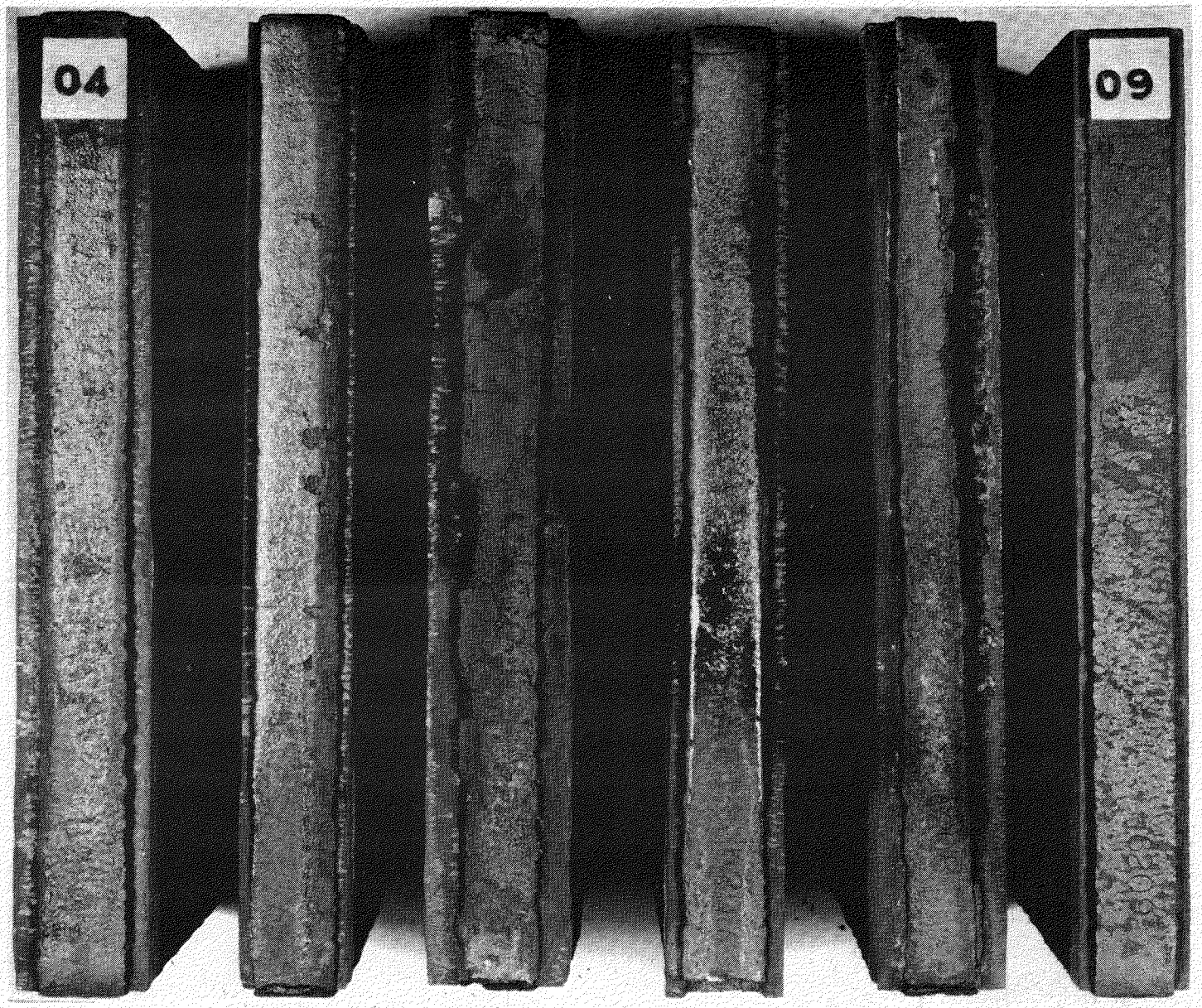
Approx. 3/10X

FIGURE 81: INCONEL Filler Metal 72 overlays on INCOLOY alloy 800H after exposure in a CGA.



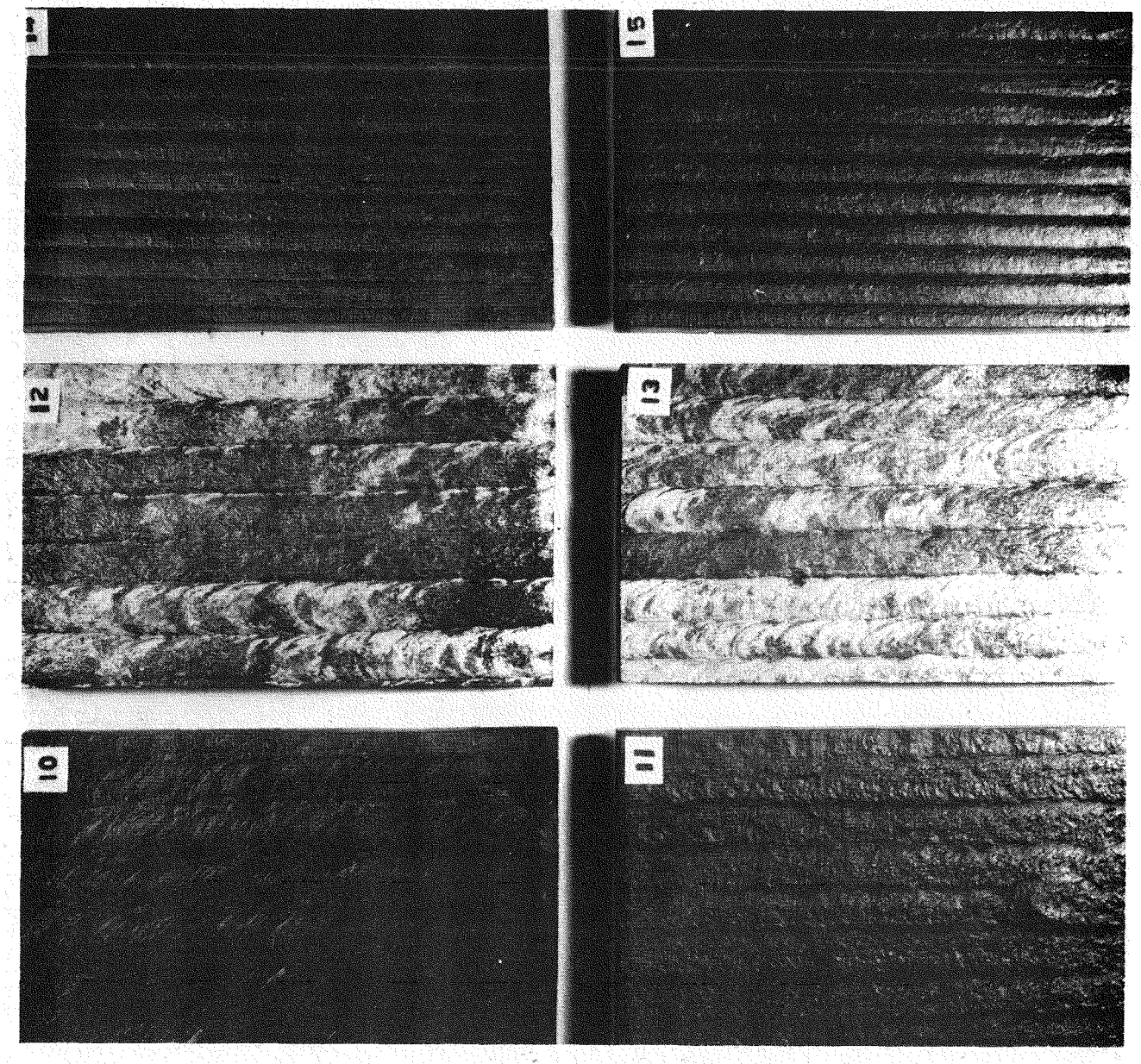
Approx. 3/10X

FIGURE 82: Filler Metal R139 overlays on 304L after after exposure in a CGA.



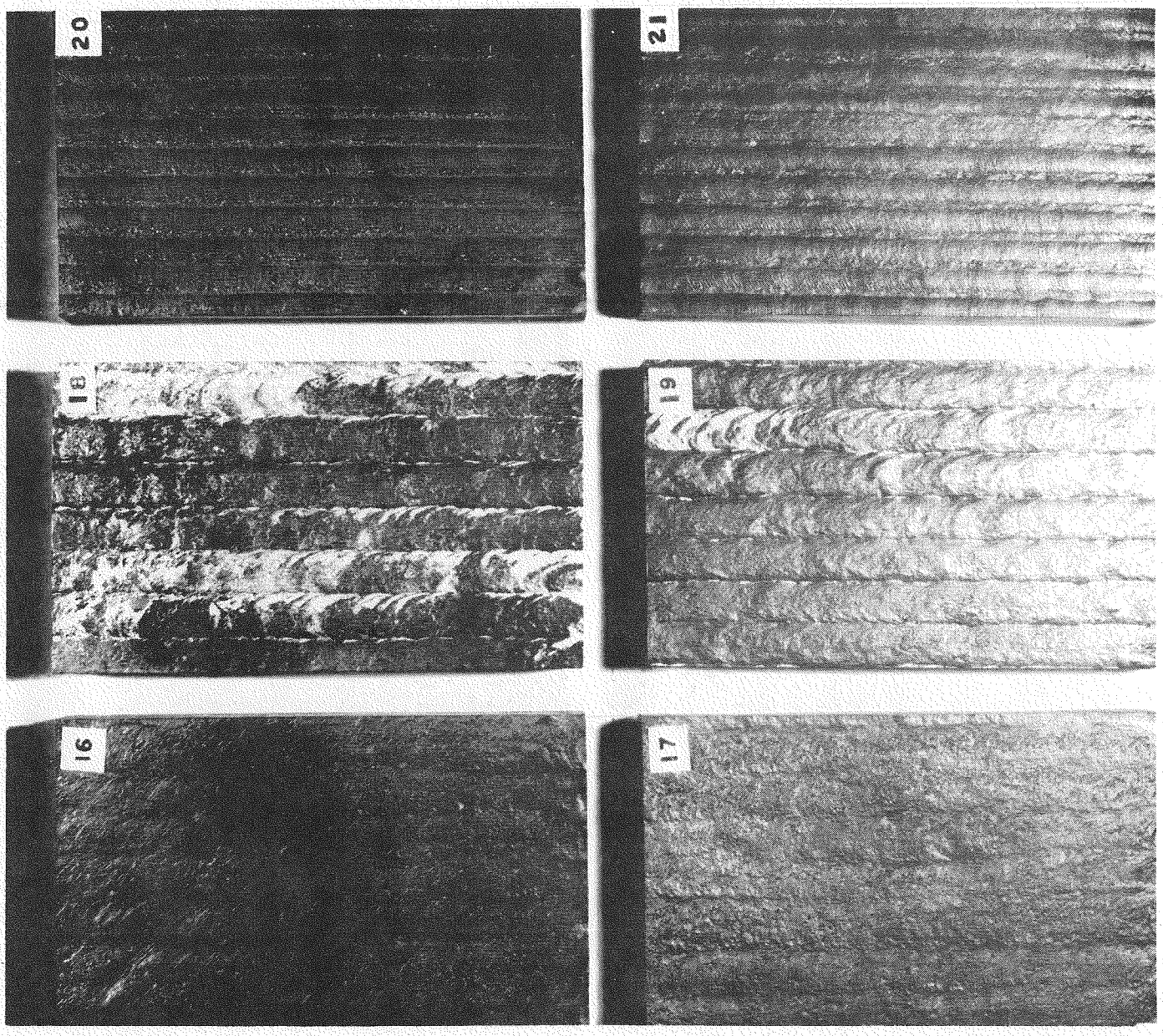
Approx. 1/2X

FIGURE 83: Edge view, Filler Metal R139 - 304L weldments after exposure in a CGA.



Approx. 3/10X

FIGURE 84: Filler Metal R139 overlays on 310SS after exposure in a CGA.



Approx. 3/10X

FIGURE 85: Filler Metal R139 overlays on INCOLOY alloy 800H after exposure in a CGA.

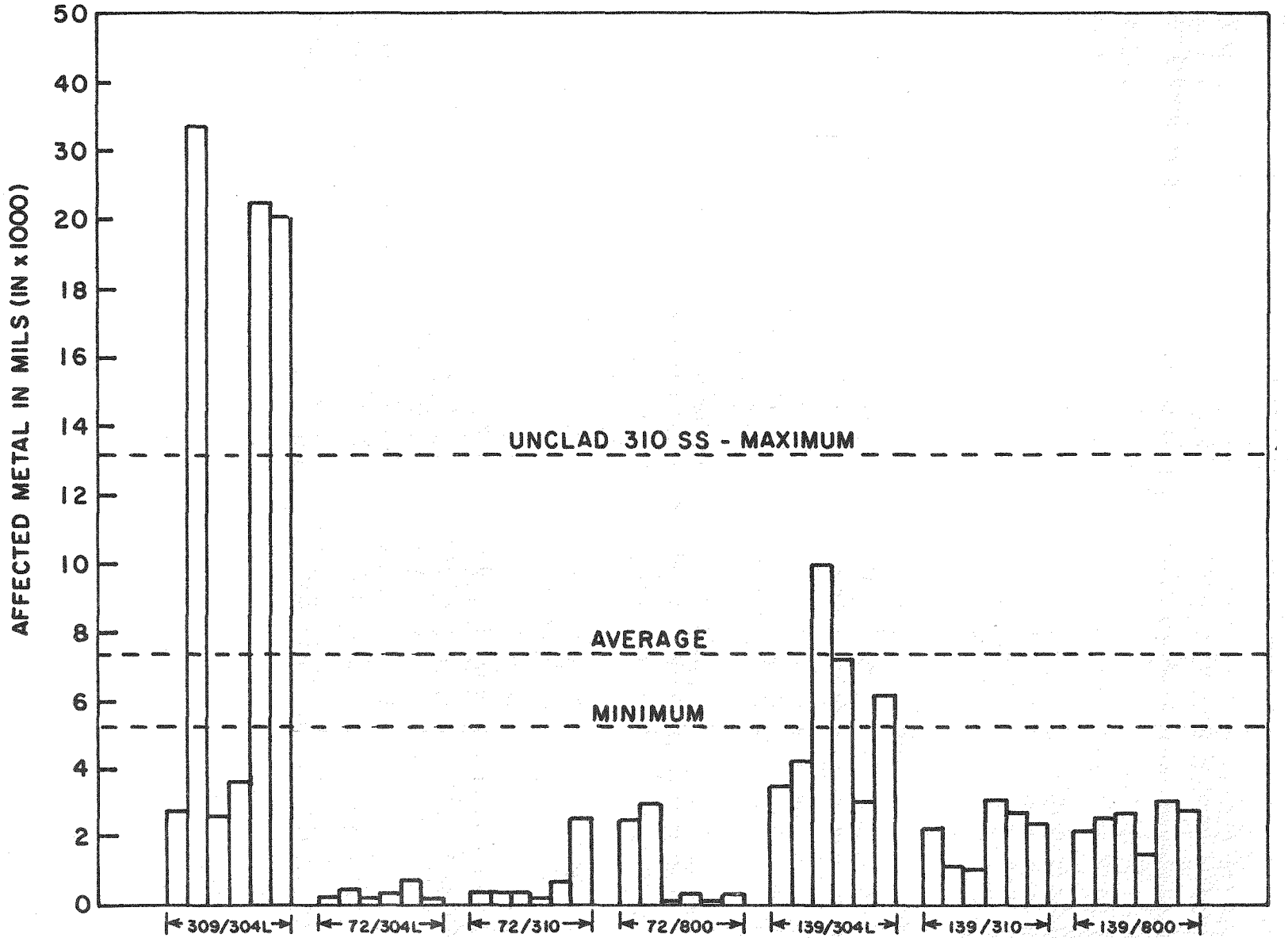


FIGURE 86 - MAXIMUM DEPTH OF AFFECTED METAL IN OVERLAYS AT A SINGLE REFERENCE POINT COMPARED TO UNCLAD 310 STAINLESS STEEL.

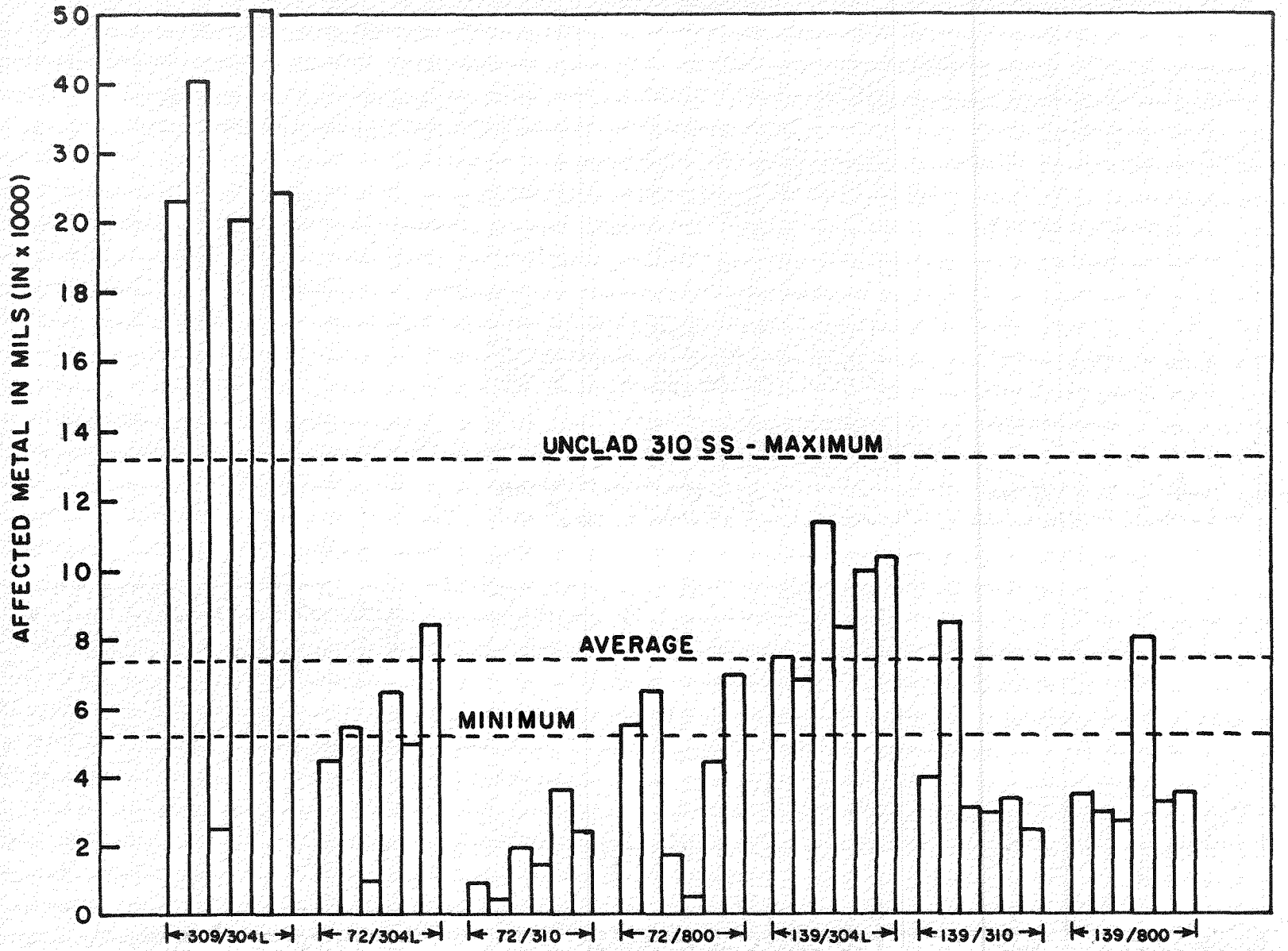
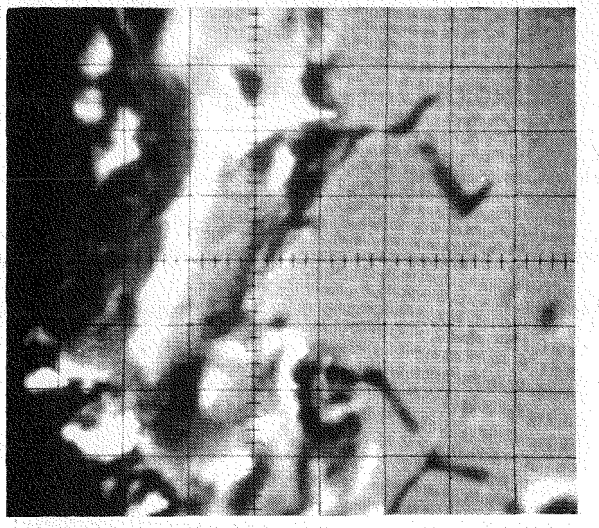
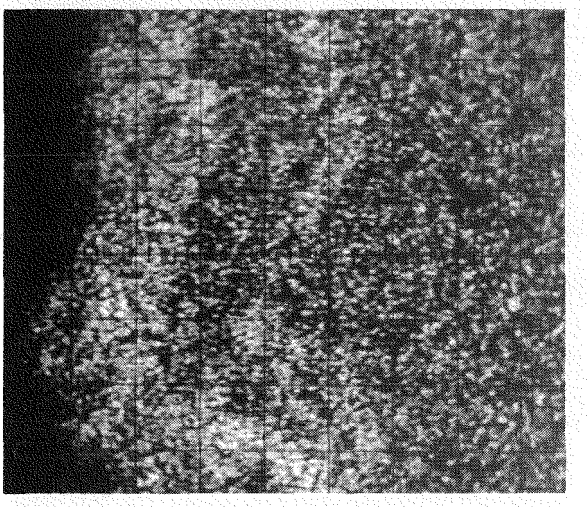


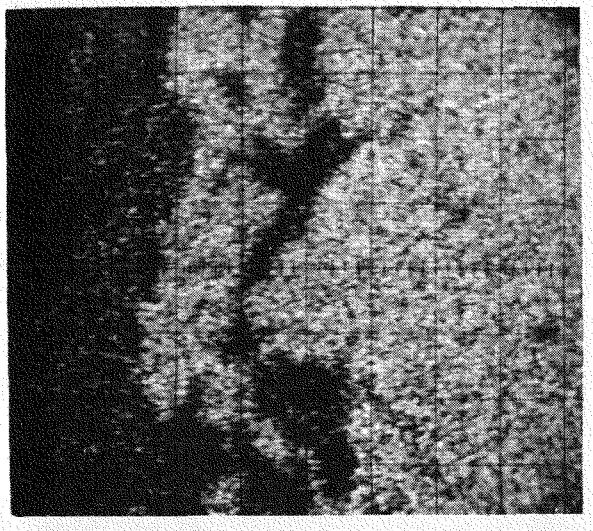
FIGURE 87 - MAXIMUM DEPTH OF AFFECTED METAL IN OVERLAYS COMPARED TO UNCLAD 310 STAINLESS STEEL - 25.4mm (1 inch) SPECIMEN.



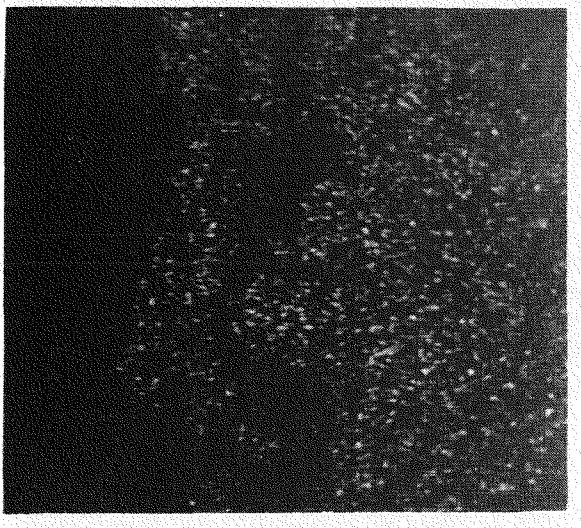
6180 1000X



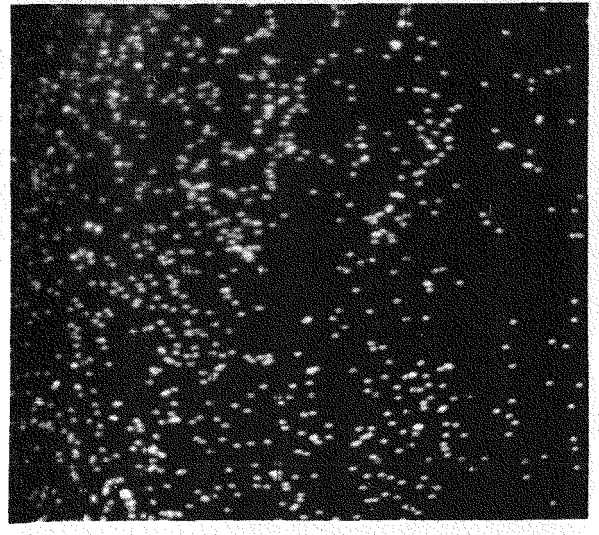
6180 Cr 1000X



6180 Fe 1000X



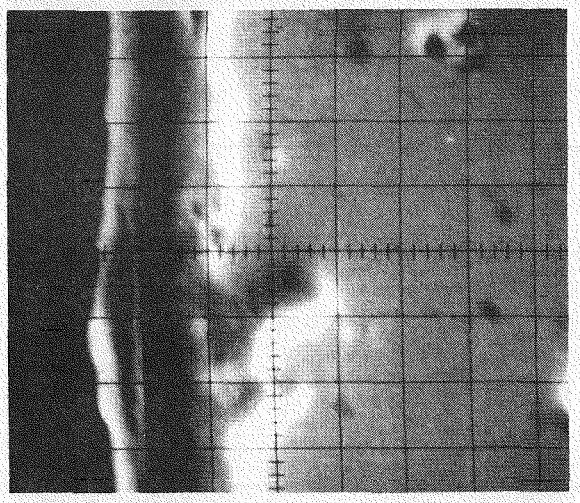
6180 Ni 1000X



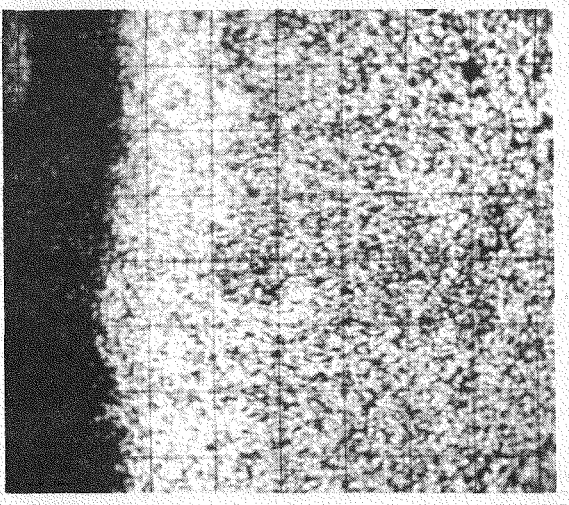
6180 Oxygen 1000X

Figure 88:

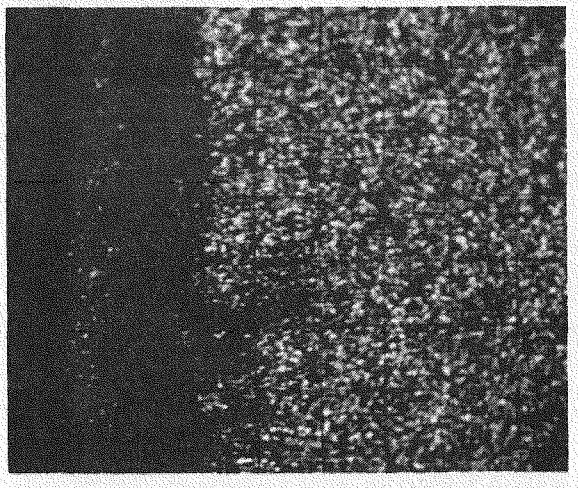
Kα x-ray images of scale and adjacent area of AWS-ER309 overlay from W6180 after exposure in a CGA, 304 L substrate, GMAW process, double layer.



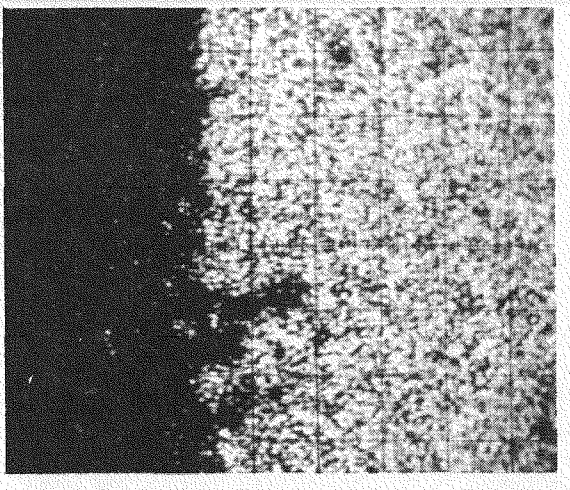
6190 1000X



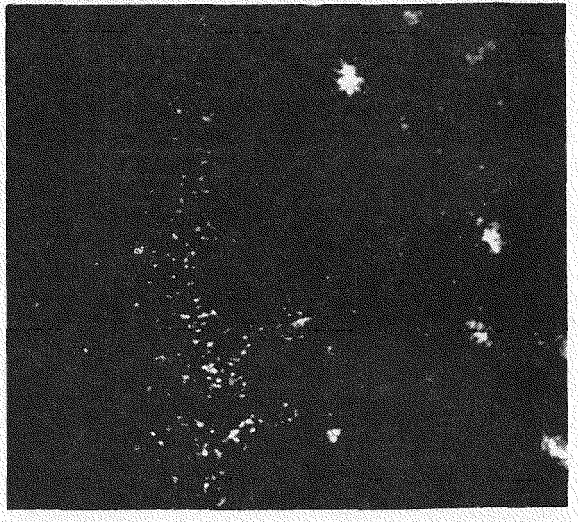
6190 Cr 1000X



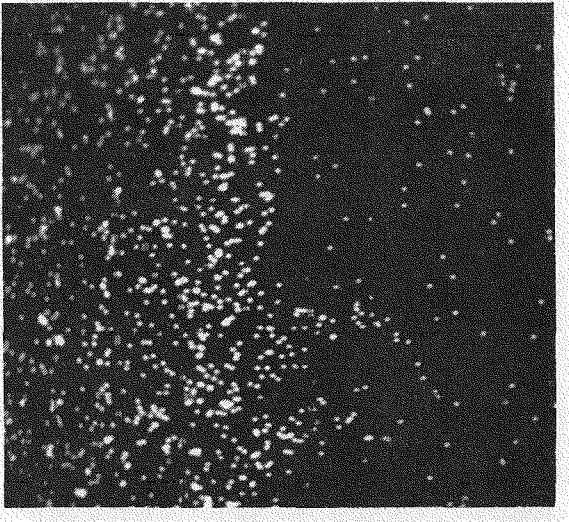
6190 Fe 1000X



6190 Ni 1000X

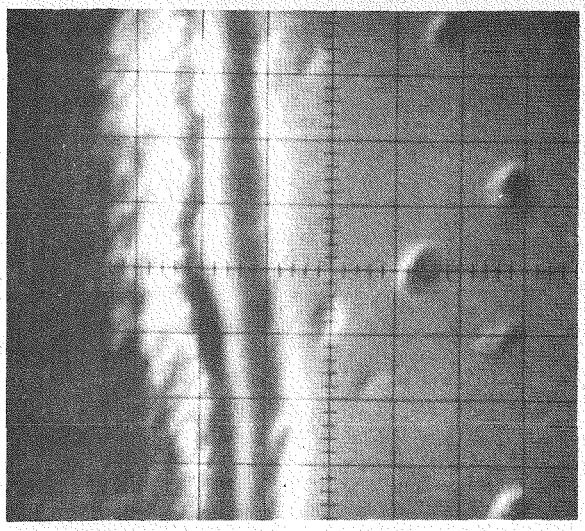


6190 Ti 1000X

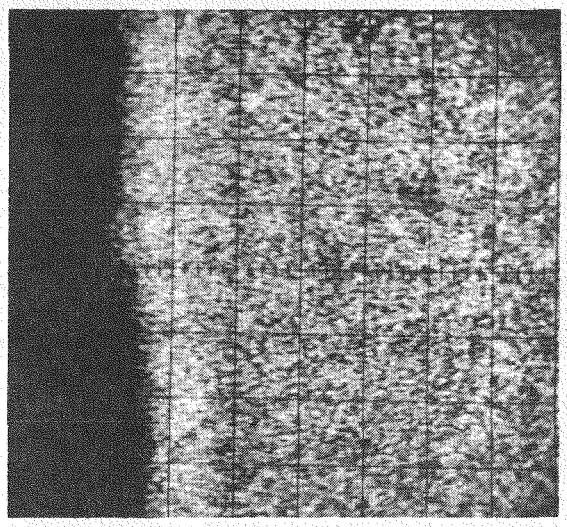


6190 Oxygen 1000X

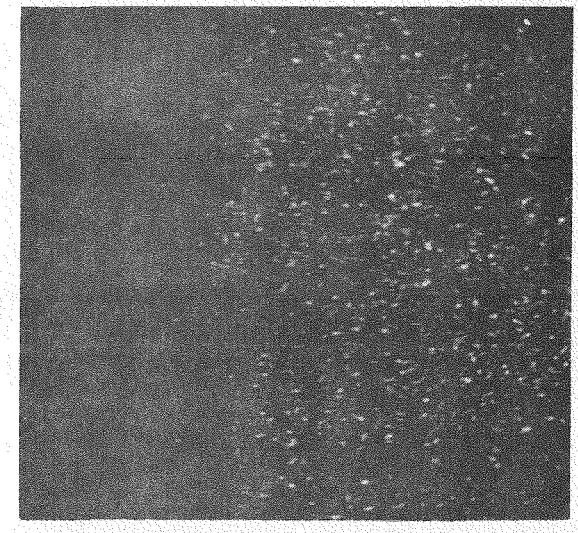
FIGURE 89: Kα x-ray images of scale and adjacent area of INCONEL Filler Metal 72 overlay from W6190 after exposure in a CGA, 304L substrate, GTAW-HW process, double layer.



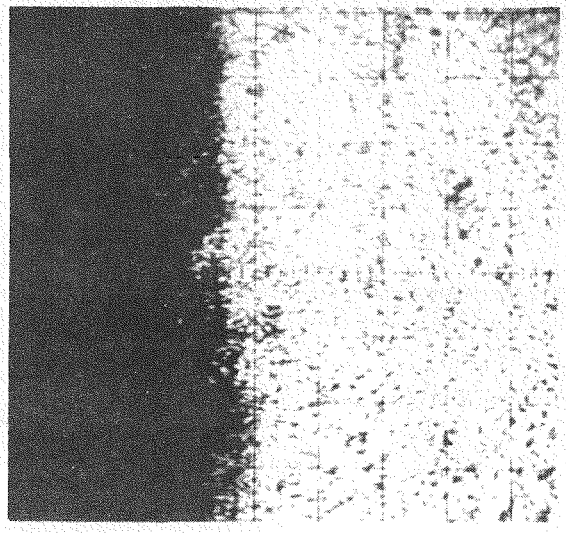
6194 1000X



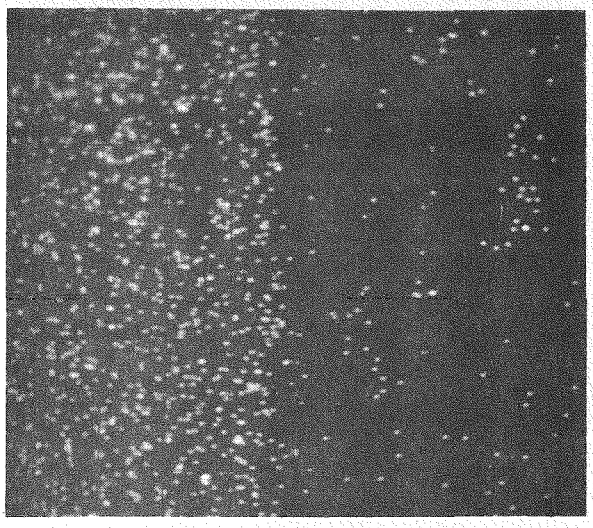
6194 Cr 1000X



6194 Fe 1000X



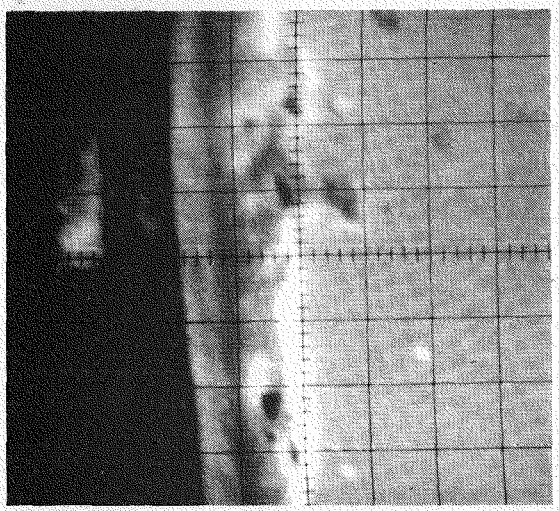
6194 Ni 1000X



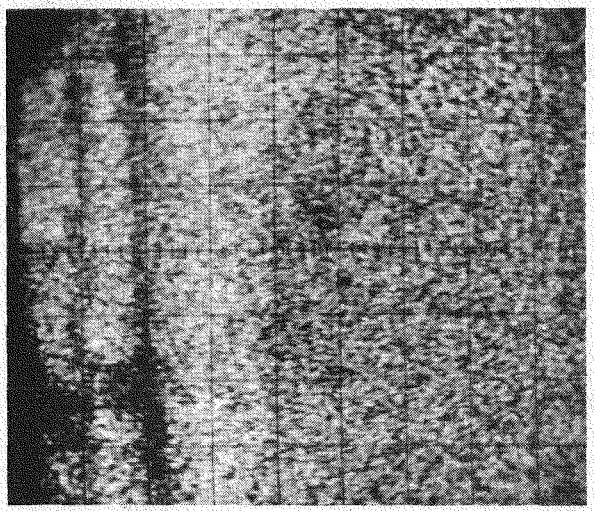
6180 Oxygen 1000X

Figure 90:

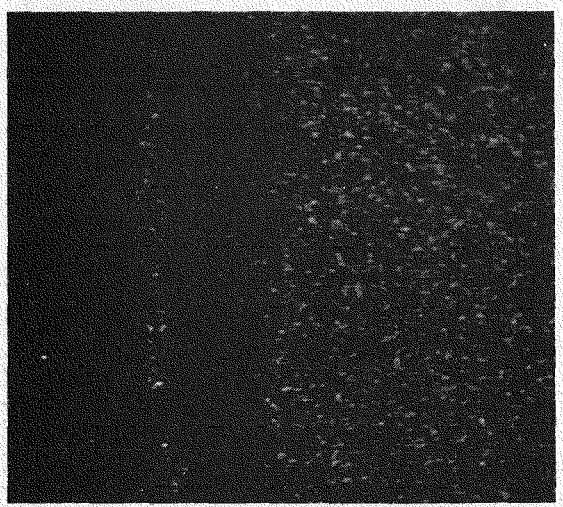
K_α x-ray images of scale and adjacent area of INCONEL Filler Metal 72 overlay from W6194 after exposure in a CGA, 310SS substrate, SAW process, double layer.



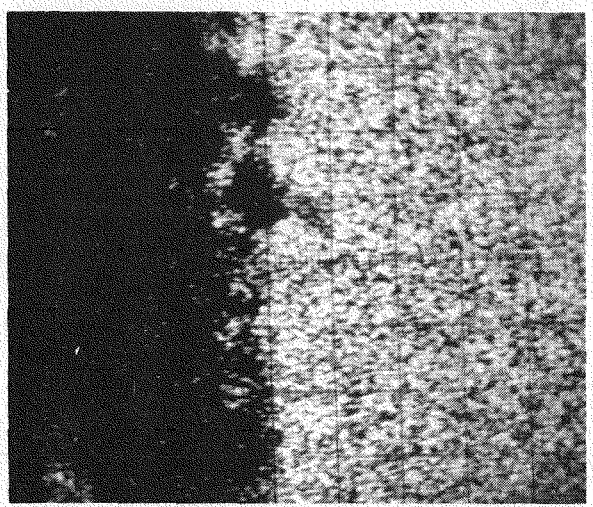
6198 1000X



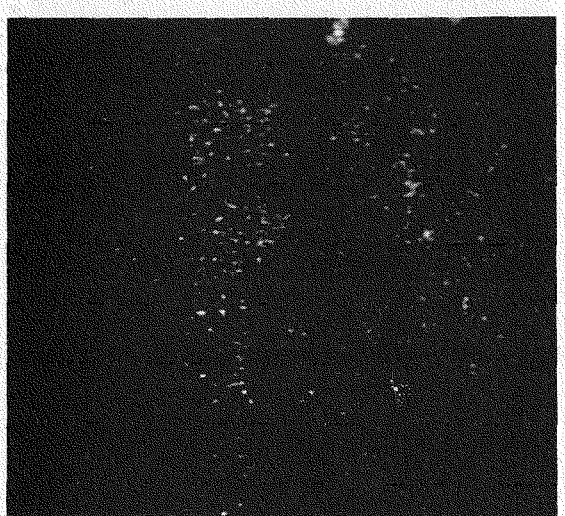
6198 Cr 1000X



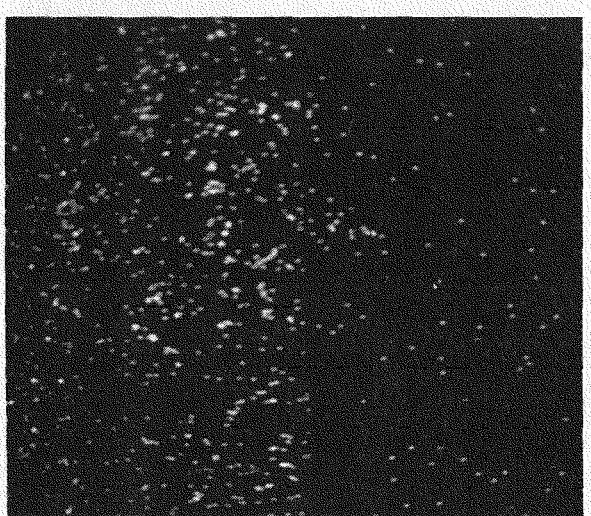
6198 Fe 1000X



6198 Ni 1000X

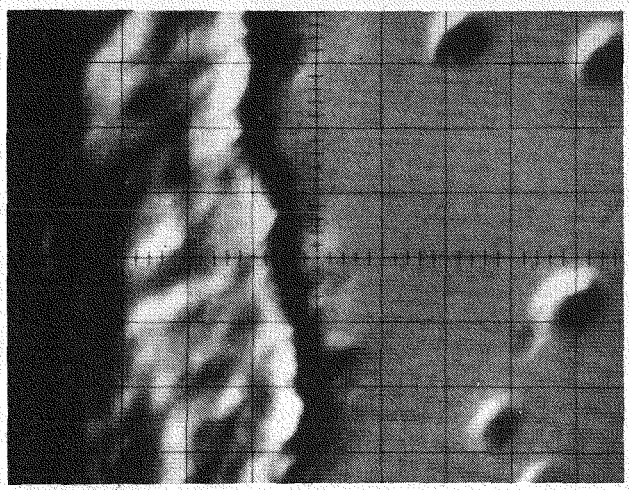


6180 Ti 1000X

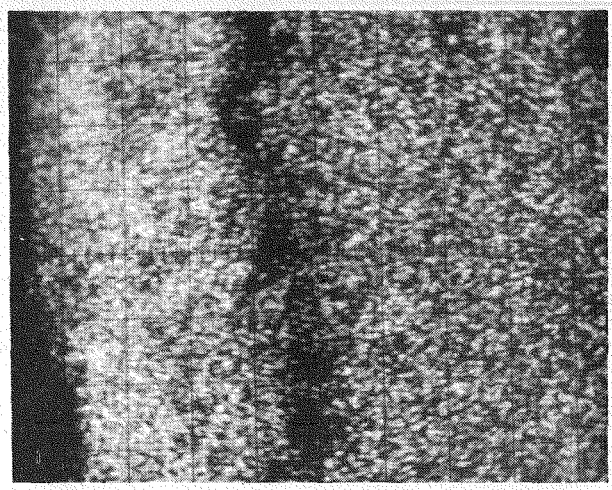


6198 Oxygen 1000X

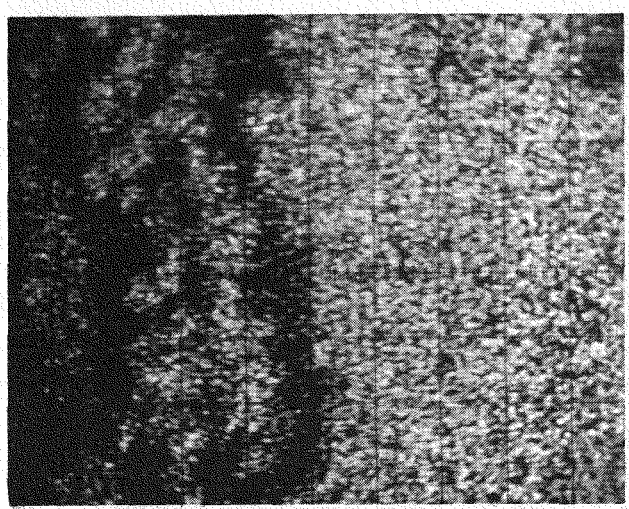
FIGURE 91: Kα x-ray images of scale and adjacent area of INCONEL Filler Metal 72 overlay from W6198 after exposure in a CGA, INCOLOY alloy 800H substrate, GMAW process, double layer.



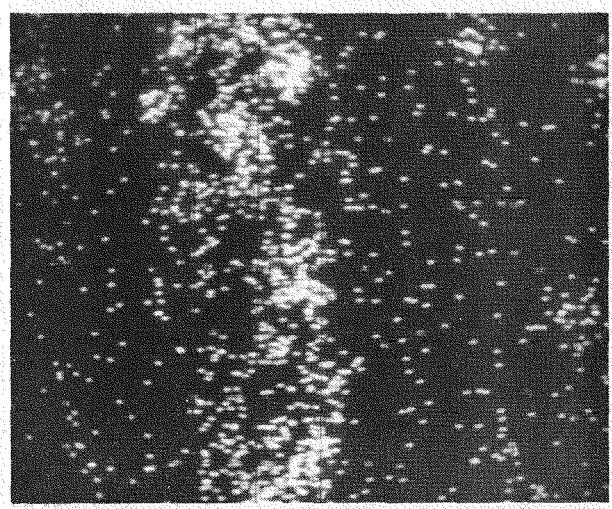
6208 1000X



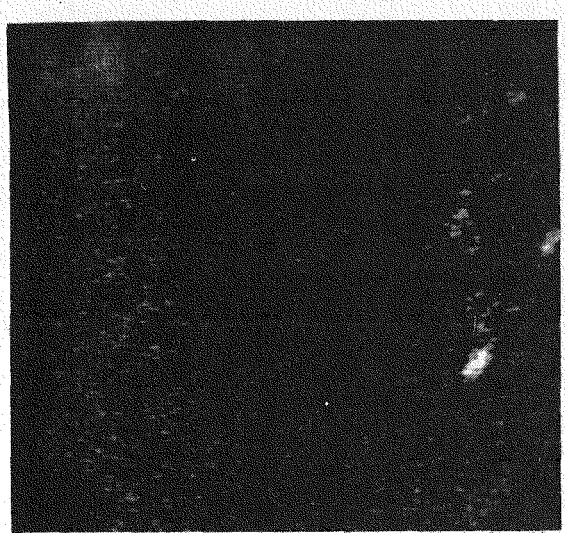
6208 Cr 1000X



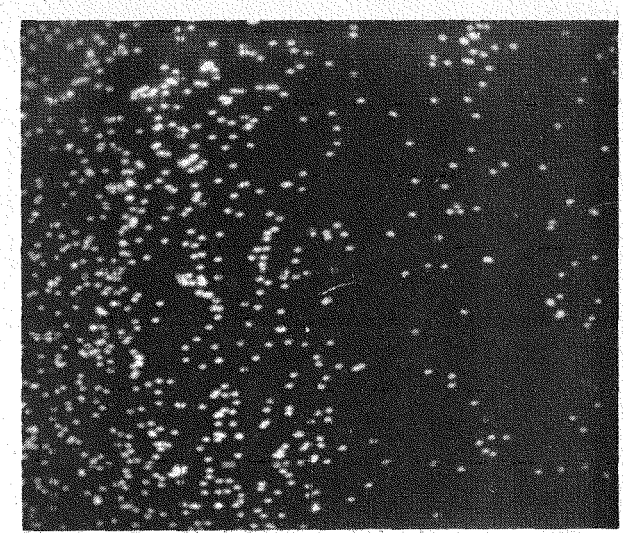
6208 Fe 1000X



6208 Al 1000X

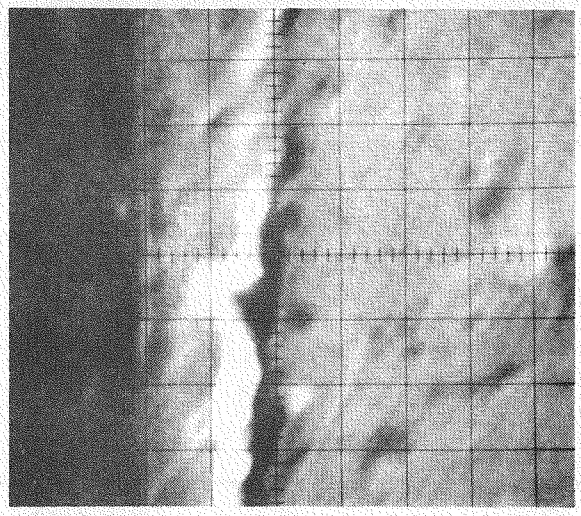


6208 Ti 1000X

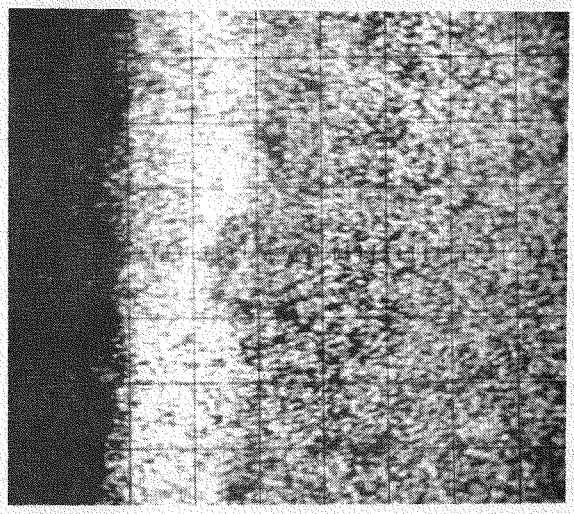


6208 Oxygen 1000X

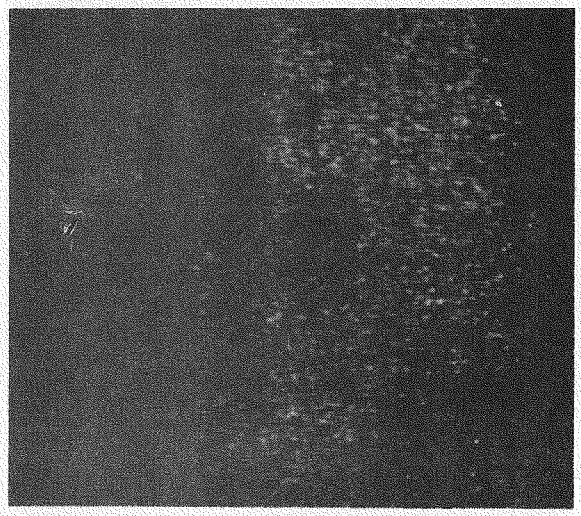
FIGURE 92: $K\alpha$ x-ray images of scale and adjacent area of R139 overlay from W6208 after exposure in a CGA, 304L substrate, GTAW-HW process, double layer.



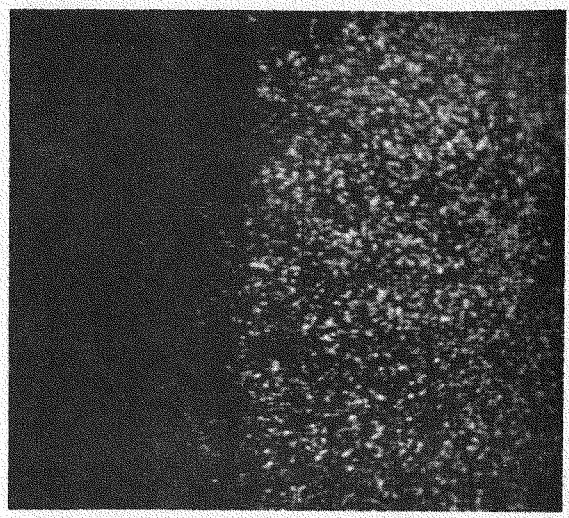
6212 1000X



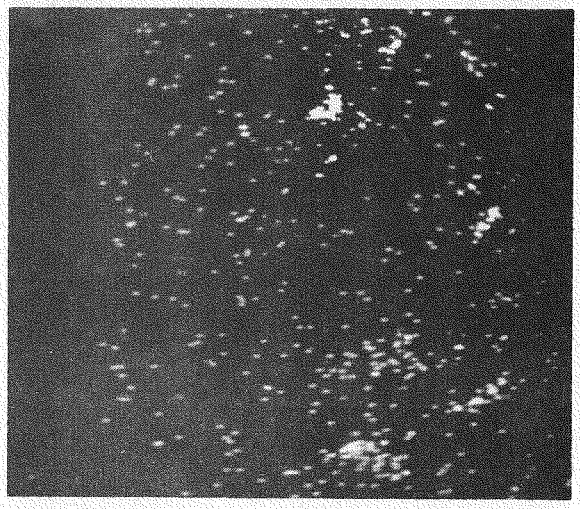
6212 Cr 1000X



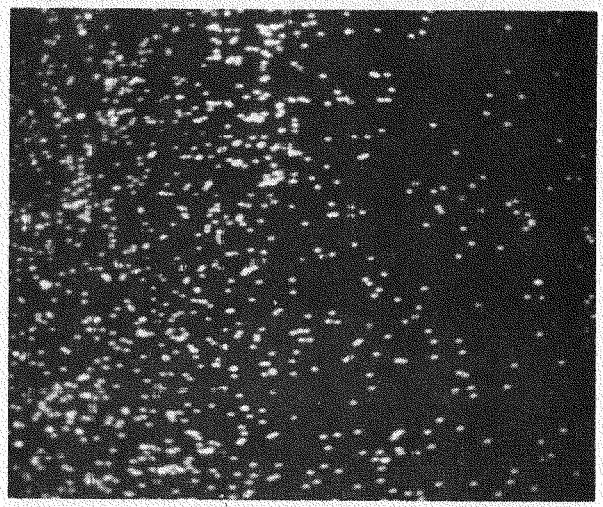
6212 Fe 1000X



6212 Ni 1000X

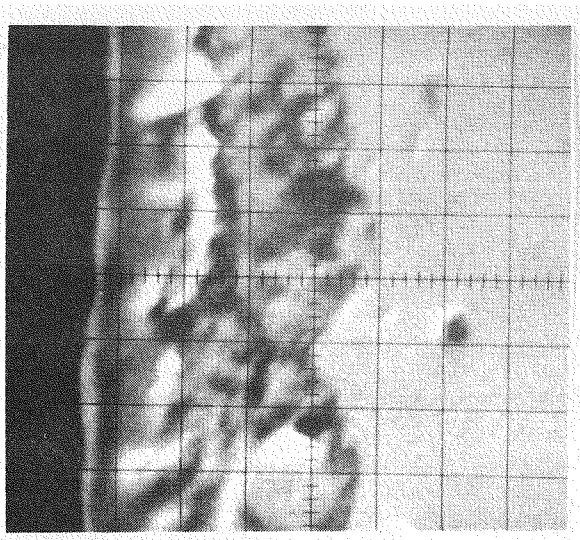


6212 Al 1000X

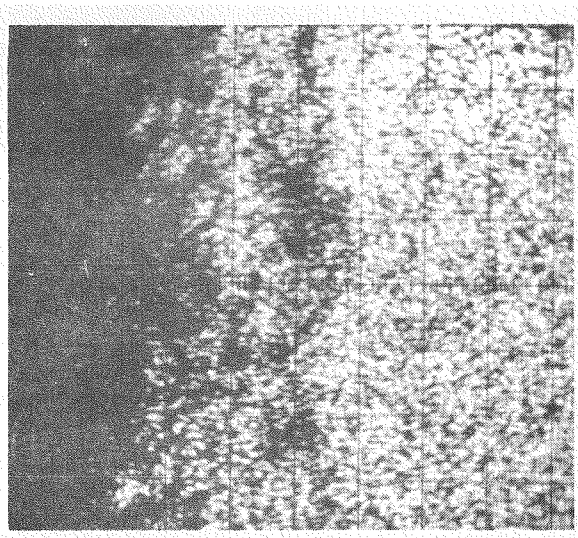


6212 Oxygen 1000X

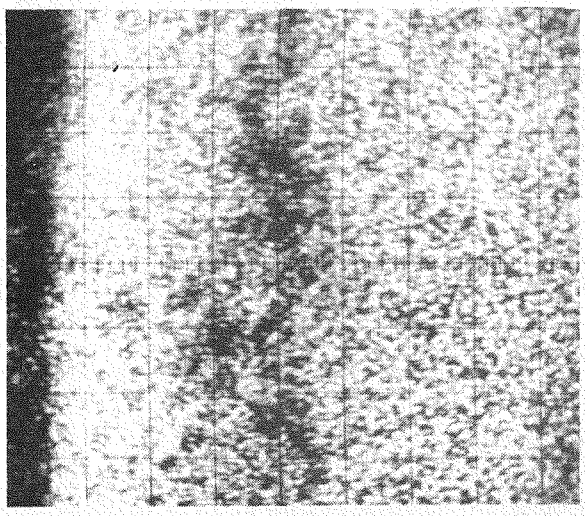
FIGURE 93: Kα x-ray images of scale and adjacent area of R139 overlay from W6212 after exposure in a CGA, 310SS substrate, SAW process, double layer.



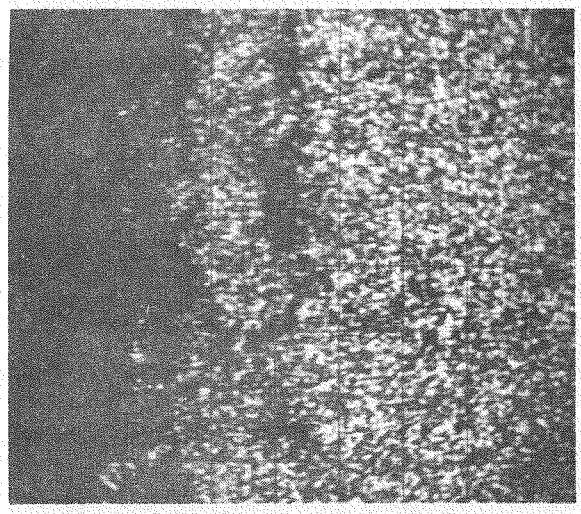
6216 1000X



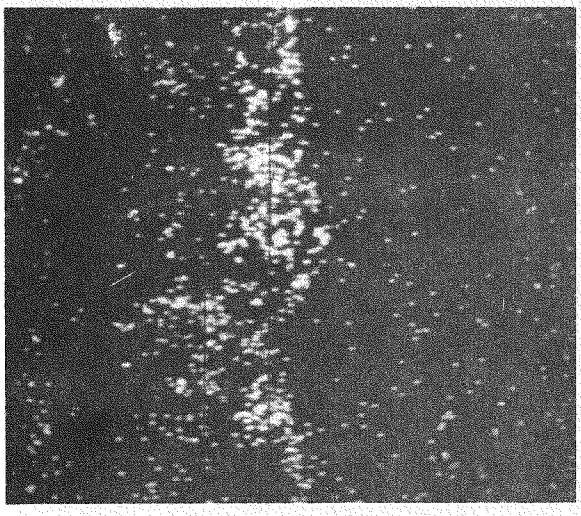
6216 Ni 1000X



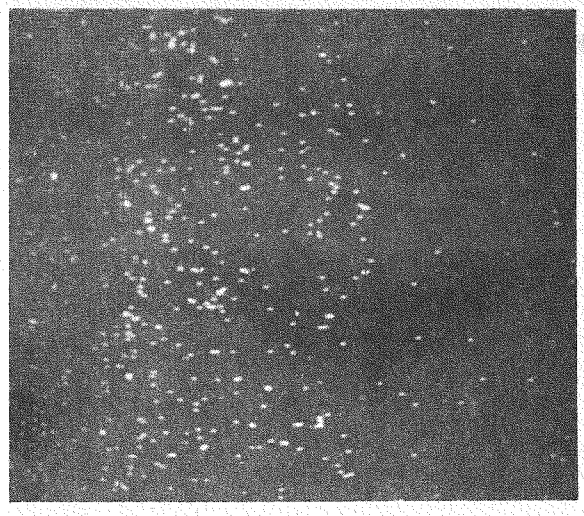
6216 Cr 1000X



6216 Fe 1000X

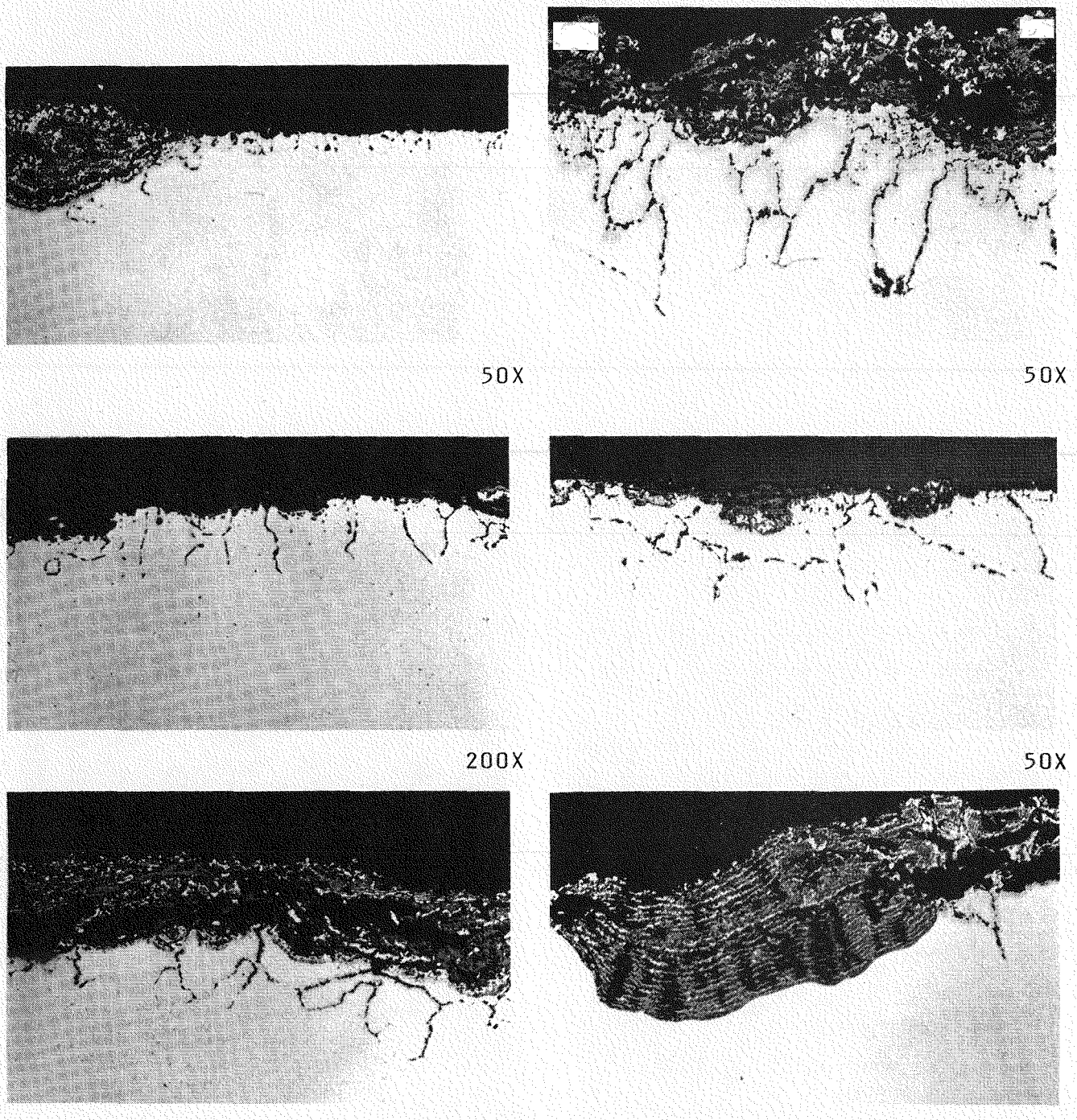


6216 Al 1000X



6216 Oxygen 1000X

FIGURE 94: Kα x-ray images of scale and adjacent area of R139 overlay from W6216 after exposure in a CGA, INCOLOY alloy 800H substrate, GMAW process, double layer.



50X 50X

200X 50X

50X 50X

Double Layer		Single Layer
Top 6180	GMAW	Top 6181
Middle 6182	SAW	Middle 6183
Bottom 6184	GTAW-HW	Bottom 6185

FIGURE 95: CGA exposed AWS-ER309 on type 304L. Note magnification of W6182.
All unetched

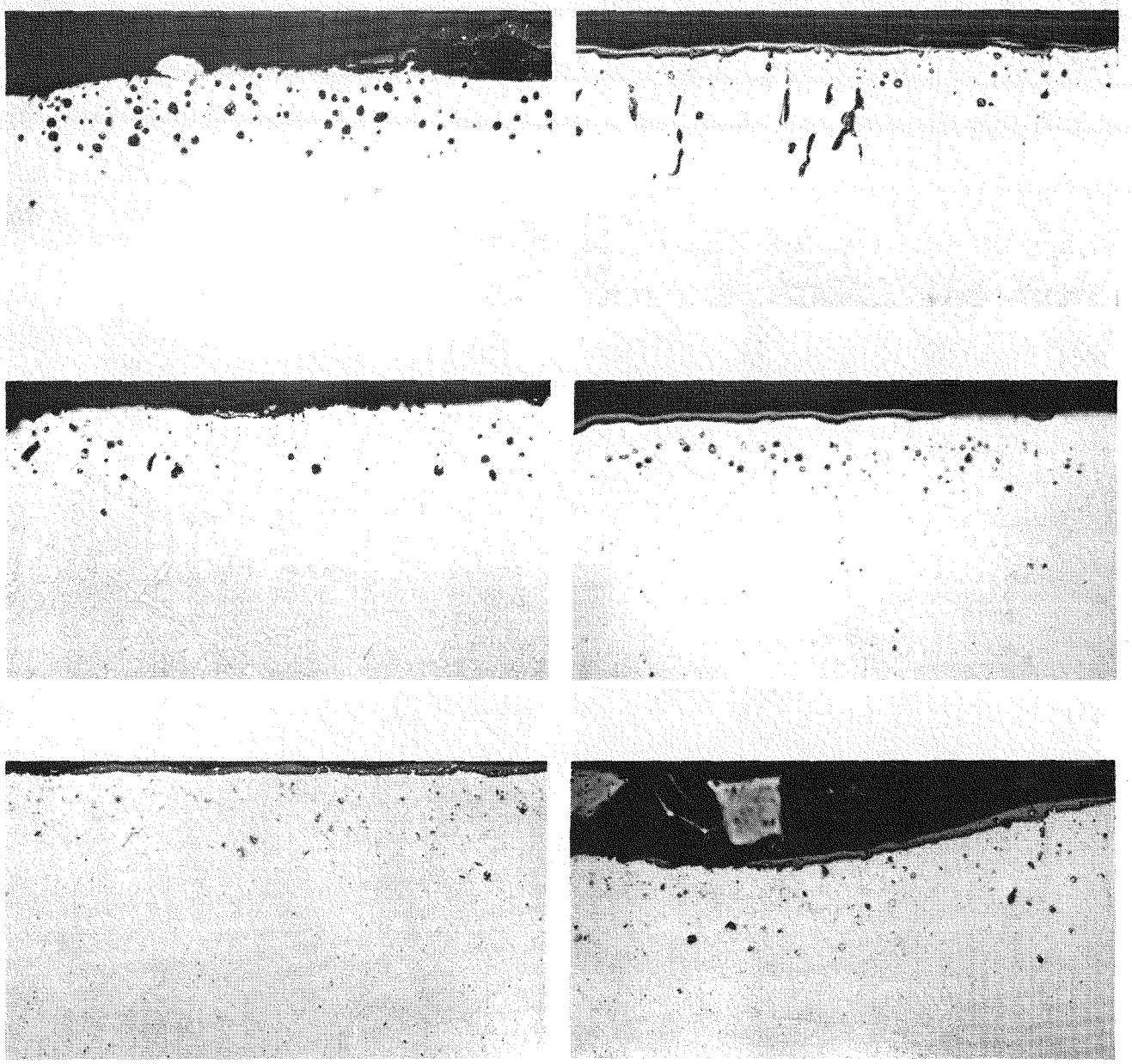


FIGURE 96: INCONEL Filler Metal 72 overlays made by the gas-metal arc process on type 304L (top, W6186,7), type 310 (middle, W6192,3), and INCOLOY alloy 800H (bottom, W6198,9) CGA exposed. (200X) All unetched

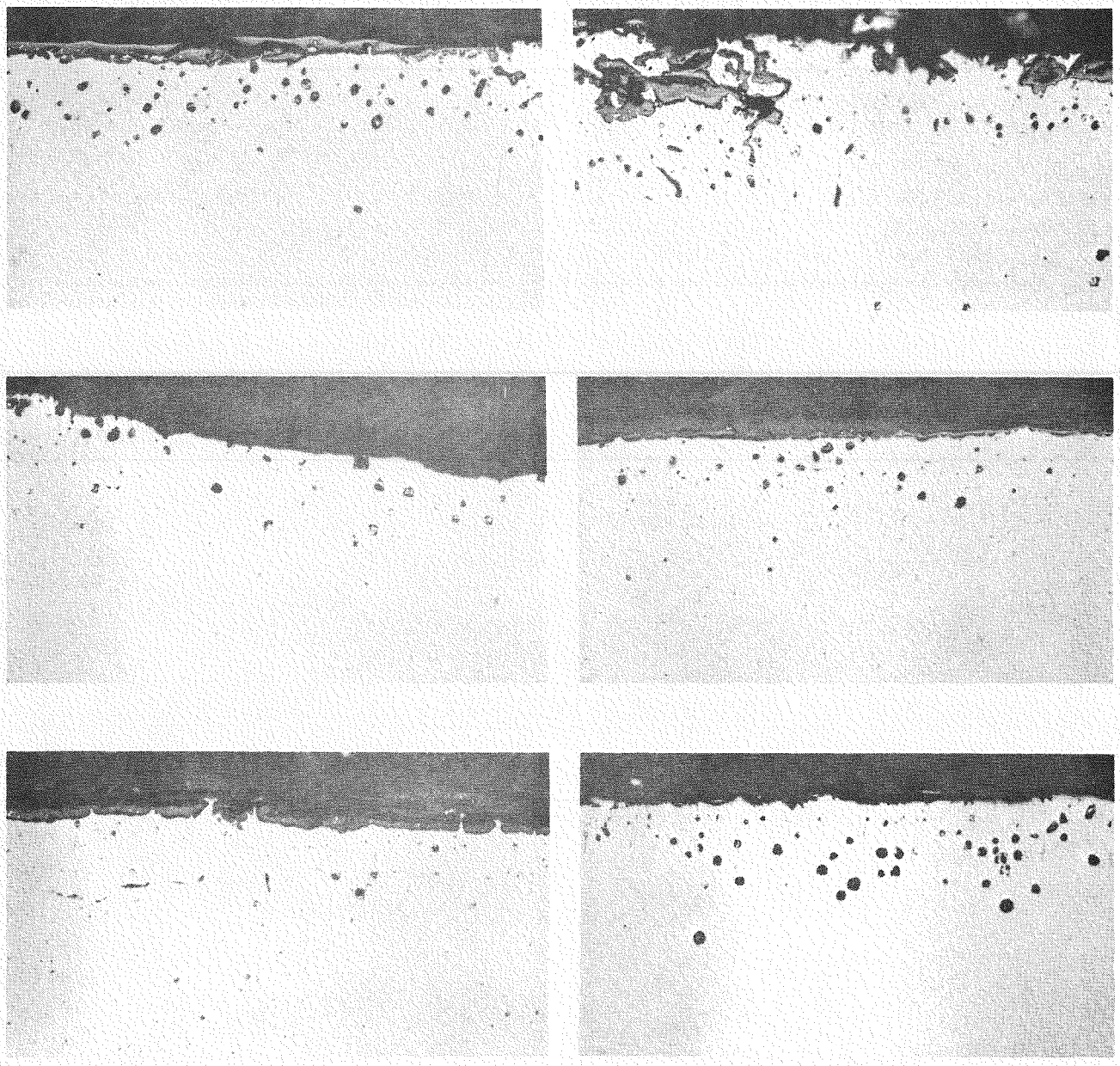
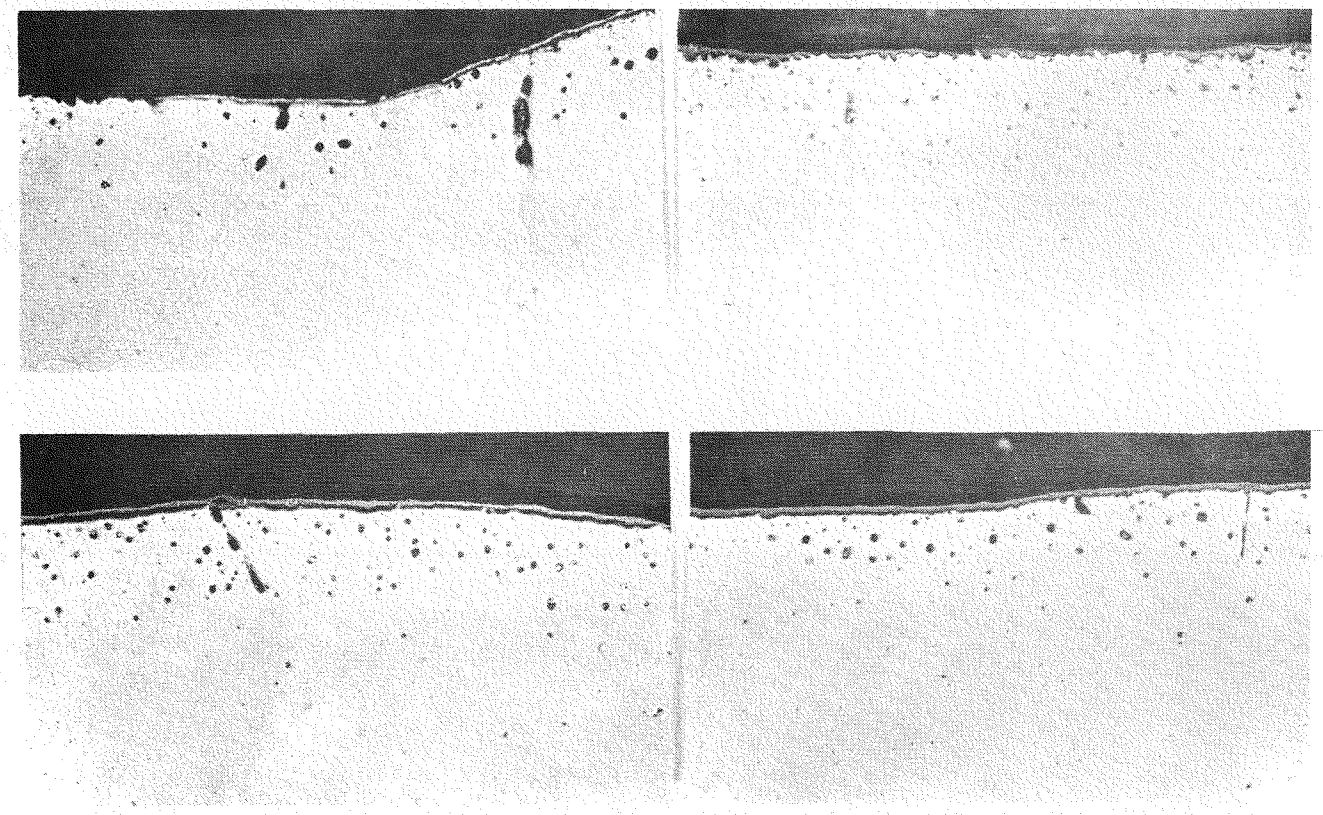
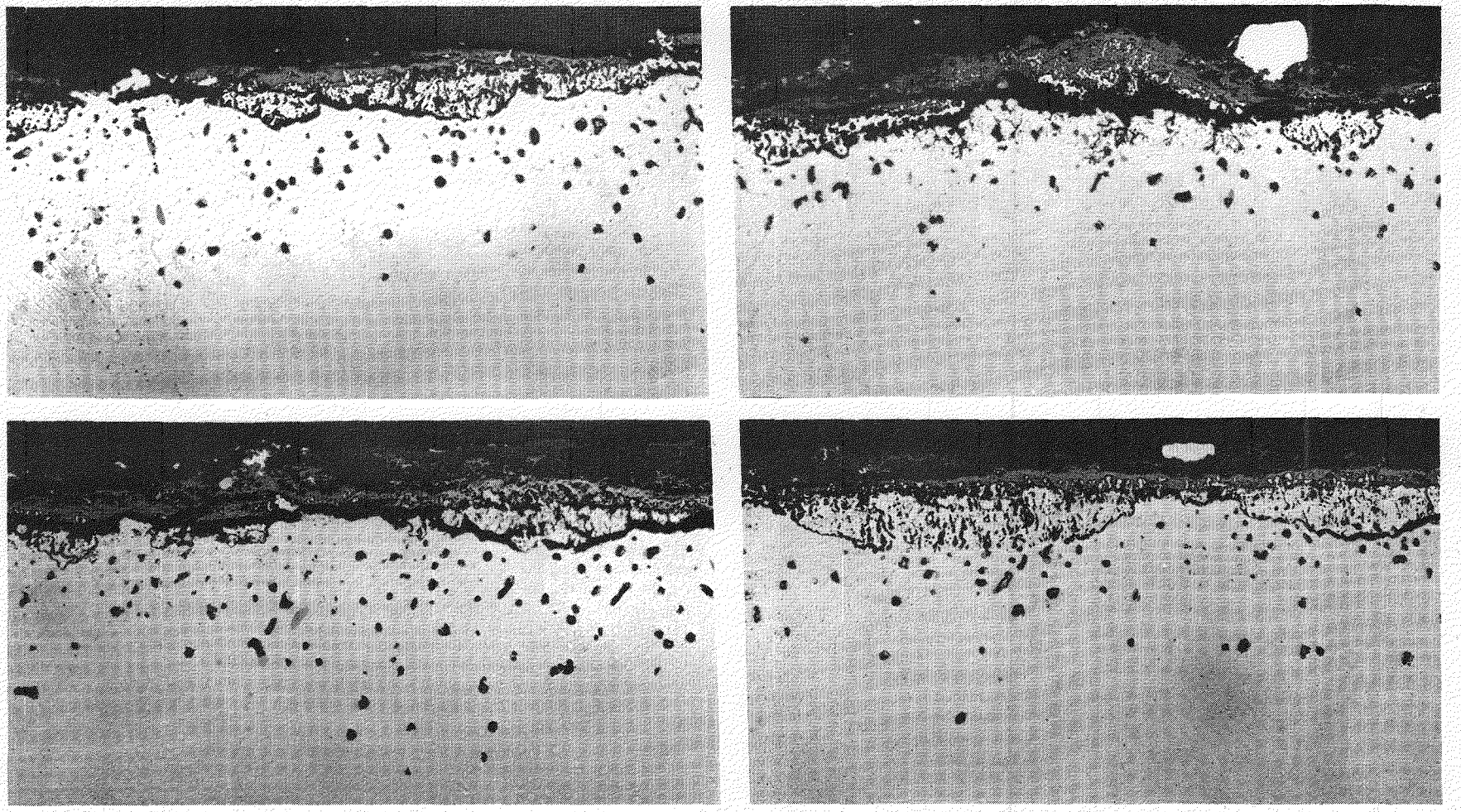


FIGURE 97: Weld produced using INCONEL Filler Metal 72 with the gas-tungsten arc process, hot wire addition, on type 304L (top, W6190,1), type 310 (middle, W6196,7), and alloy 800H (bottom, W6202,3) - CGA exposed.
(200X) All unetched



Double Single

FIGURE 98: Weld overlays of INCONEL Filler Metal 72 produced by the submerged arc process on type 304L (top, W6188,9), and type 310 (bottom, W6194,5). Weld on 800H identical to that on type 310 - CGA exposed. (200X) All unetched



W6204
Double Layer

W6205
Single Layer

FIGURE 99: Gas-metal arc weld overlays of R139 on type 304L. Complex scale formation, scale separation along continuous internal alumina. CGA exposed. (200X)
All unetched

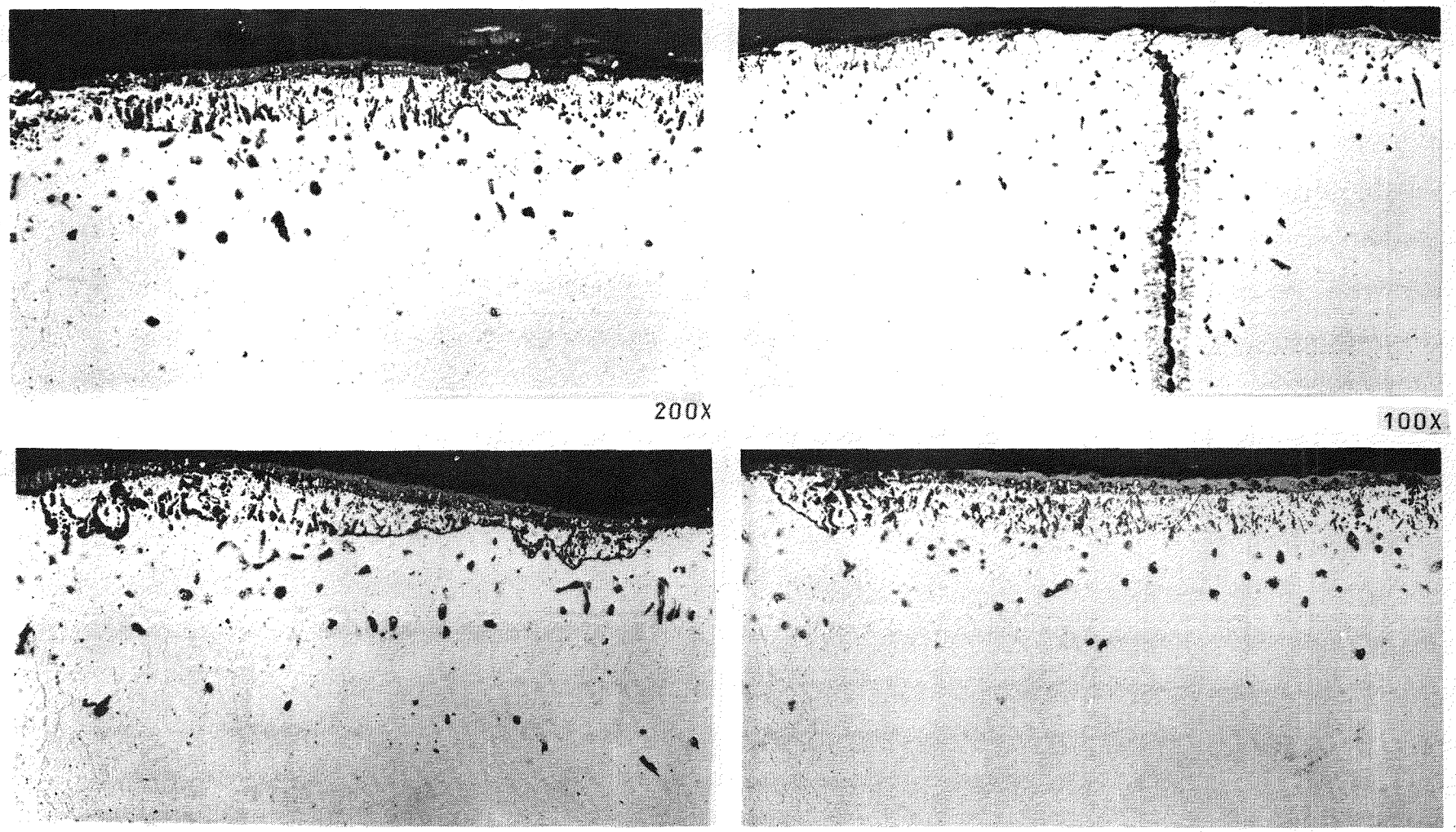
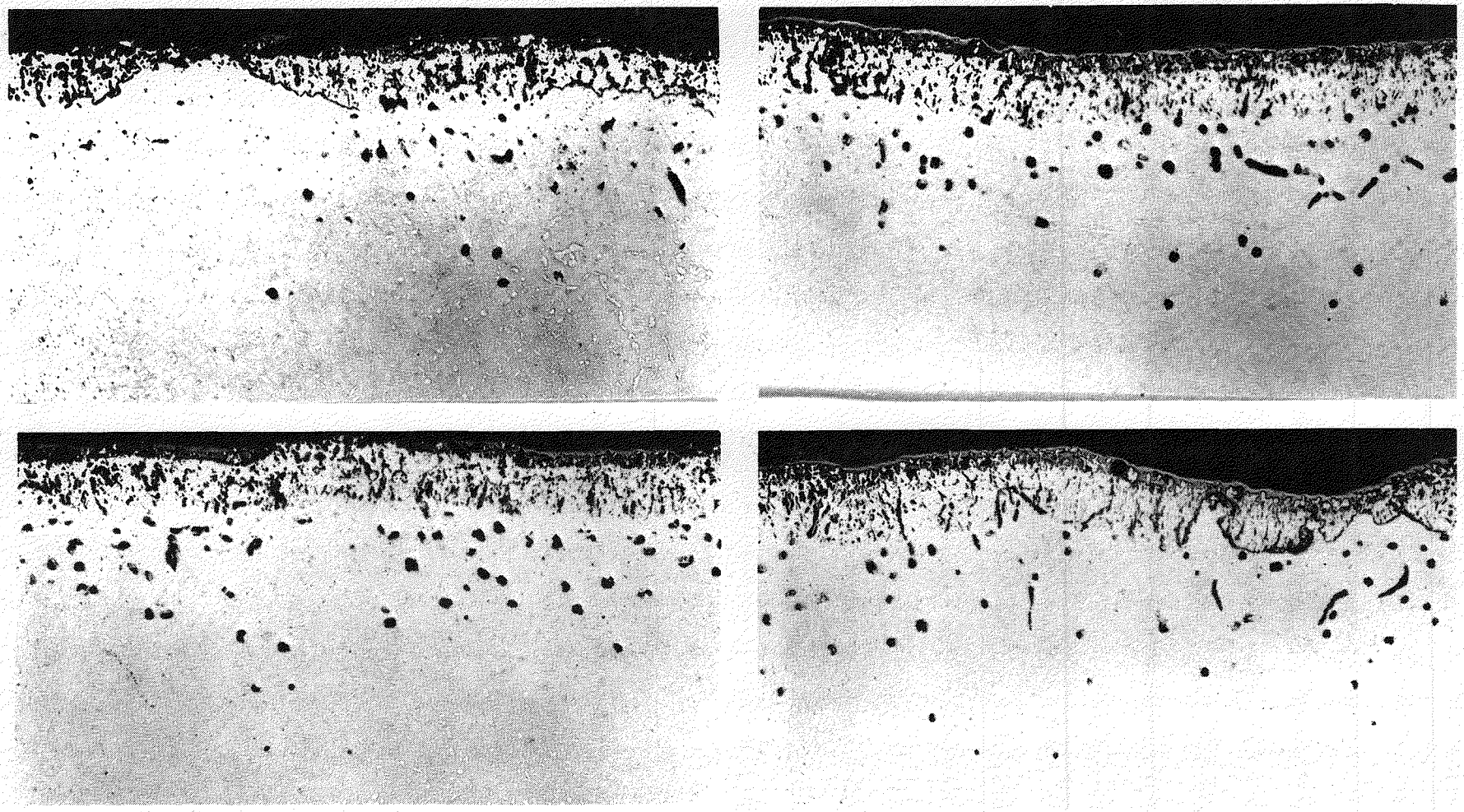


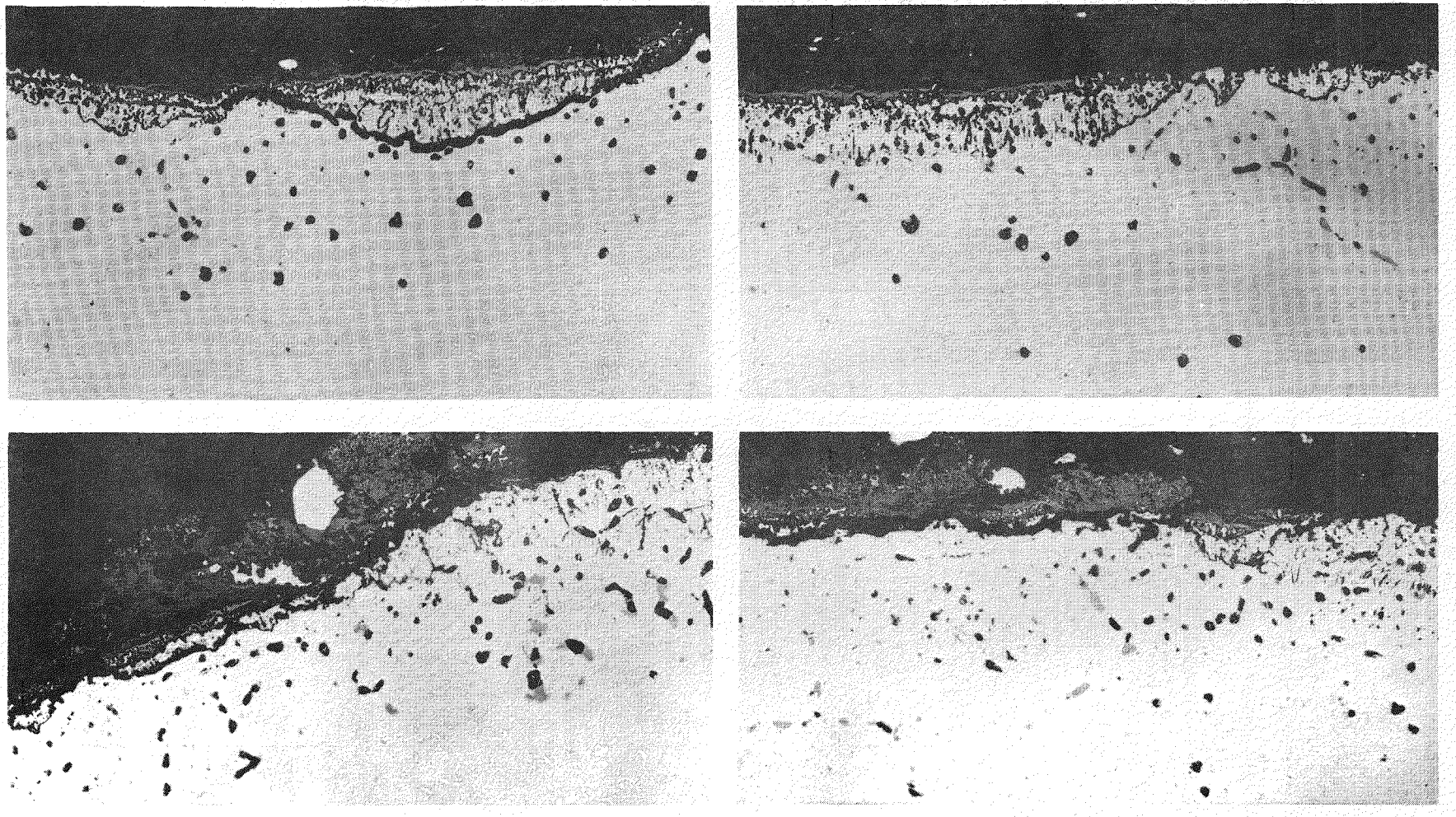
FIGURE 100: Welds made with the gas-metal arc process using R139 on type 310 - CGA exposed. Note limited corrosion in weld defect. No sulfide formation. All unetched



W6216
Double Layer

W6217
Single Layer

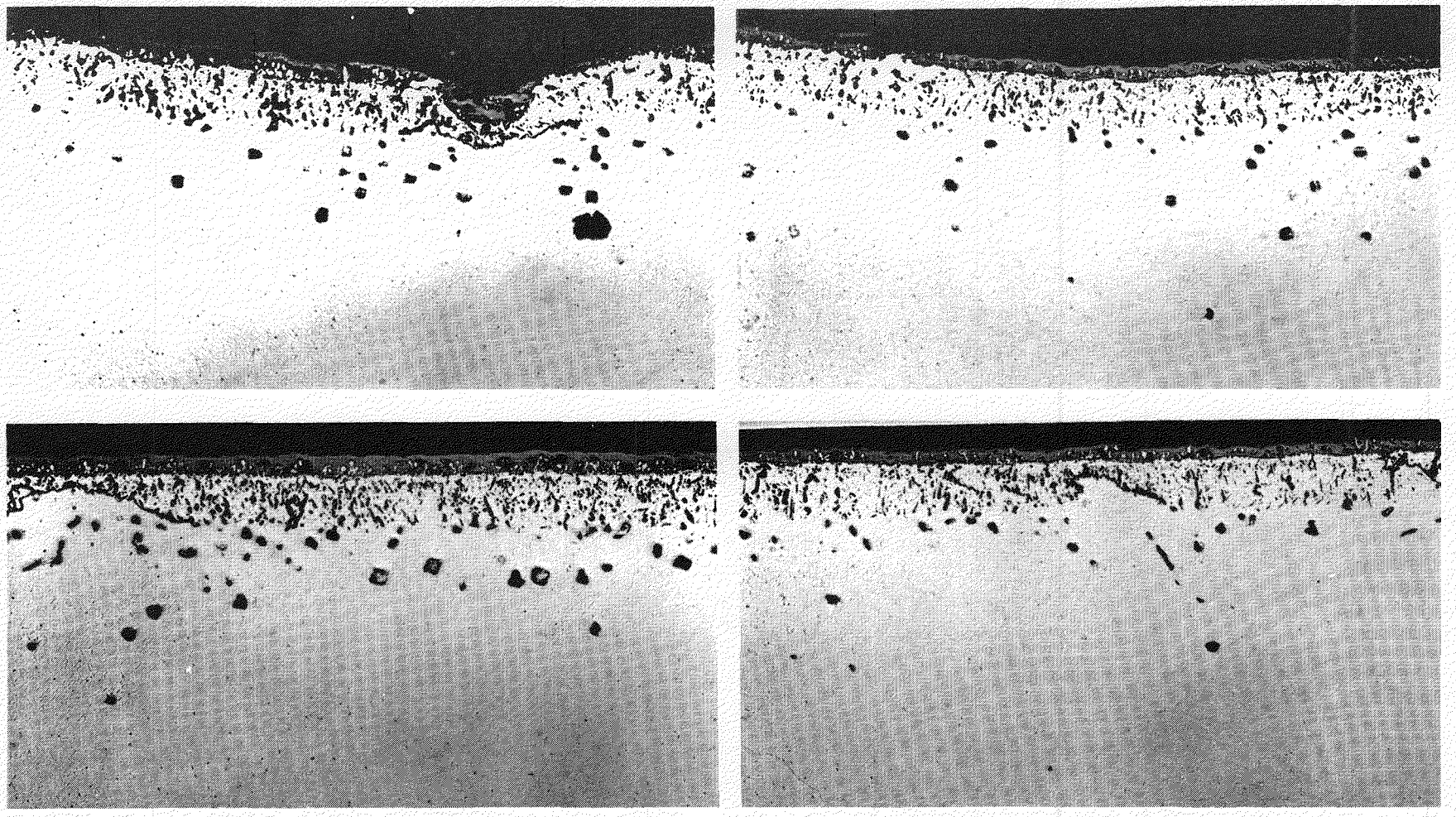
FIGURE 101: Gas-metal arc overlays of R139 on INCOLOY alloy 800H - CGA exposed. No internal sulfidation. (200X)
All unetched



W6208
Double Layer

W6209
Single Layer

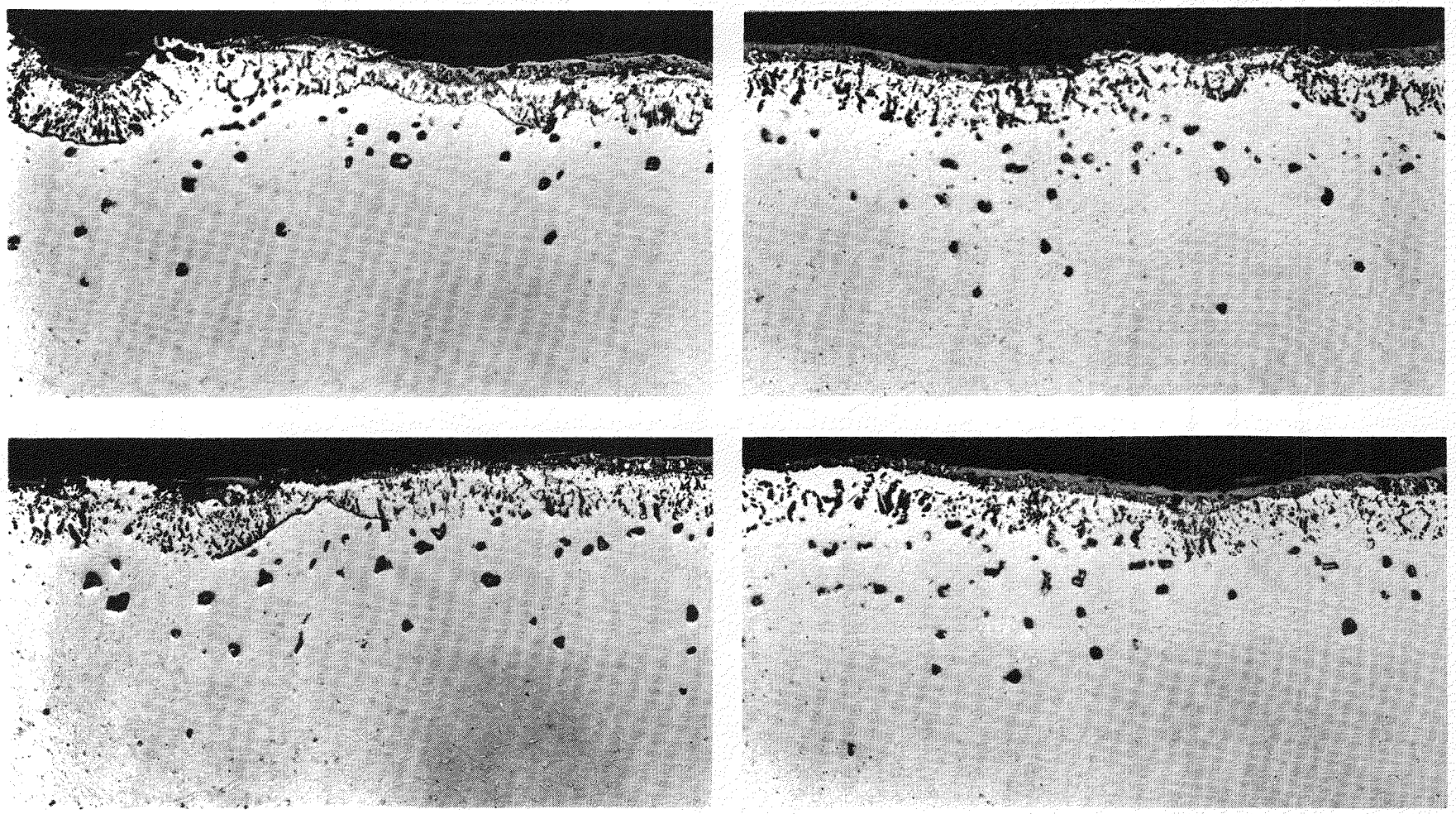
FIGURE 102: Gas-tungsten arc with hot wire addition overlays of R139 on type 304L stainless steel - CGA exposed. Metal sulfides in scale, internal sulfides below. (200X) All unetched



W6214
Double Layer

W6215
Single Layer

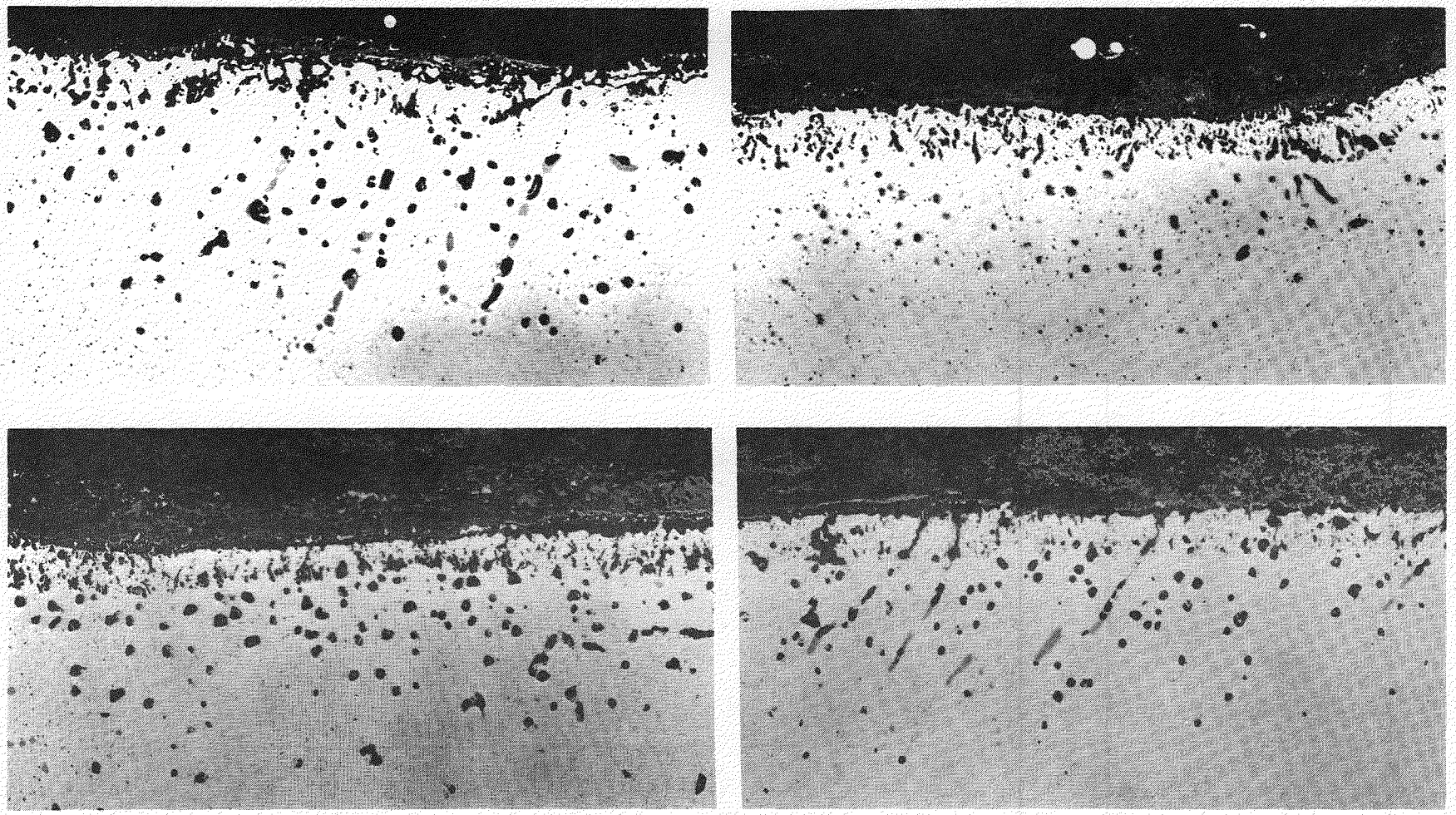
FIGURE 103: Gas-tungsten arc with hot wire addition overlays of R139 on type 310SS - CGA exposed. Note compact, protective chromia scales, no internal sulfidation. (200X) All unetched



W6220
Double Layer

W6221
Single Layer

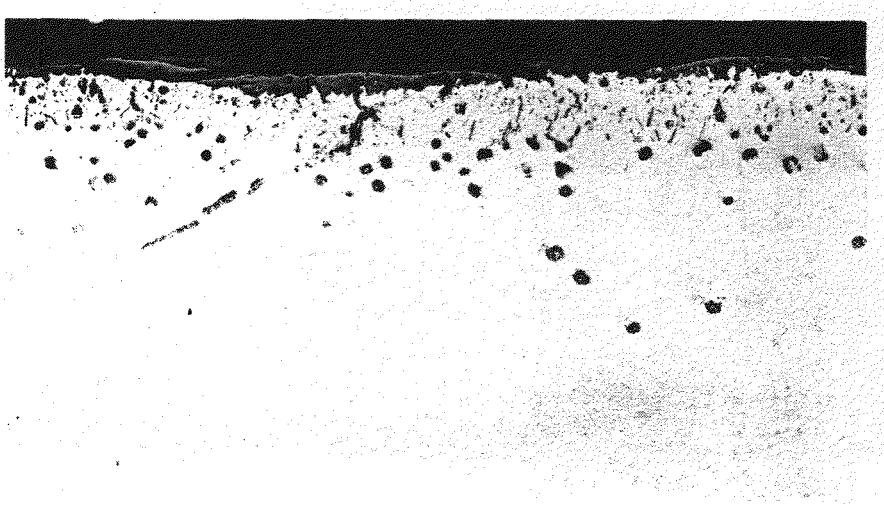
FIGURE 104: Gas-tungsten arc with hot wire addition overlays of R139 on INCOLOY alloy 800H - CGA exposed.
(200X) All unetched



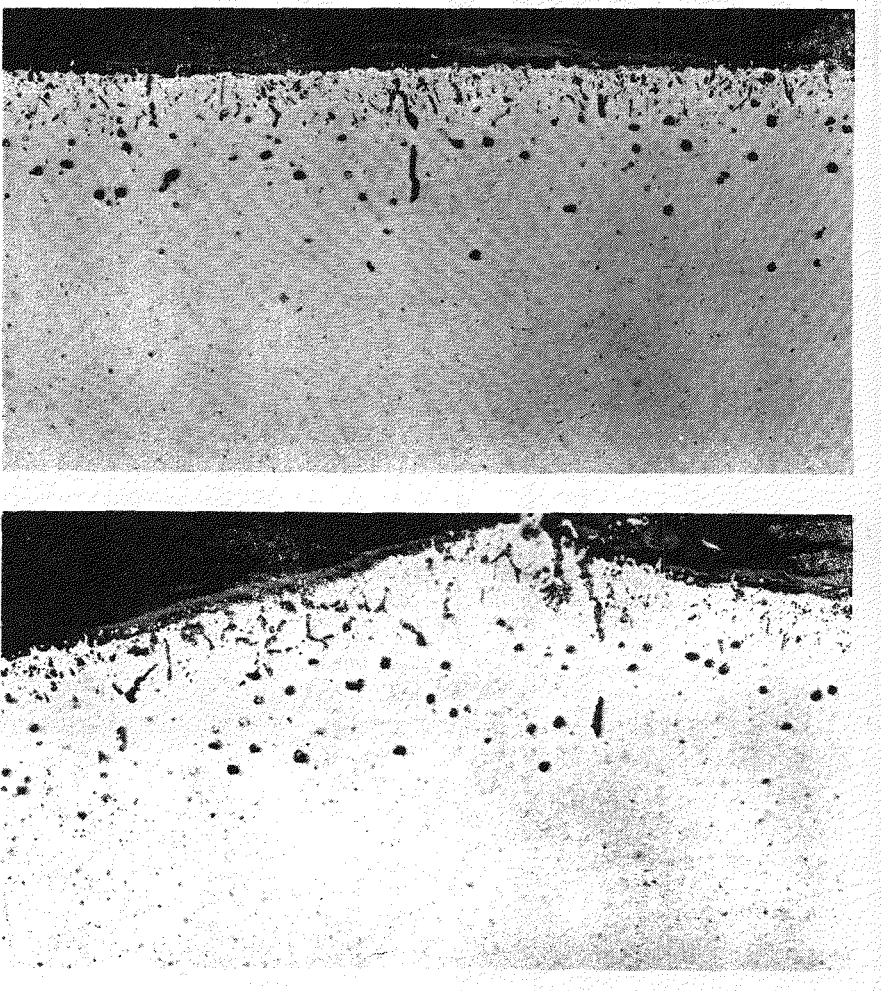
W6206
Double Layer

W6207
Single Layer

FIGURE 105: Submerged arc overlays of R139 on type 304L - CGA exposed. (200X) All unetched

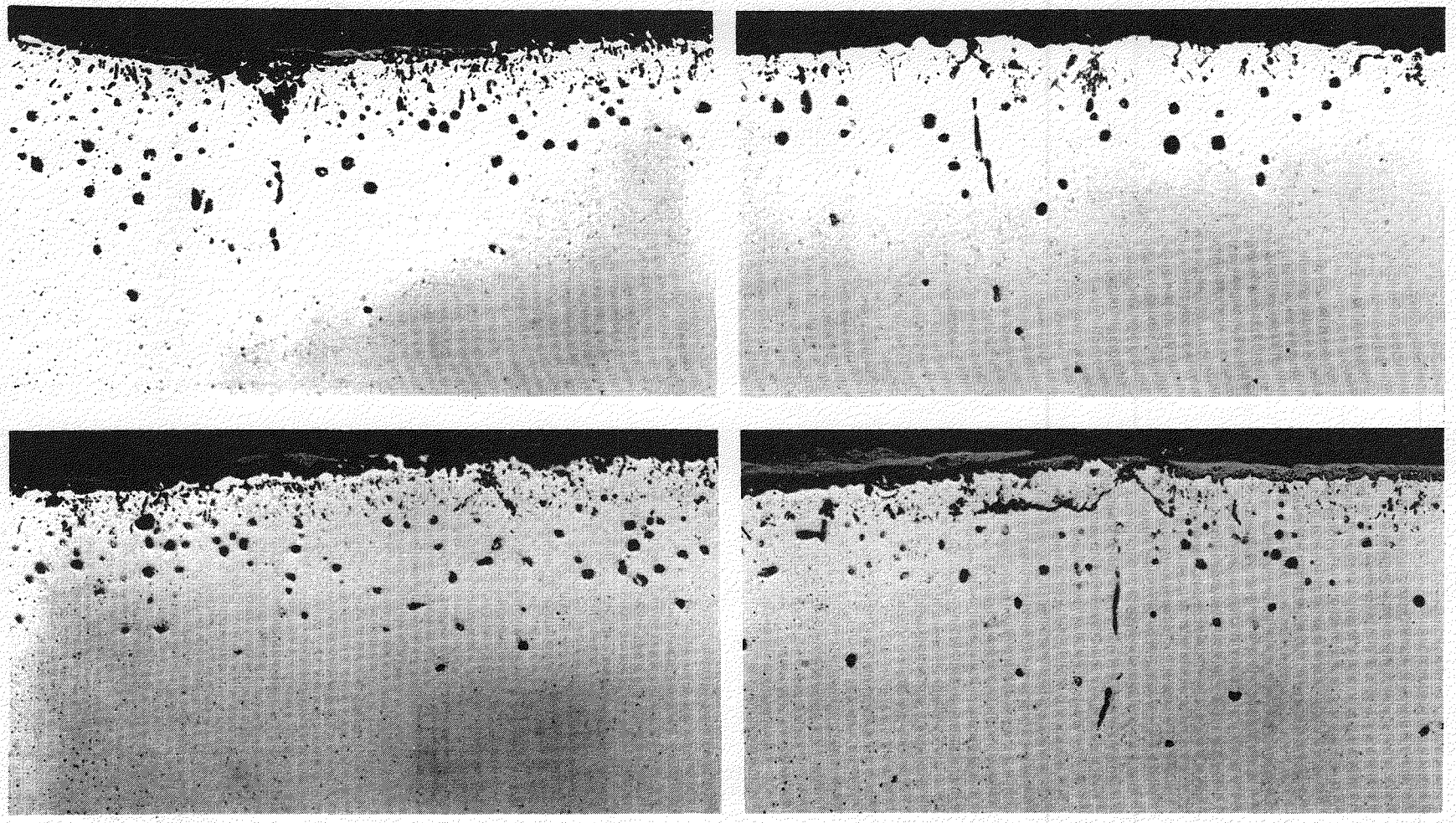


W6212



W6213

FIGURE 106: Submerged arc overlays of R139 on type 310 stainless steel - CGA exposed.
(200X) All unetched



W6218
Double Layer

W6219
Single Layer

FIGURE 107: Submerged arc overlays of R139 on INCOLOY alloy 800H - CGA exposed.
(200X) All unetched

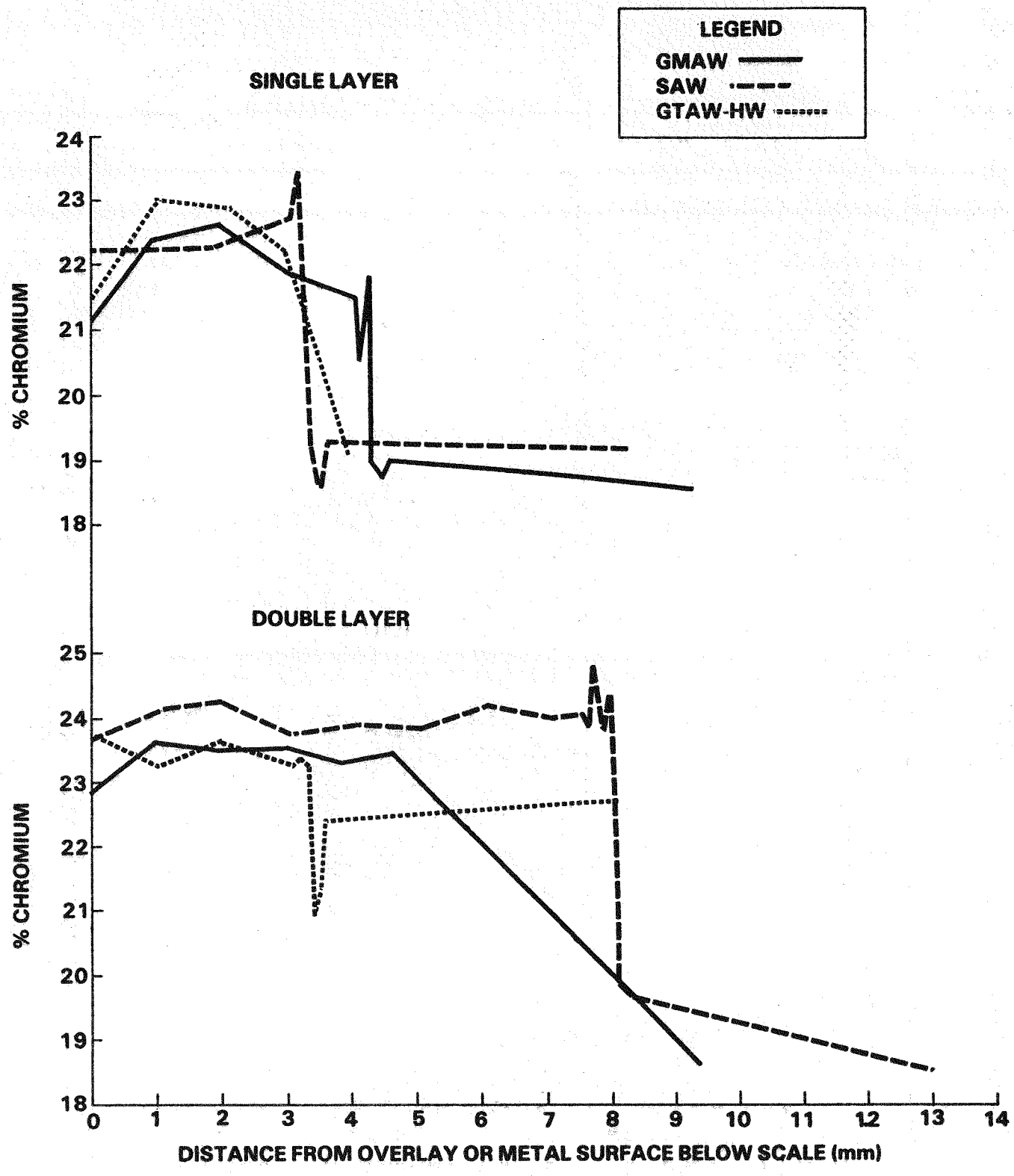


FIGURE 108 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM IN AWS-ER 309–304L WELDMENTS, AFTER EXPOSURE, SINGLE AND DOUBLE LAYERS.

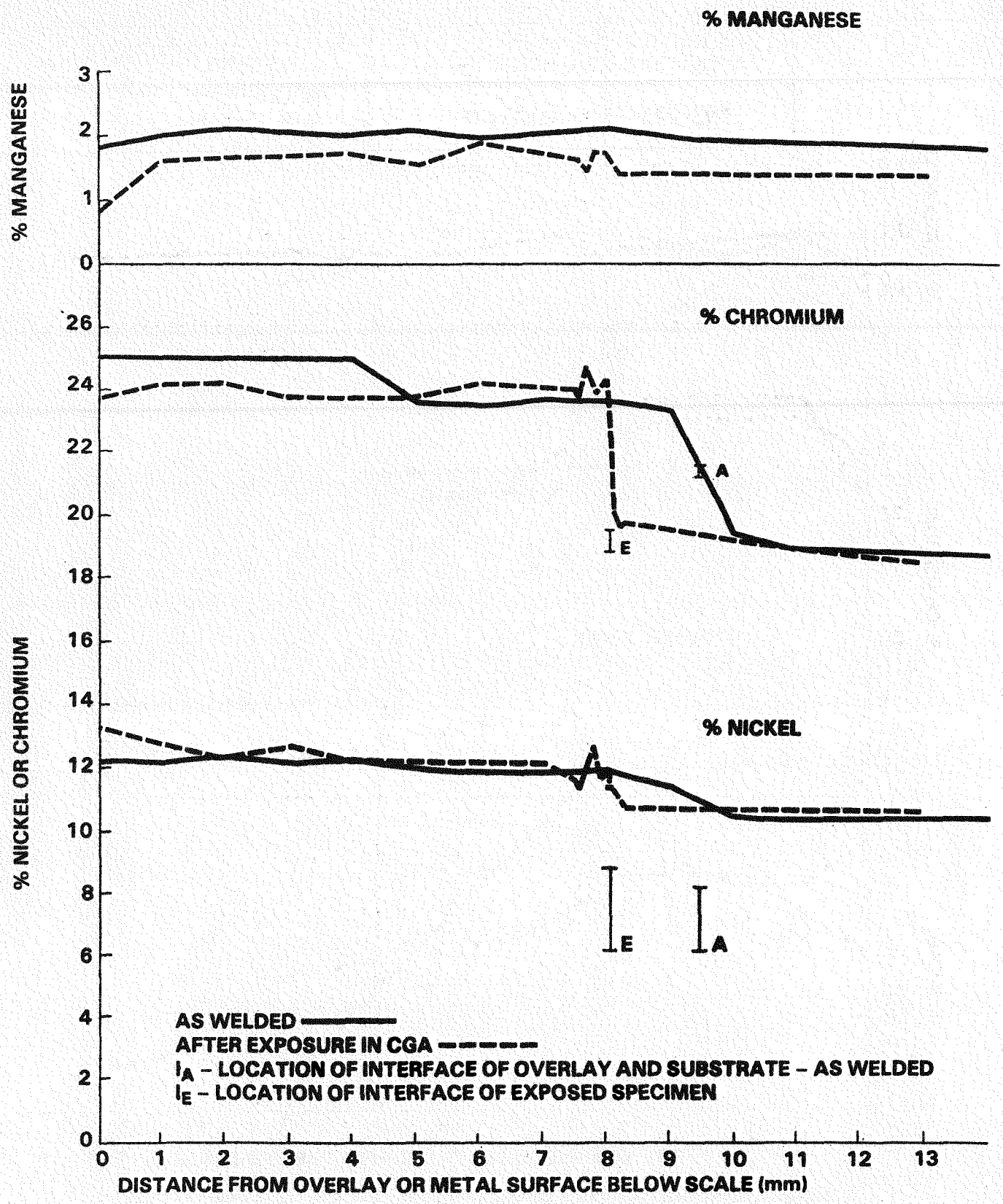


FIGURE 109 EFFECT OF EXPOSURE ON THE DISTRIBUTION OF NICKEL, CHROMIUM AND MANGANESE IN AN AWS-ER 309–304L WELDMENT, DOUBLE LAYER, SAW PROCESS.

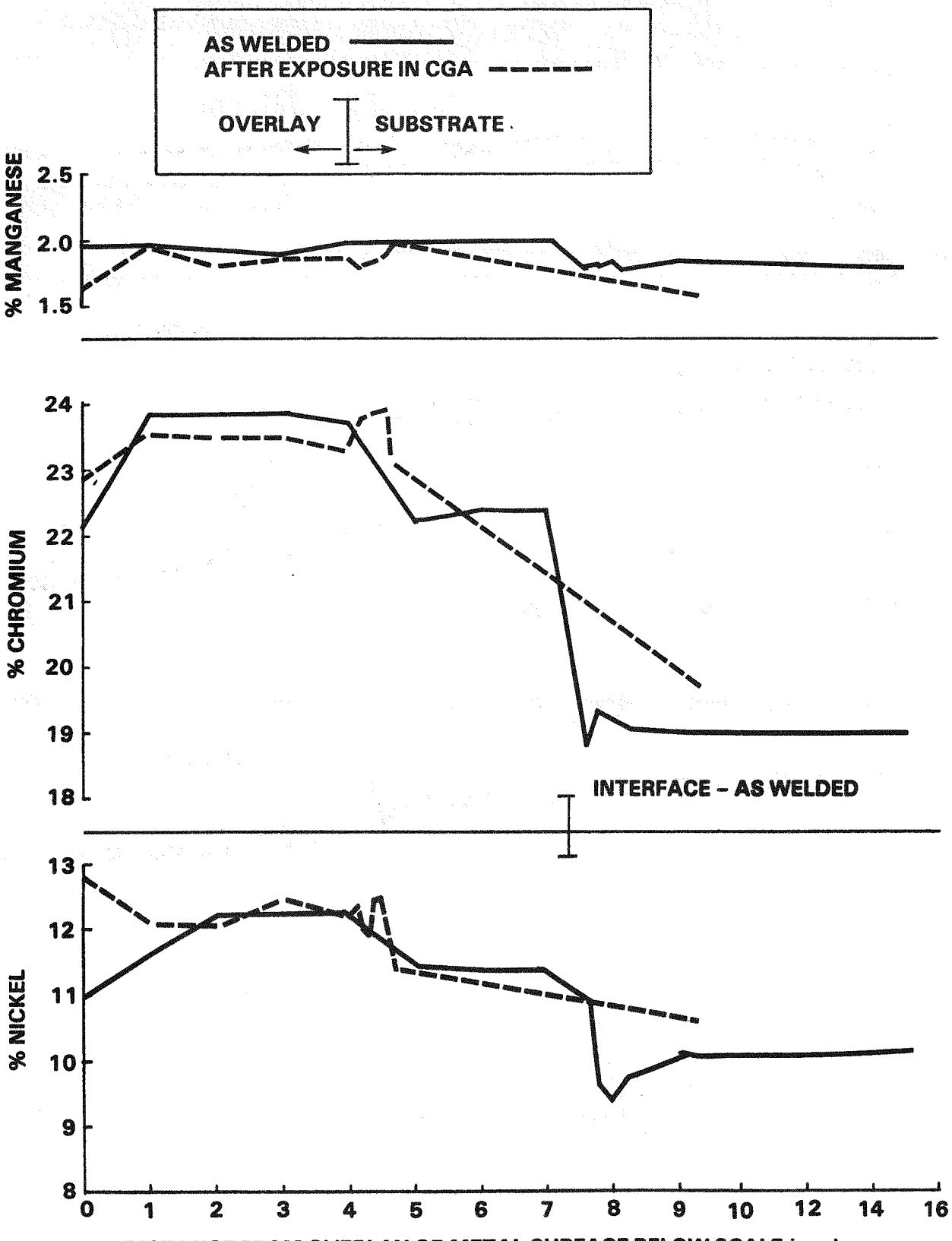


FIGURE 110 EFFECT OF EXPOSURE ON THE DISTRIBUTION OF NICKEL, CHROMIUM AND MANGANESE IN AN AWS-ER 309–304L WELDMENT, DOUBLE LAYER, GMAW PROCESS.

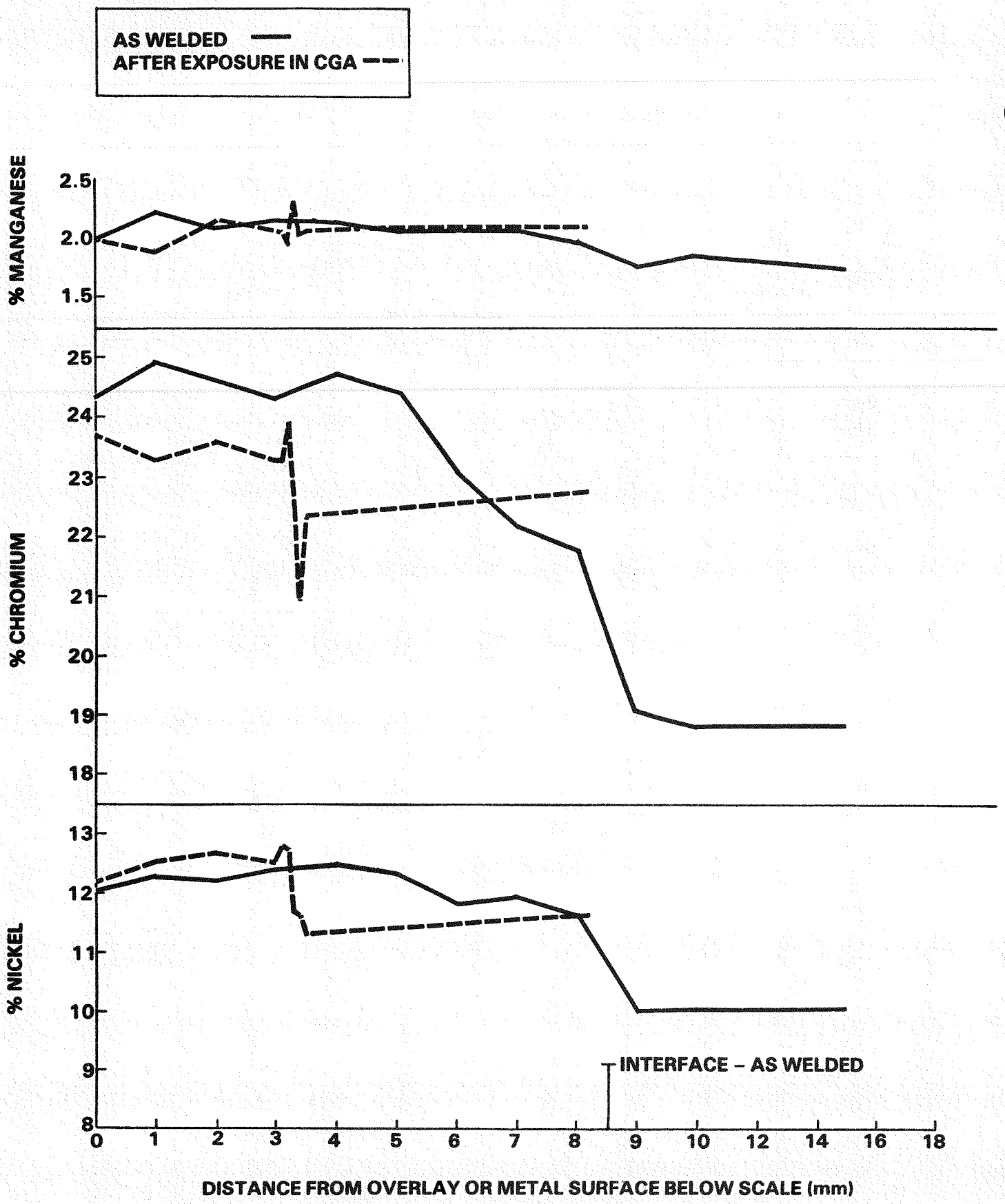


FIGURE 111 EFFECT OF EXPOSURE ON THE DISTRIBUTION OF NICKEL, CHROMIUM AND MANGANESE IN AN AWS-ER 309–304L WELDMENT, DOUBLE LAYER, GTAW-HW PROCESS.

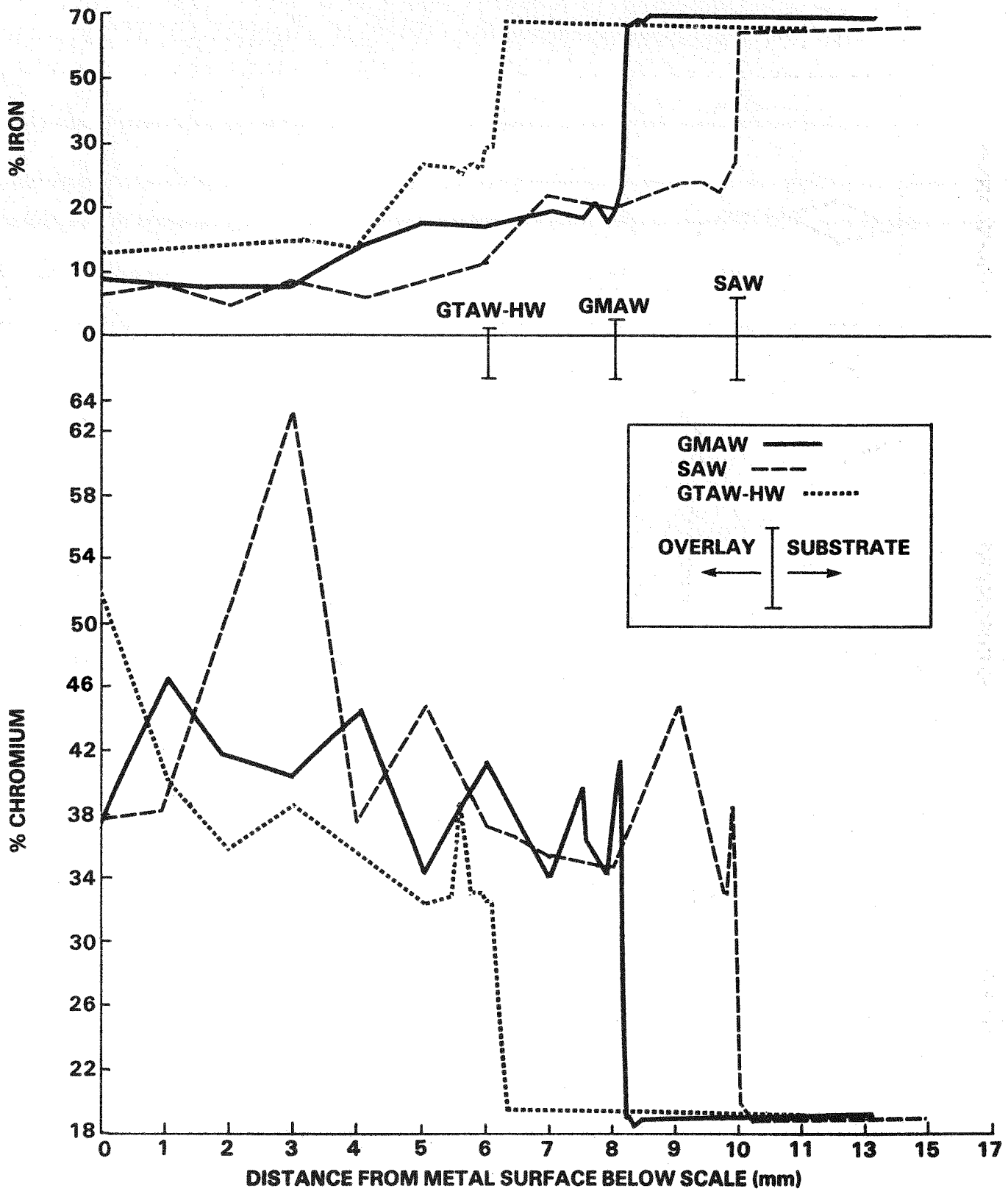


FIGURE 112 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 OVERLAYS ON 304L AFTER EXPOSURE, DOUBLE LAYERS.

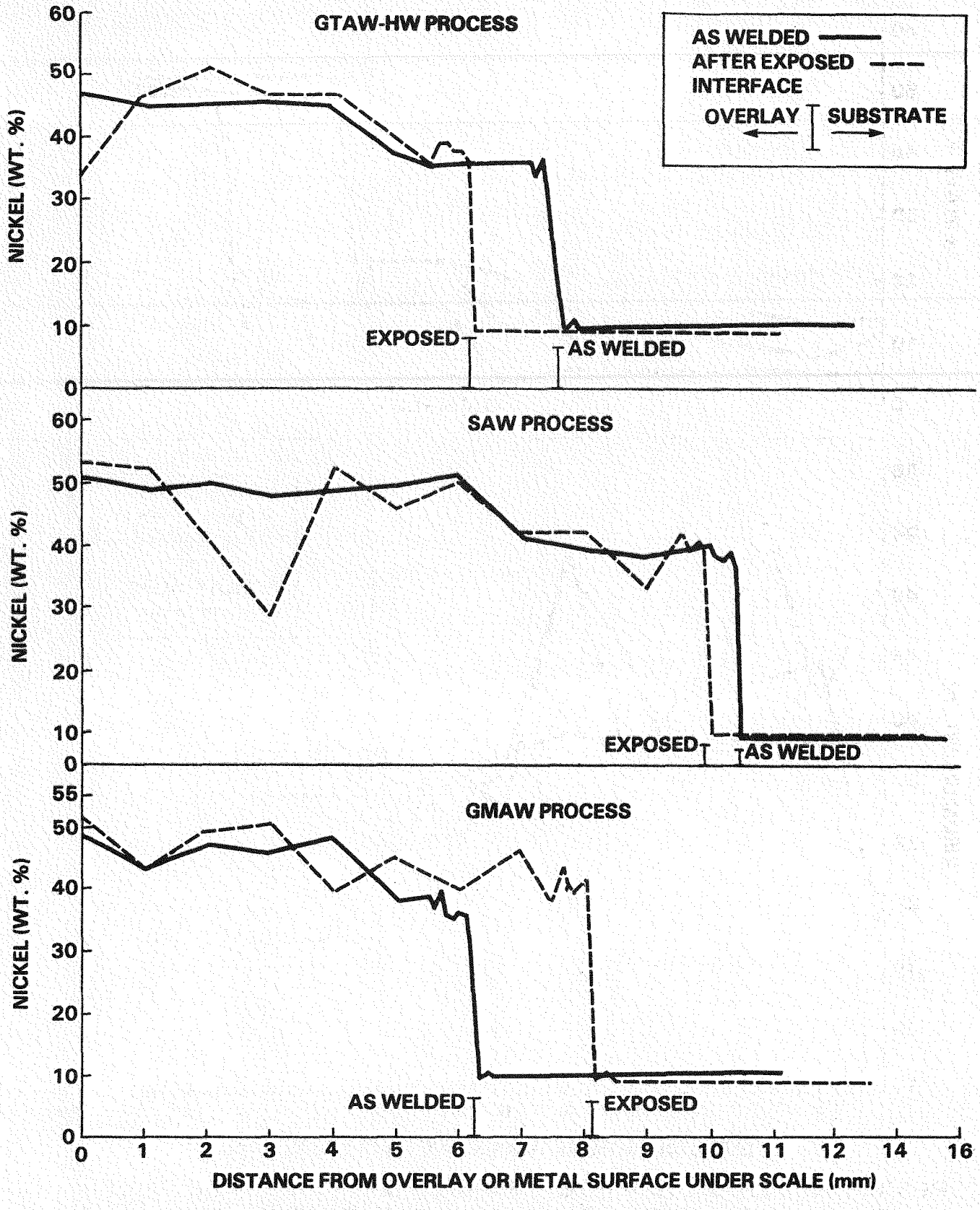


FIGURE 113. – EFFECT OF EXPOSURE IN A CGA ON THE DISTRIBUTION OF NICKEL IN INCONEL FILLER METAL 72 OVERLAYS ON 304L, DOUBLE LAYERS, ALL WELD PROCESSES.

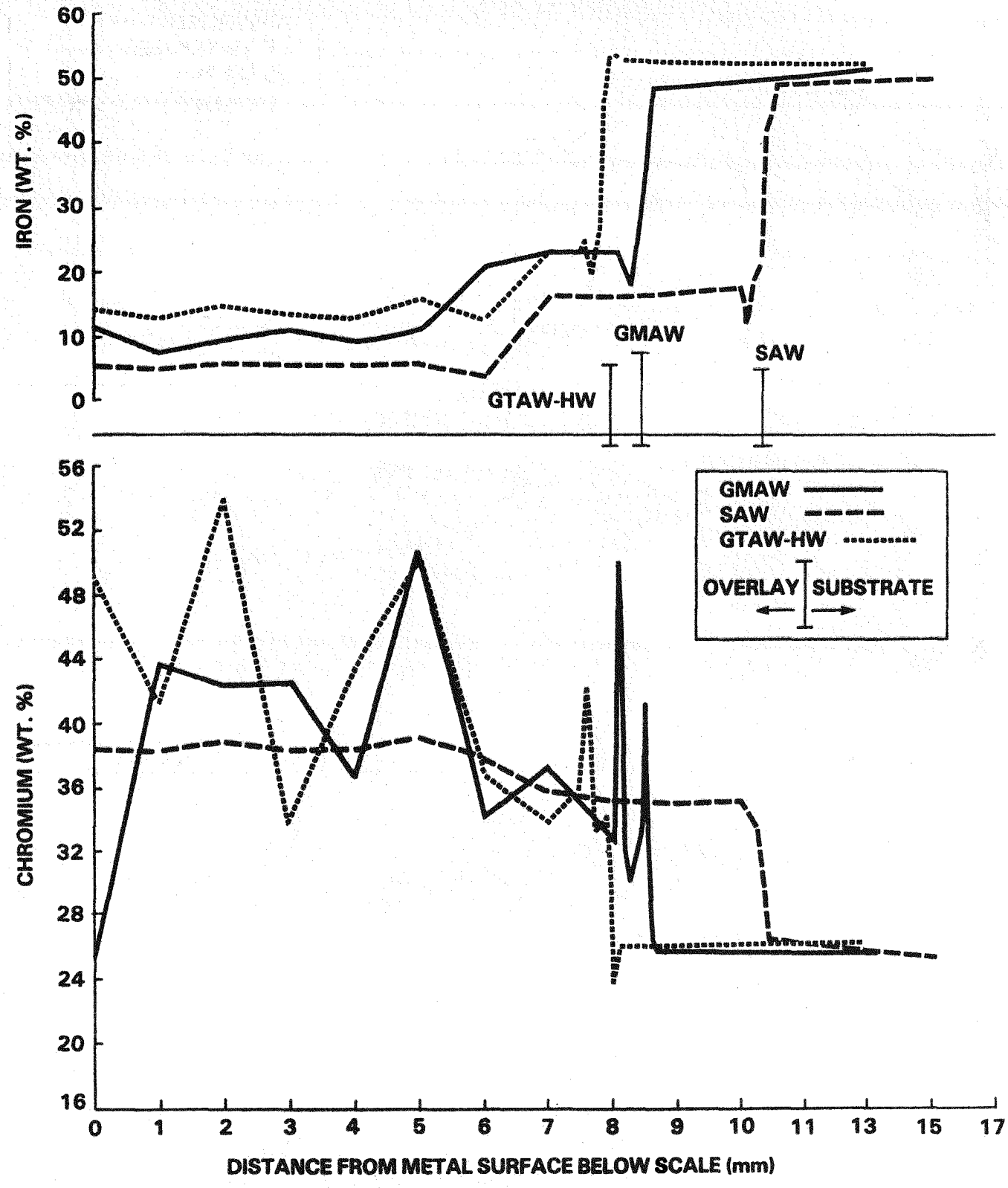


FIGURE 114. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 OVERLAYS ON 310 SS, AFTER EXPOSURE, DOUBLE LAYERS.

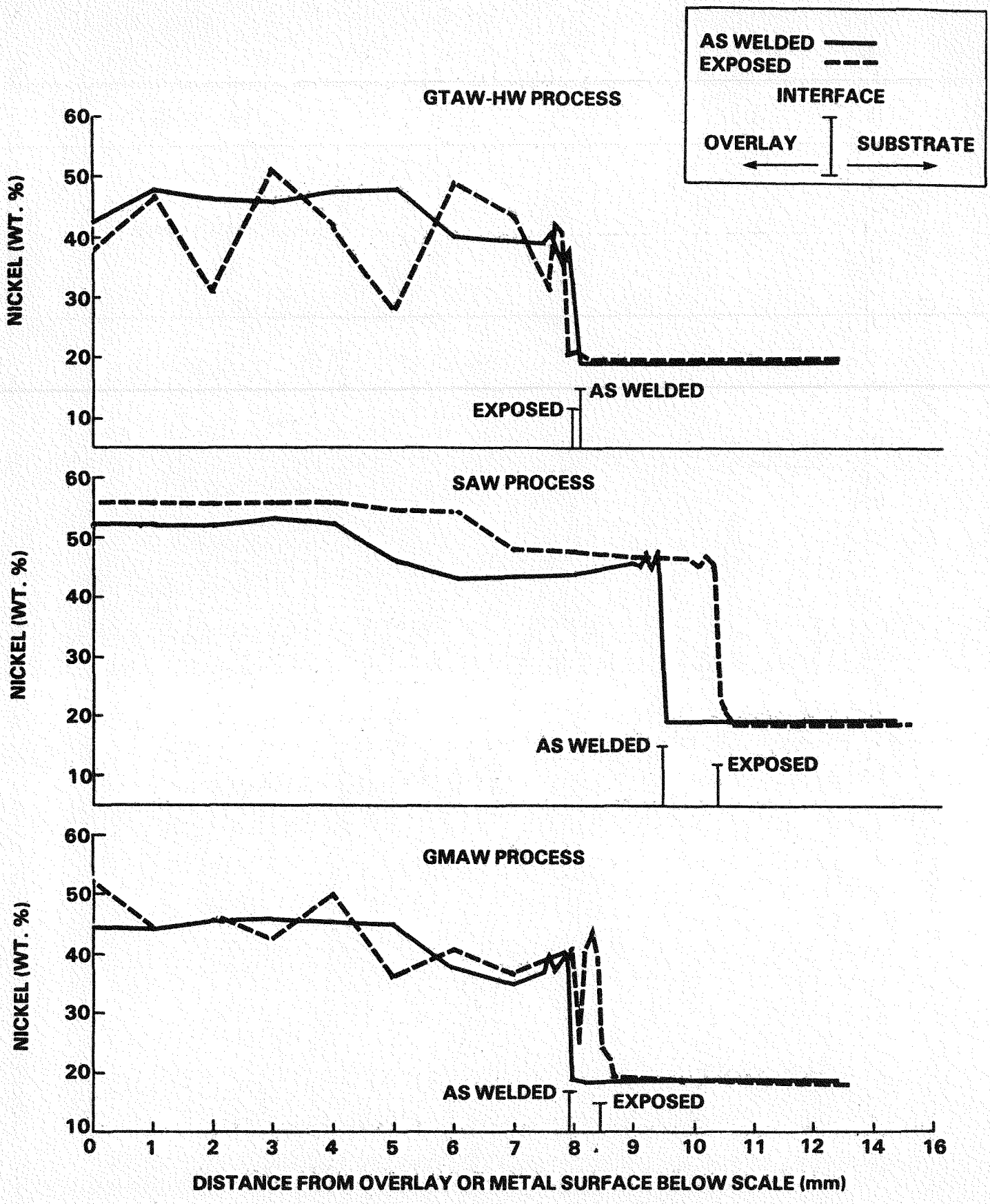


FIGURE 115 EFFECT OF EXPOSURE ON THE DISTRIBUTION OF NICKEL IN INCONEL FILLER METAL 72 OVERLAYS ON 310 SS, DOUBLE LAYERS, ALL WELD PROCESSES.

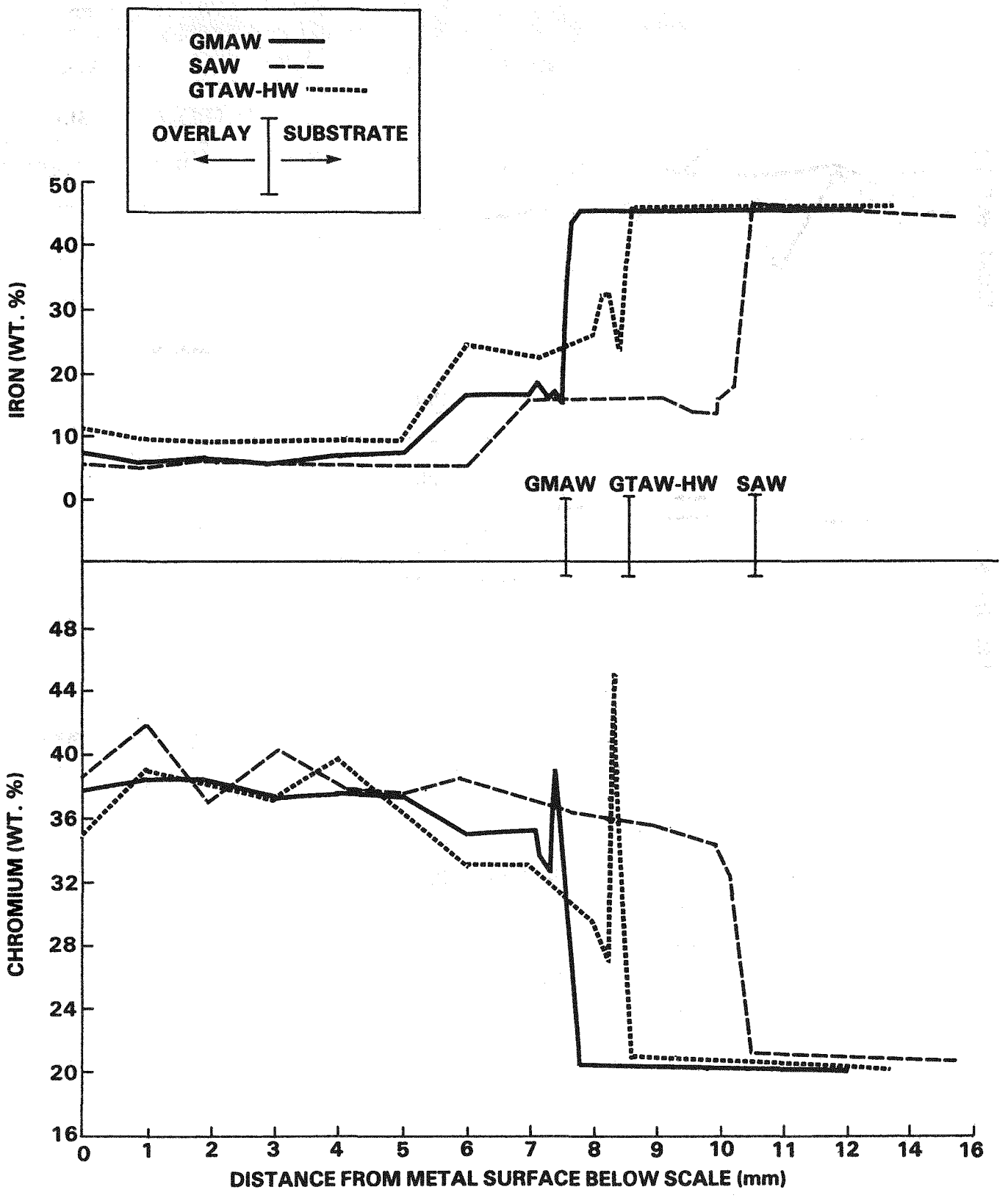


FIGURE 116 EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800 H AFTER EXPOSURE, DOUBLE LAYERS.

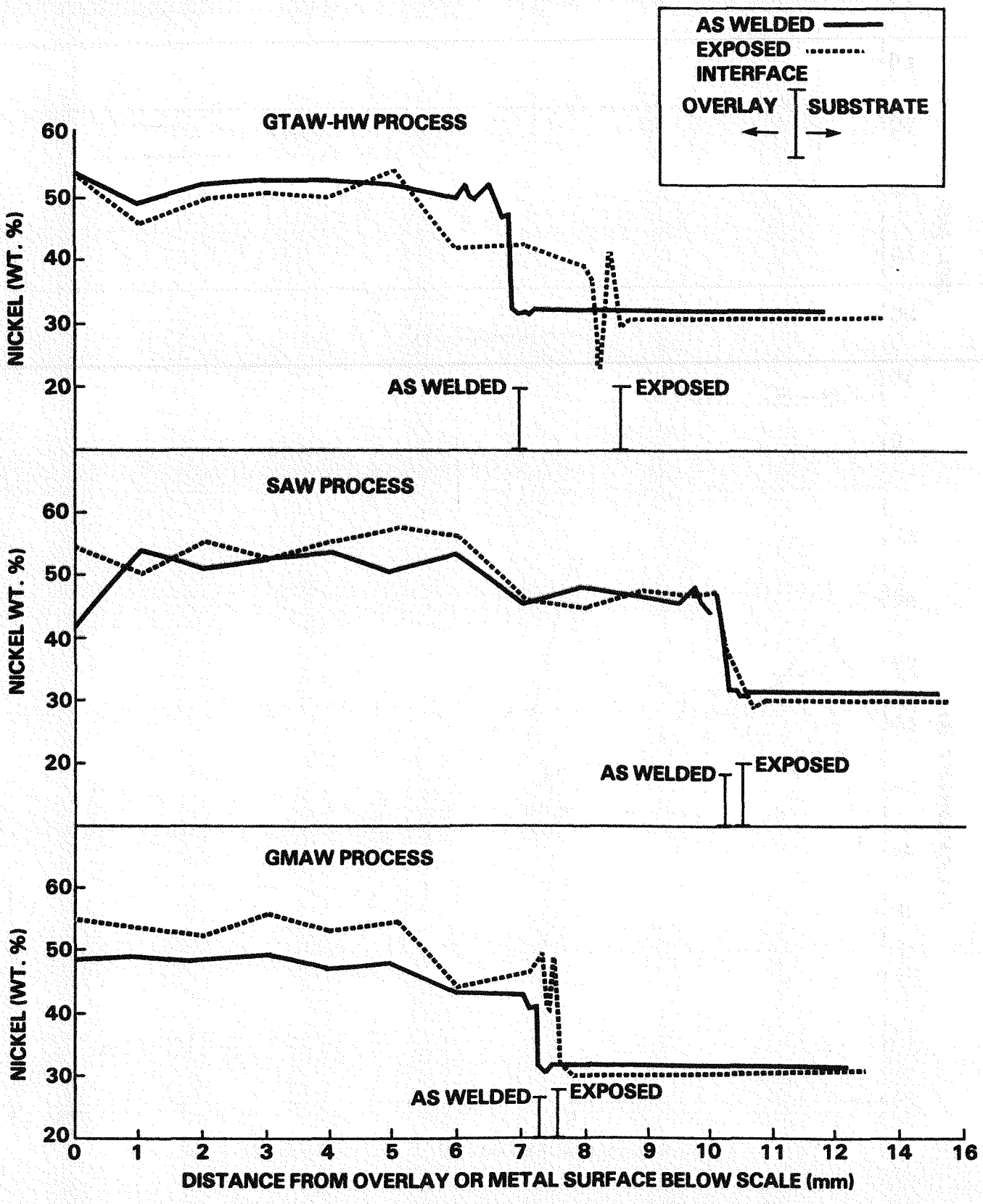


FIGURE 117. – EFFECT OF EXPOSURE ON THE DISTRIBUTION OF NICKEL IN INCONEL FILLER METAL 72 OVERLAYS ON INCONEL ALLOY 800H, DOUBLE LAYERS, ALL WELD PROCESSES

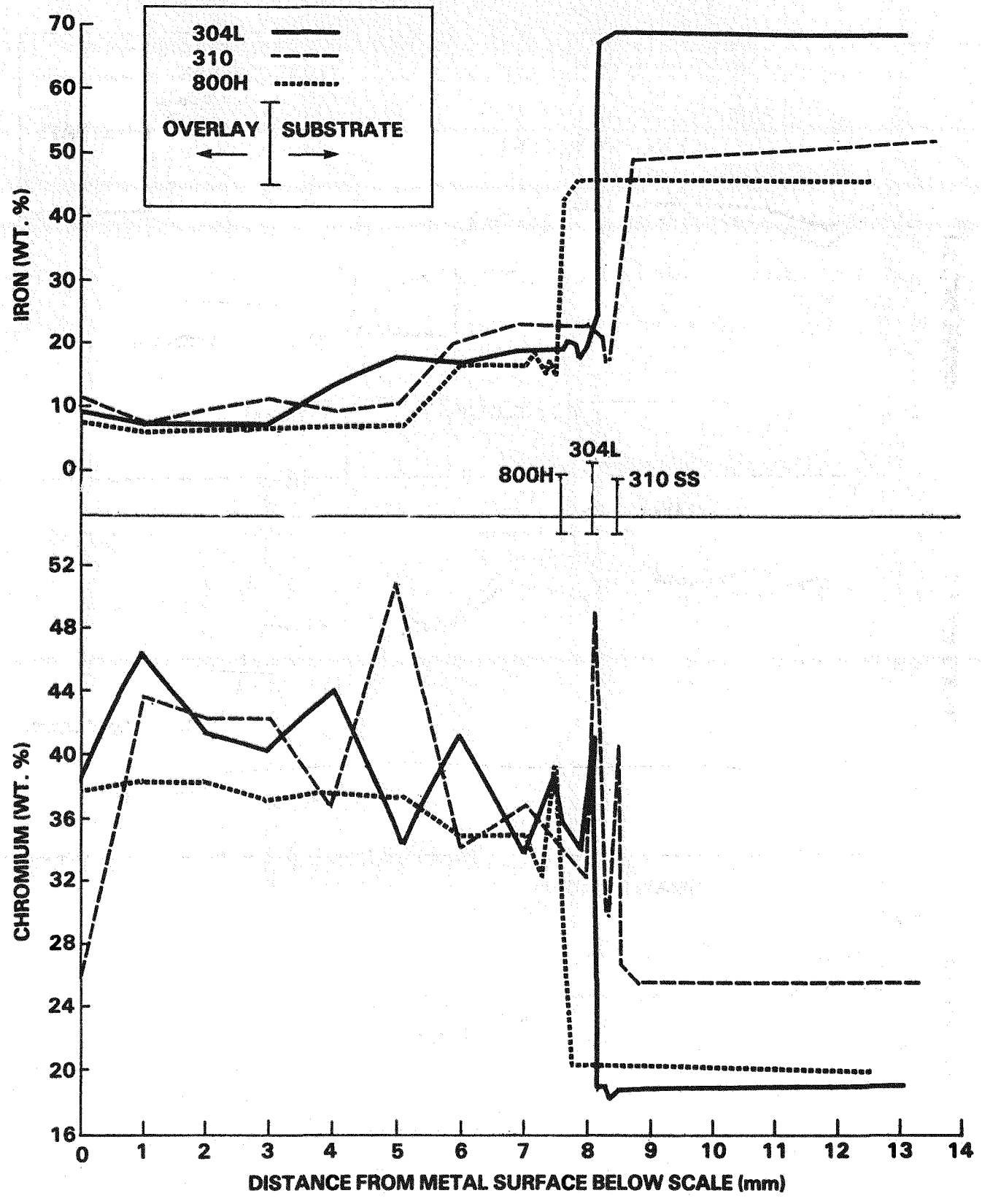


FIGURE 118. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS, AFTER EXPOSURE, GMAW PROCESS, DOUBLE LAYERS

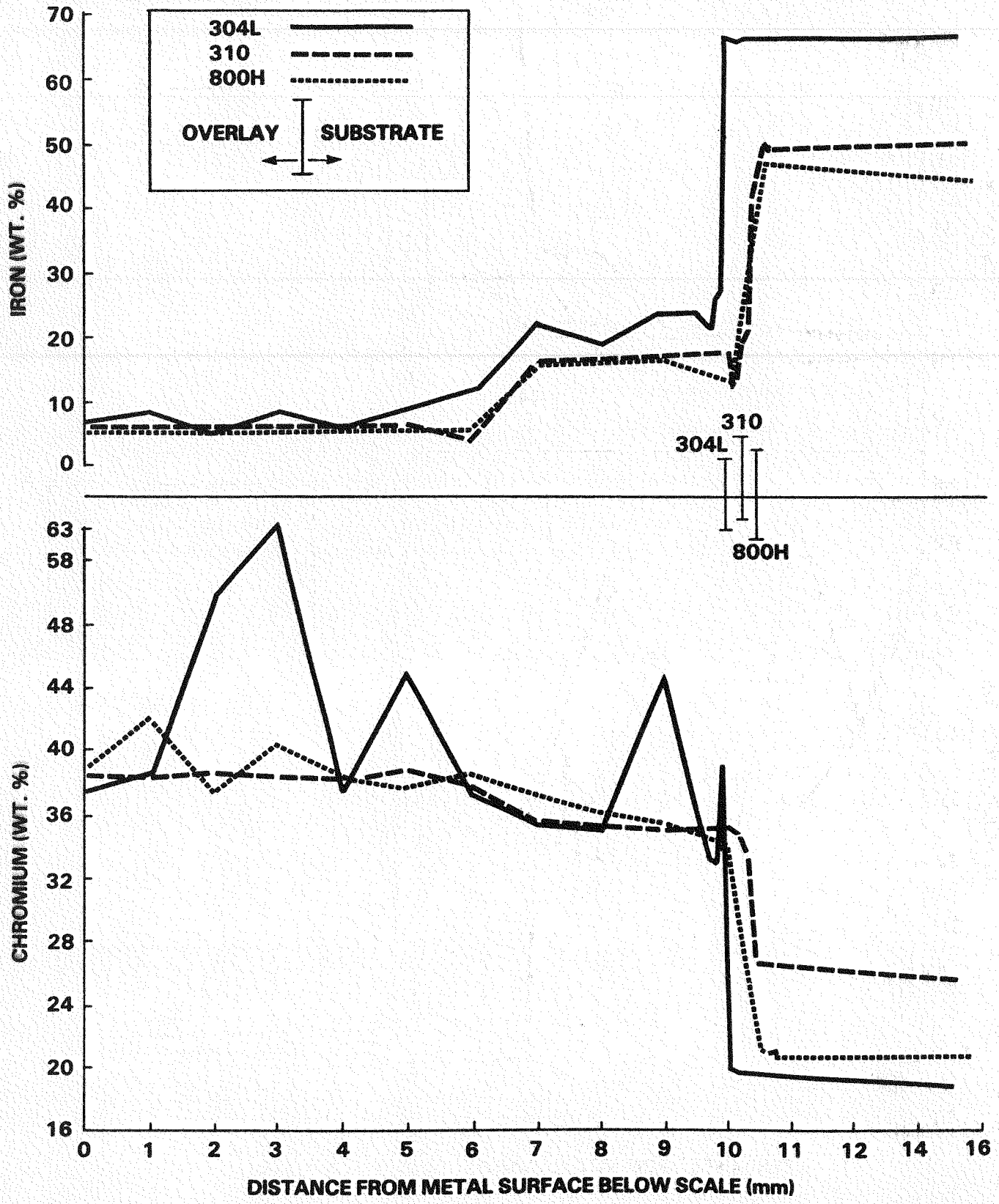


FIGURE 119. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS, SAW PROCESS, AFTER EXPOSURE, DOUBLE LAYERS

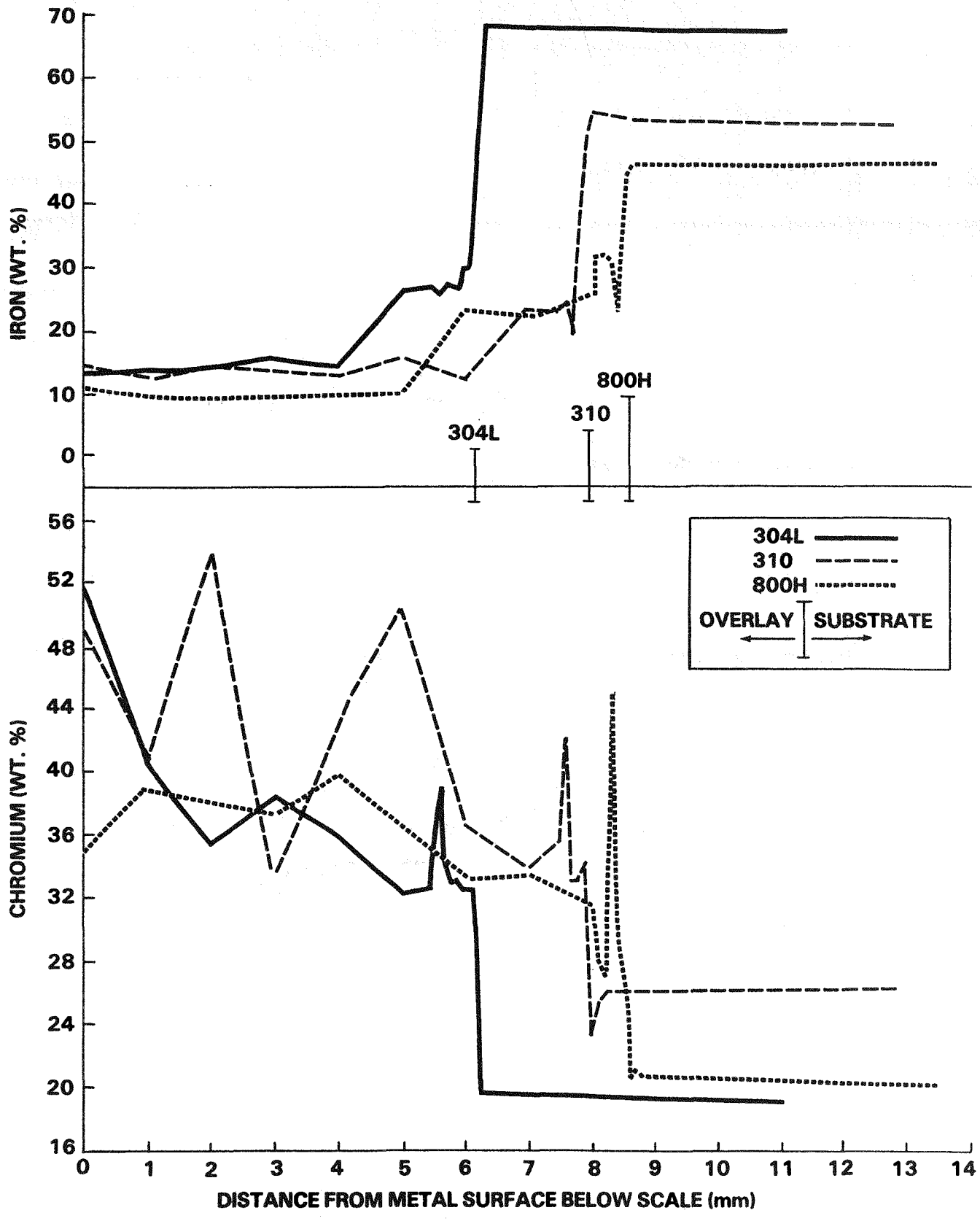


FIGURE 120. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND IRON IN INCONEL FILLER METAL 72 WELDMENTS, AFTER EXPOSURE, GTAW-HW PROCESS, DOUBLE LAYERS

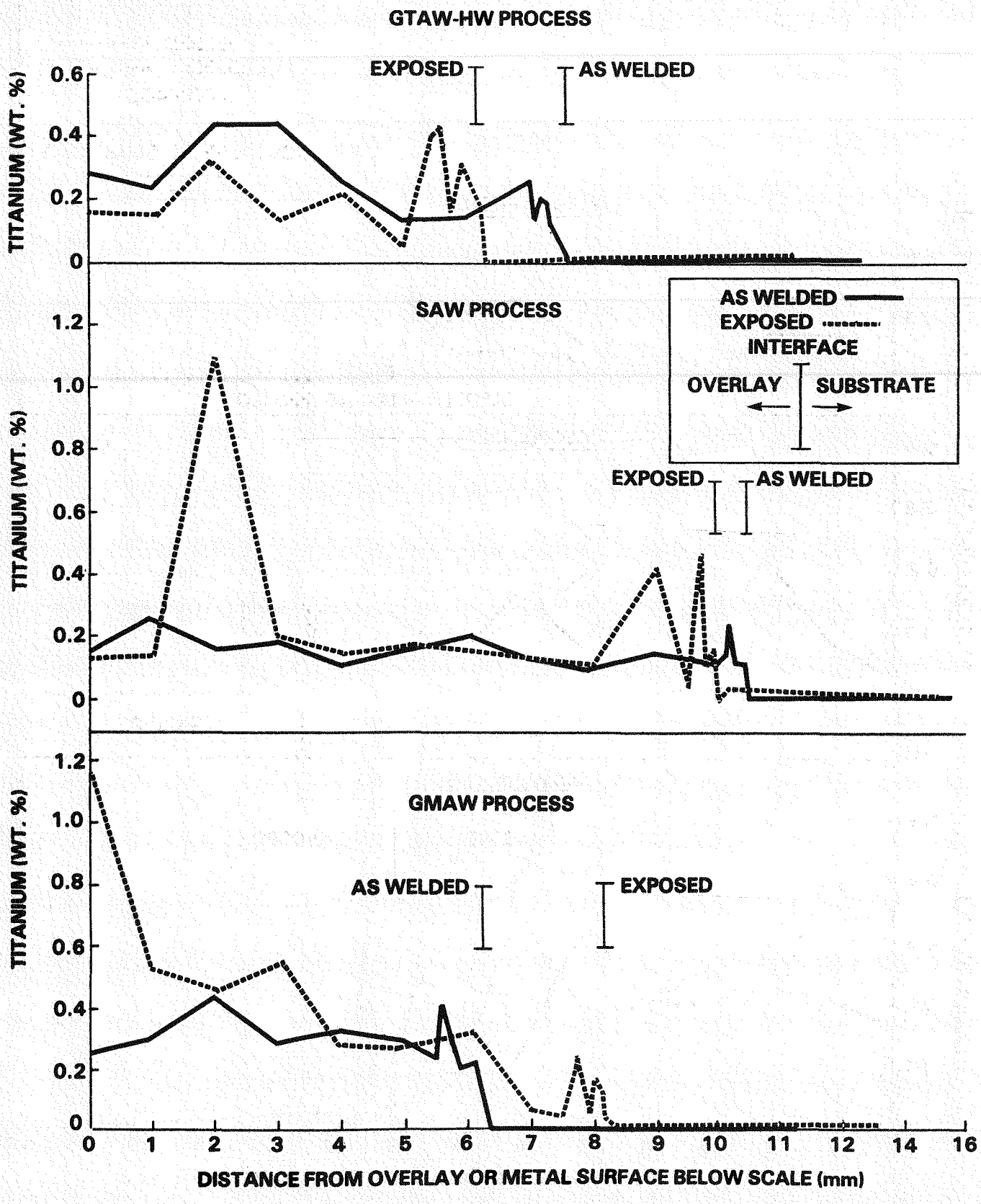


FIGURE 121. – EFFECT OF EXPOSURE ON THE DISTRIBUTION OF TITANIUM IN INCONEL FILLER METAL 72 OVERLAYS ON 304L, DOUBLE LAYERS, ALL WELD PROCESSES.

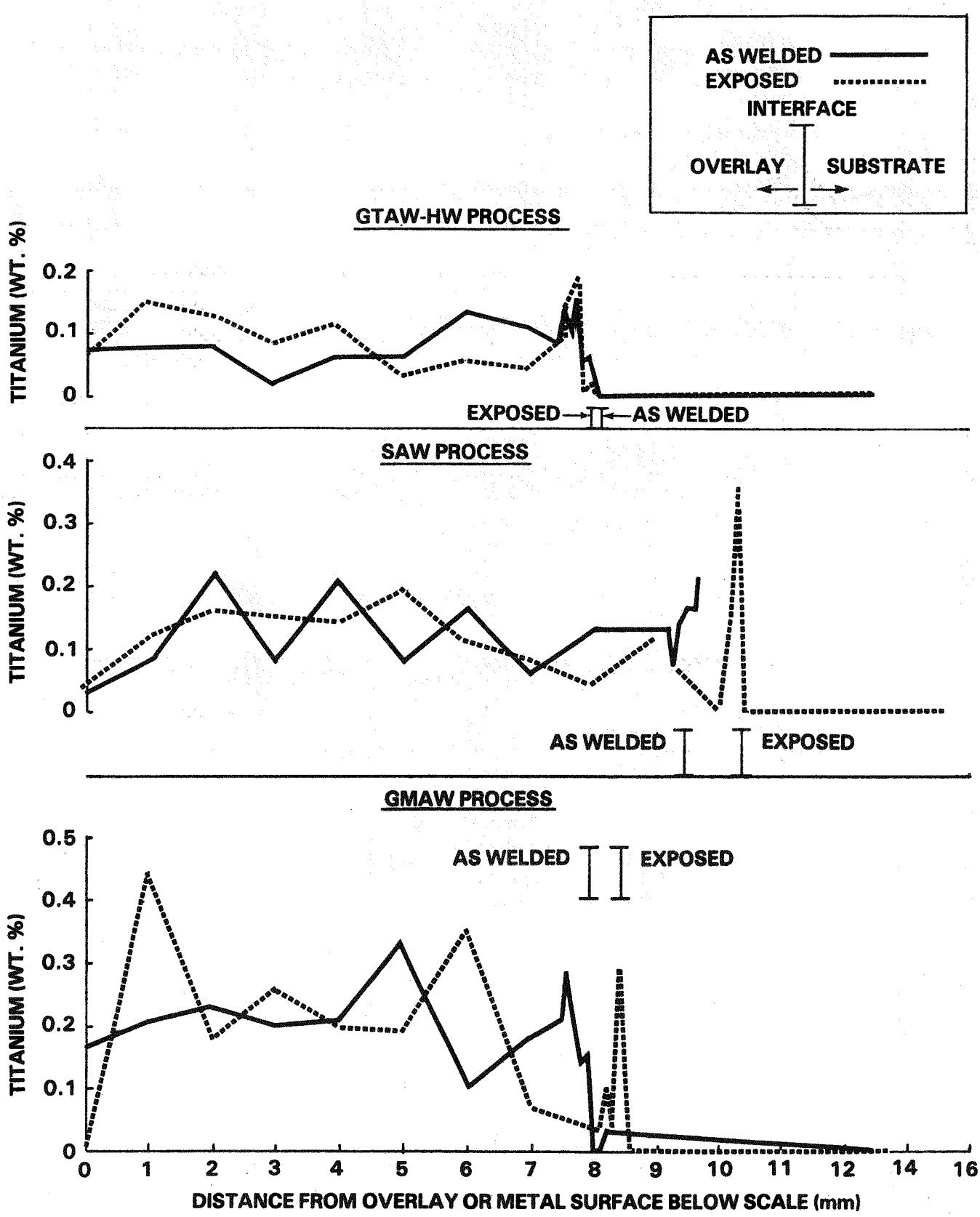


FIGURE 122. – EFFECT OF EXPOSURE ON THE DISTRIBUTION OF TITANIUM IN INCONEL FILLER METAL 72 OVERLAYS ON 310 SS, DOUBLE LAYERS, ALL WELD PROCESSES.

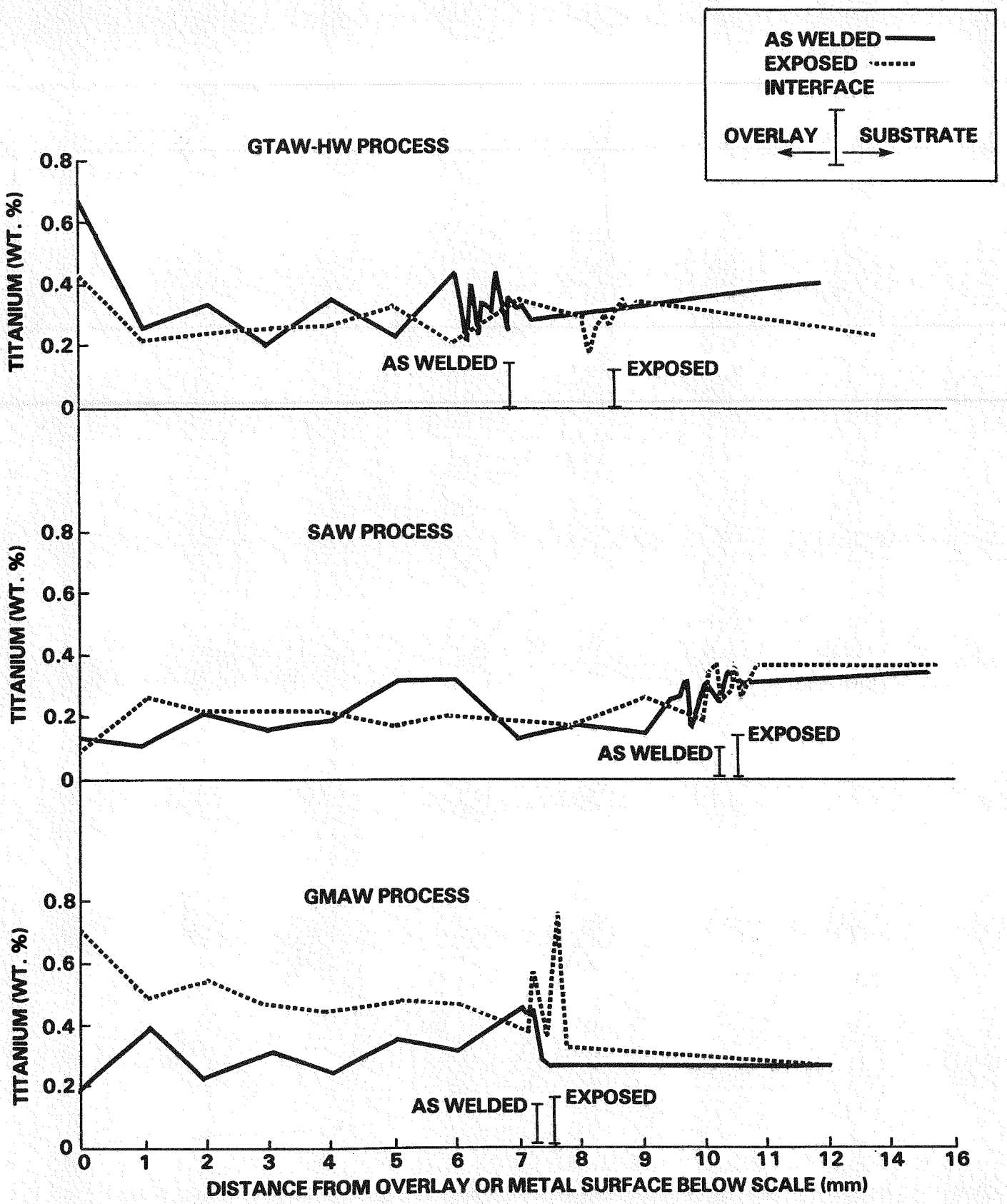


FIGURE 123. – EFFECT OF EXPOSURE ON THE DISTRIBUTION OF TITANIUM IN INCONEL FILLER METAL 72 OVERLAYS ON INCOLOY ALLOY 800H, DOUBLE LAYERS, ALL WELD PROCESSES.

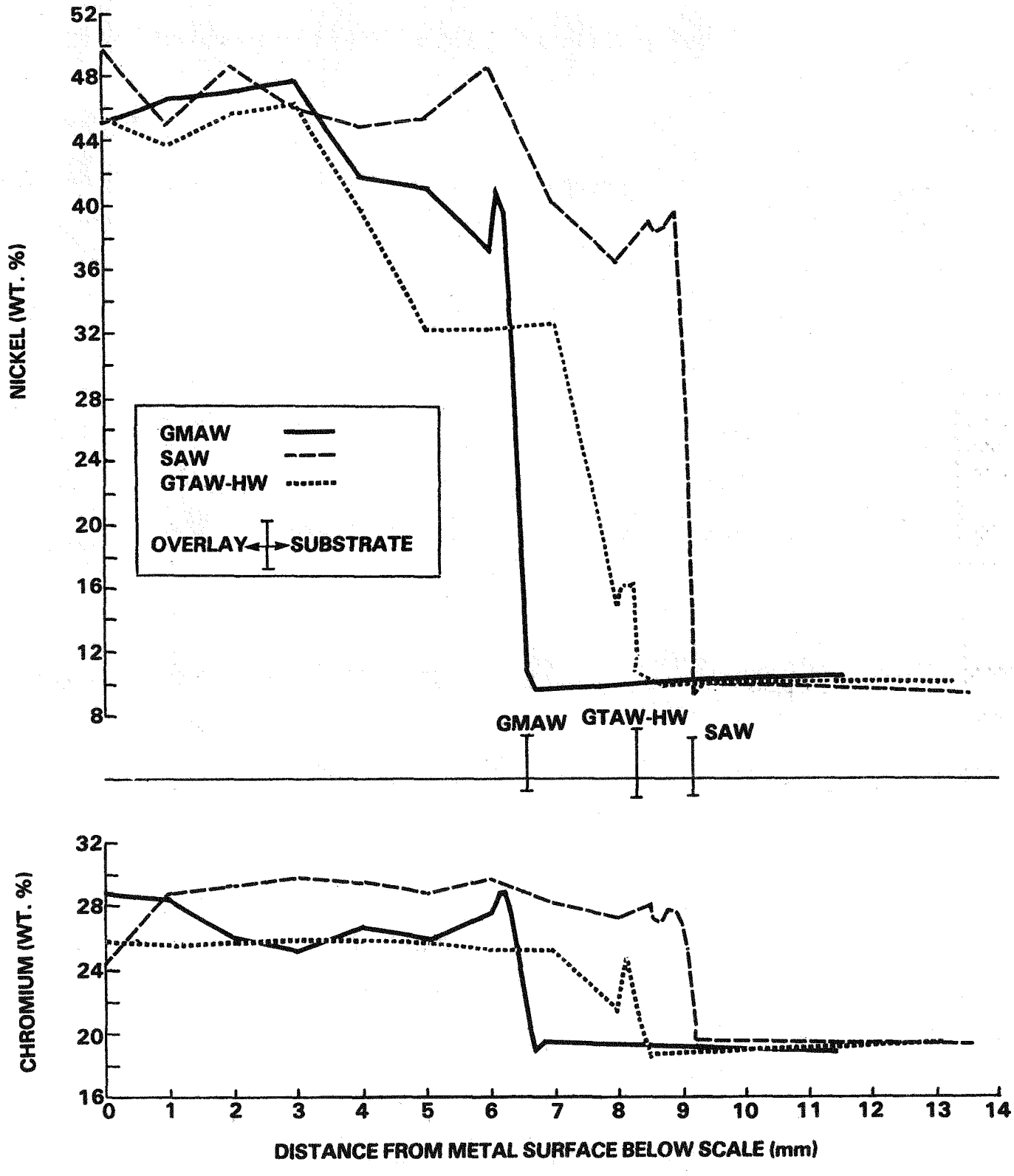


FIGURE 124. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS ON 304L AFTER EXPOSURE IN A CGA, DOUBLE LAYERS.

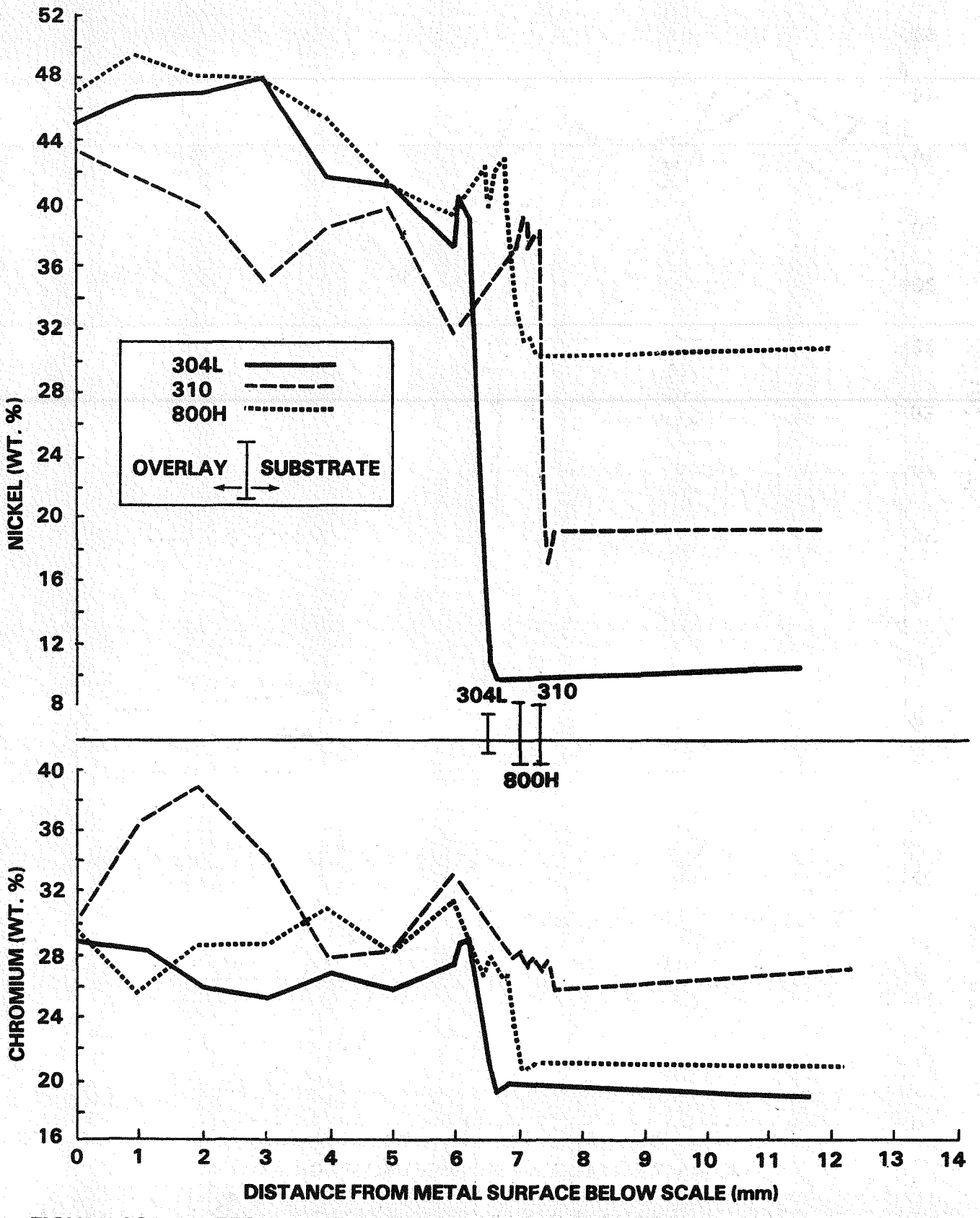


FIGURE 125. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, GMAW PROCESS, DOUBLE LAYERS

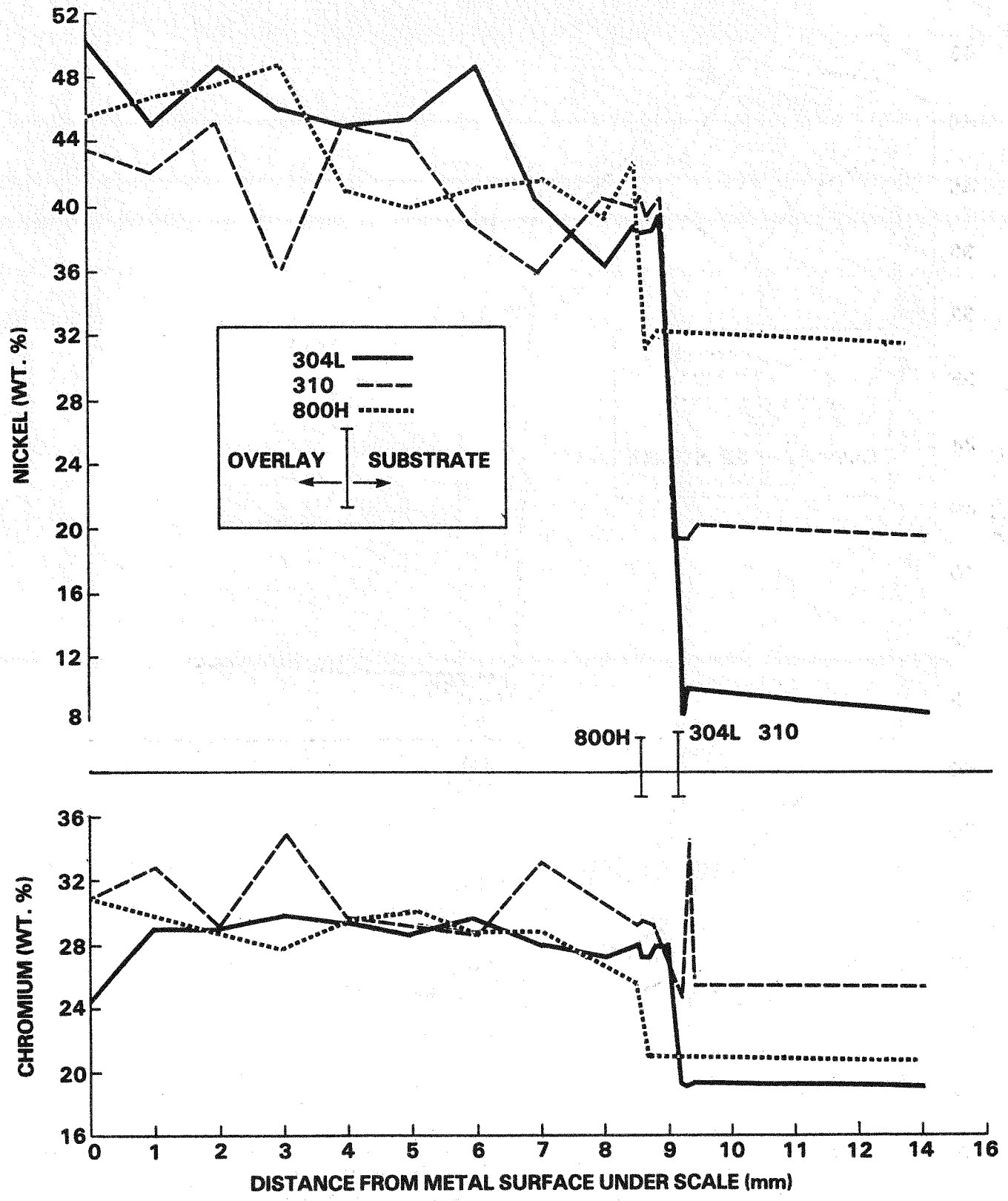


FIGURE 126. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, SAW PROCESS, DOUBLE LAYERS

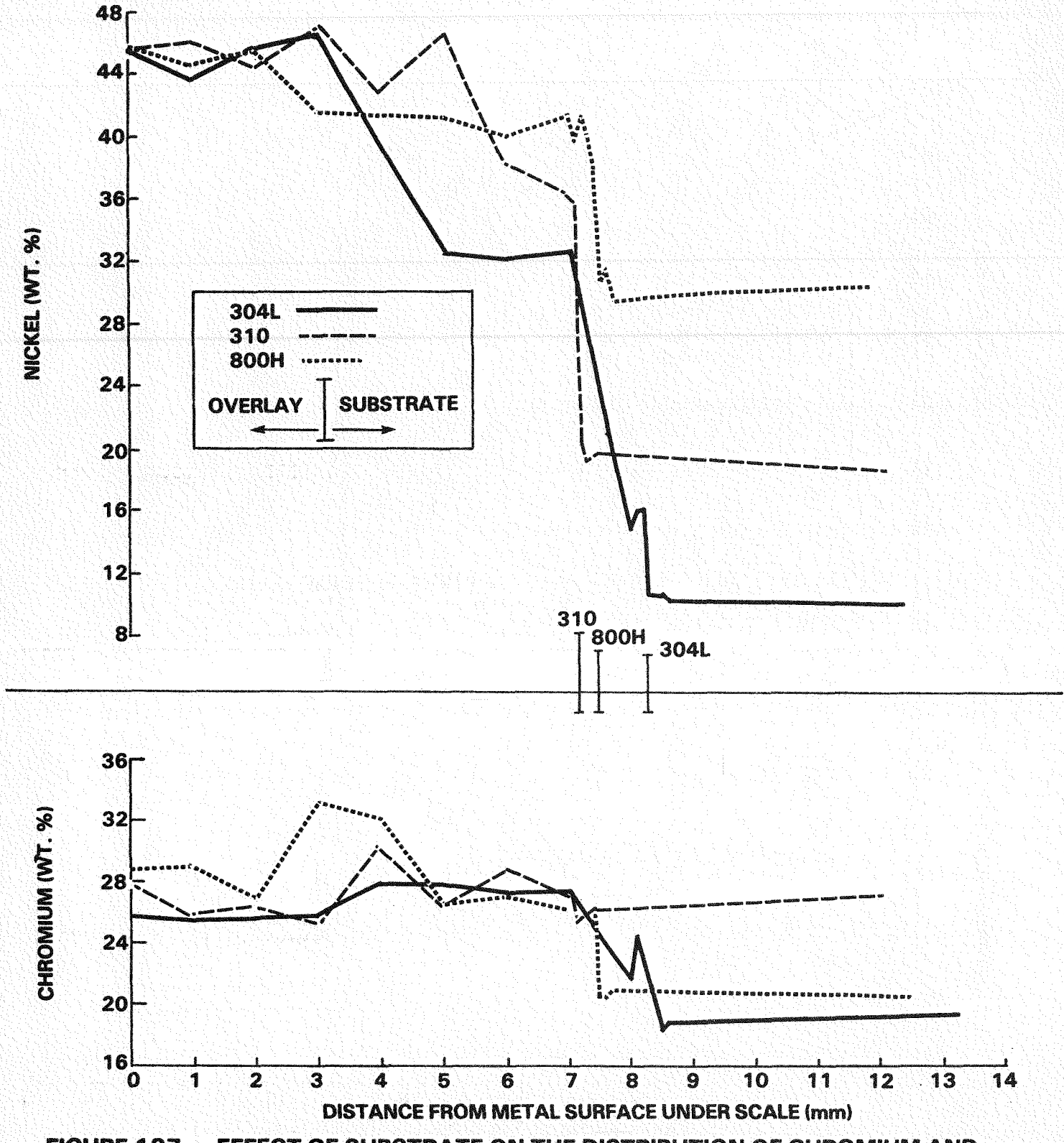


FIGURE 127. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, GTAW-HW PROCESS, DOUBLE LAYERS

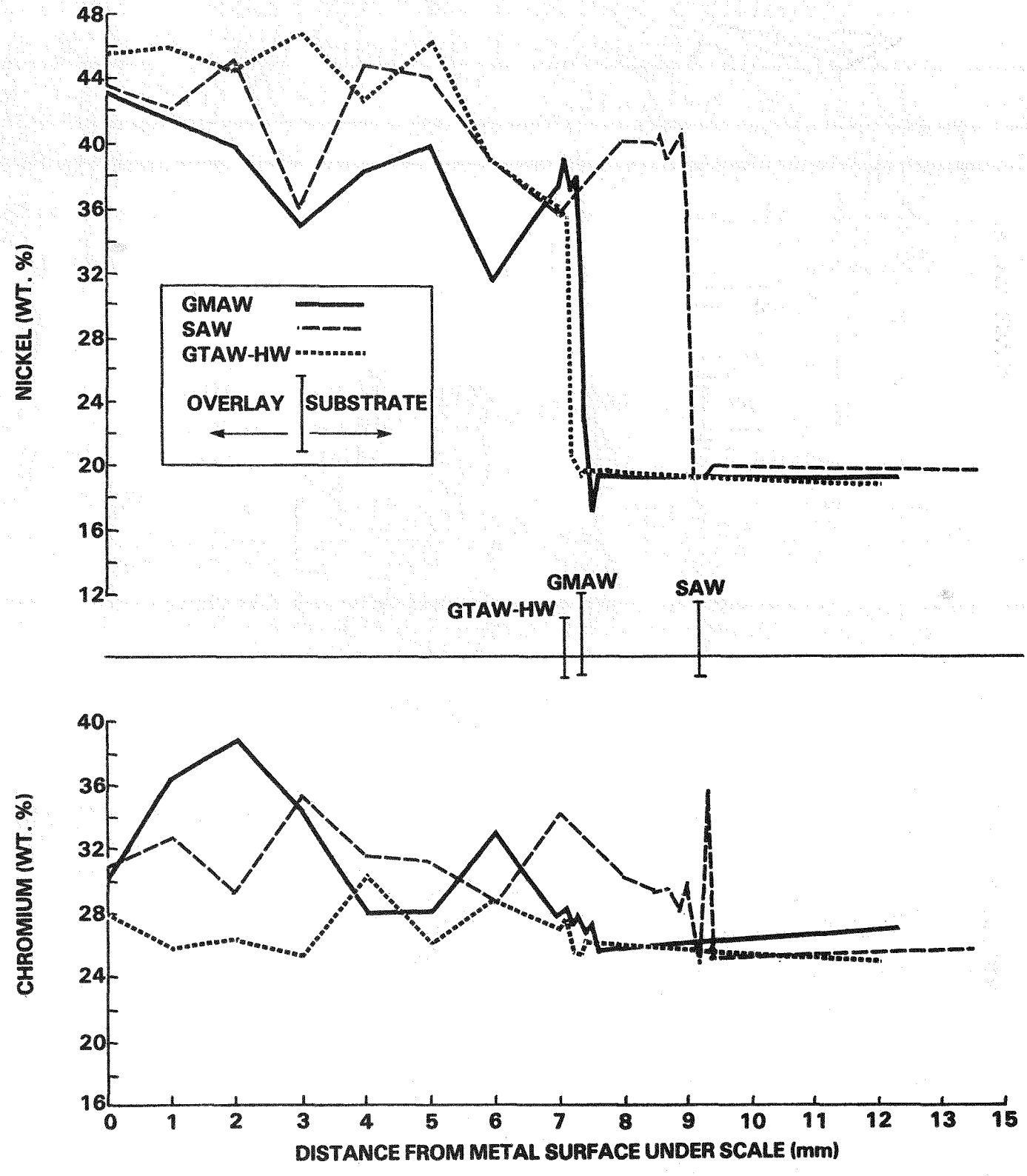


FIGURE 128. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS ON 310 SS AFTER EXPOSURE IN A CGA, DOUBLE LAYERS

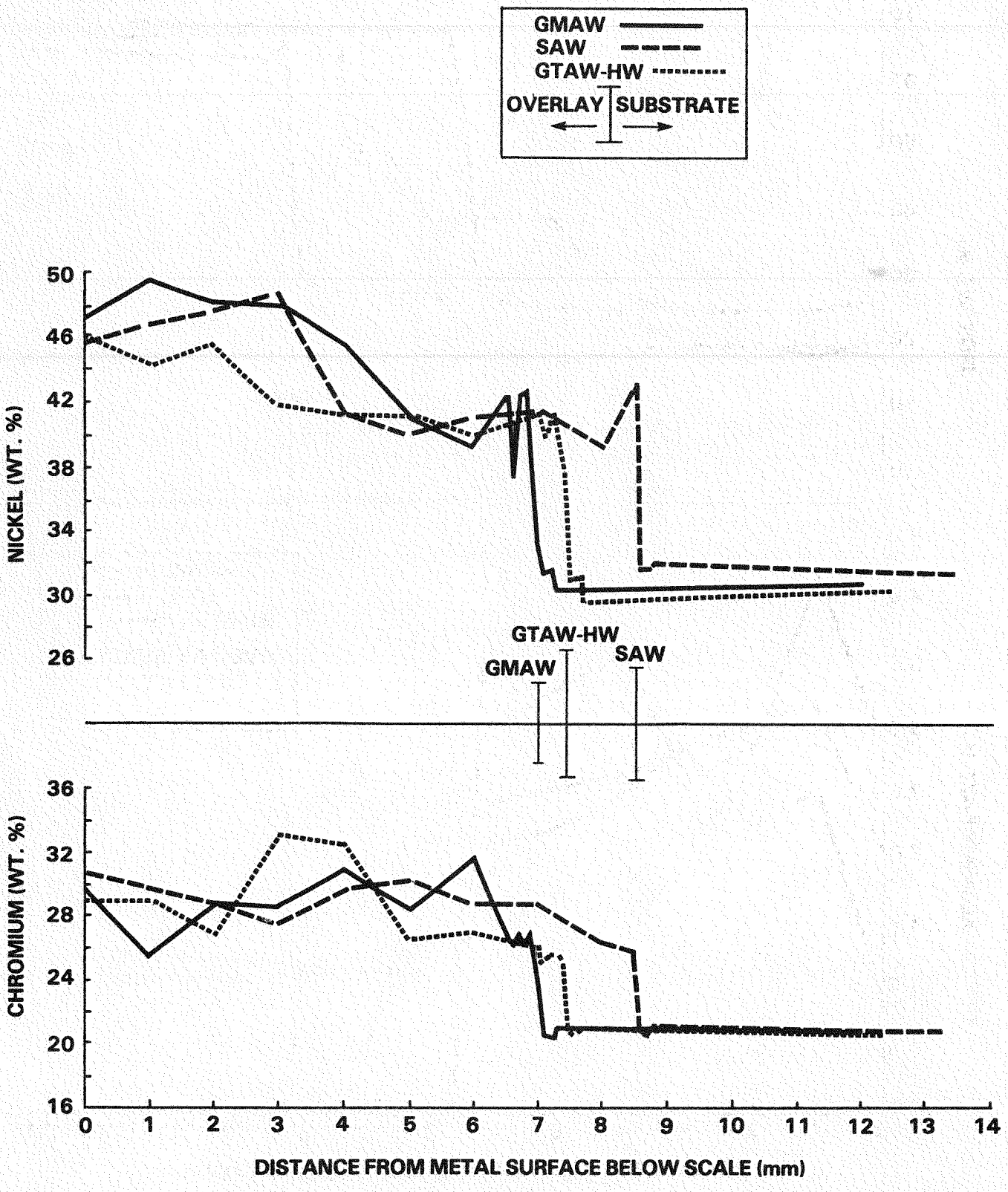


FIGURE 129. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF CHROMIUM AND NICKEL IN R139 OVERLAYS ON INCOLOY ALLOY 800H AFTER EXPOSURE IN A CGA, DOUBLE LAYERS.

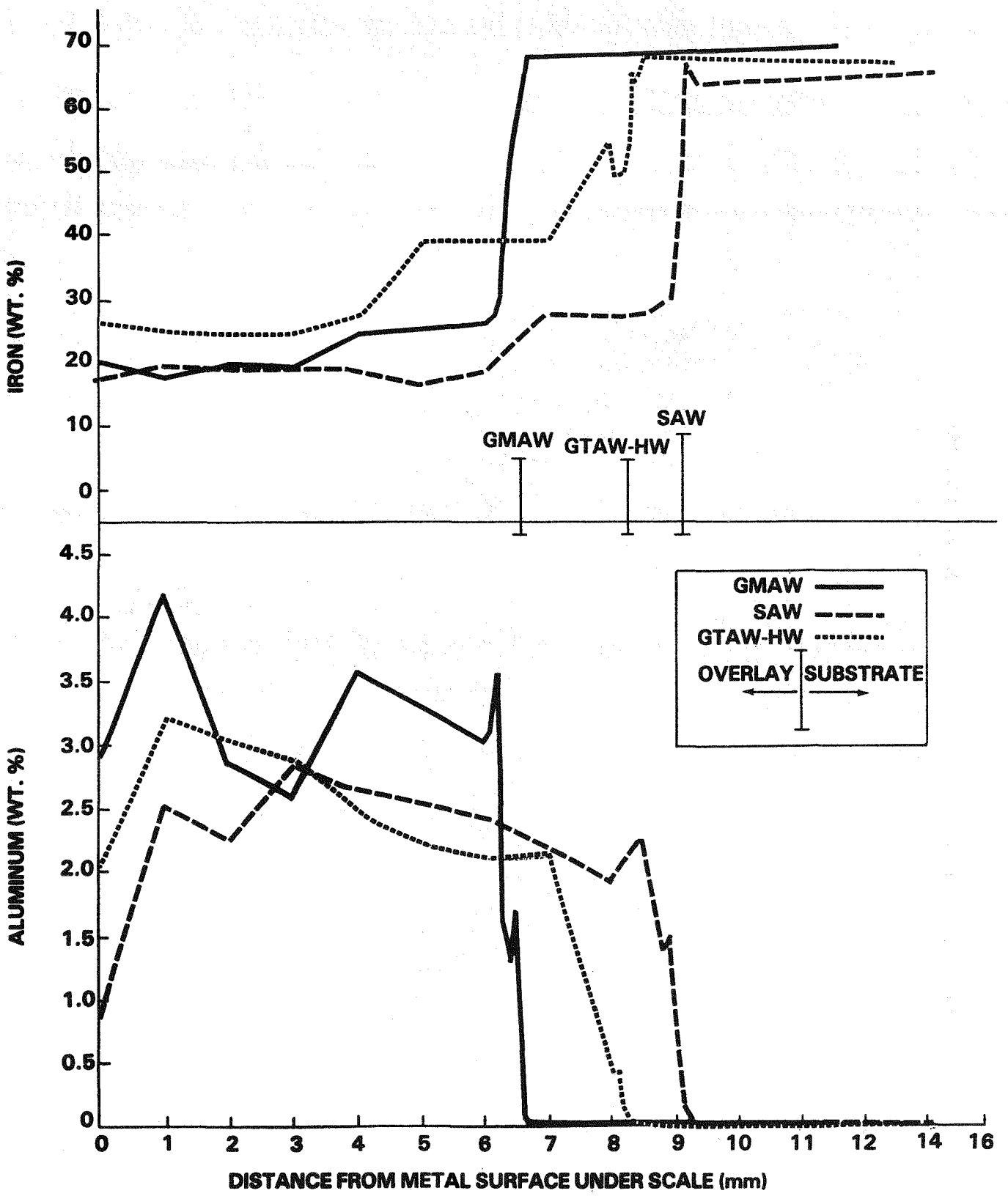


FIGURE 130. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 OVERLAYS ON 304L AFTER EXPOSURE IN A CGA, DOUBLE LAYERS.

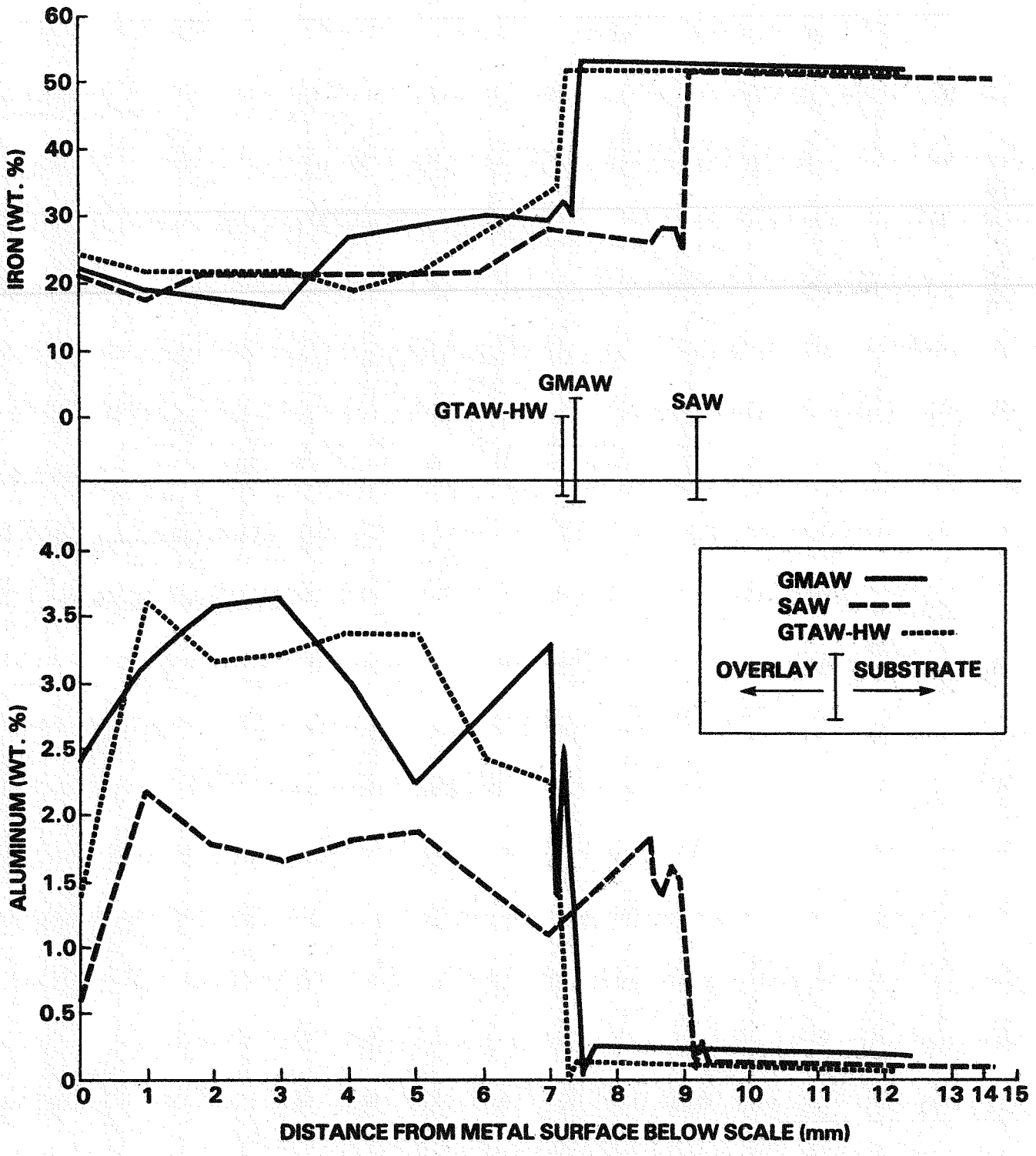


FIGURE 131. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 OVERLAYS ON 310 SS AFTER EXPOSURE TO A CGA, DOUBLE LAYERS.

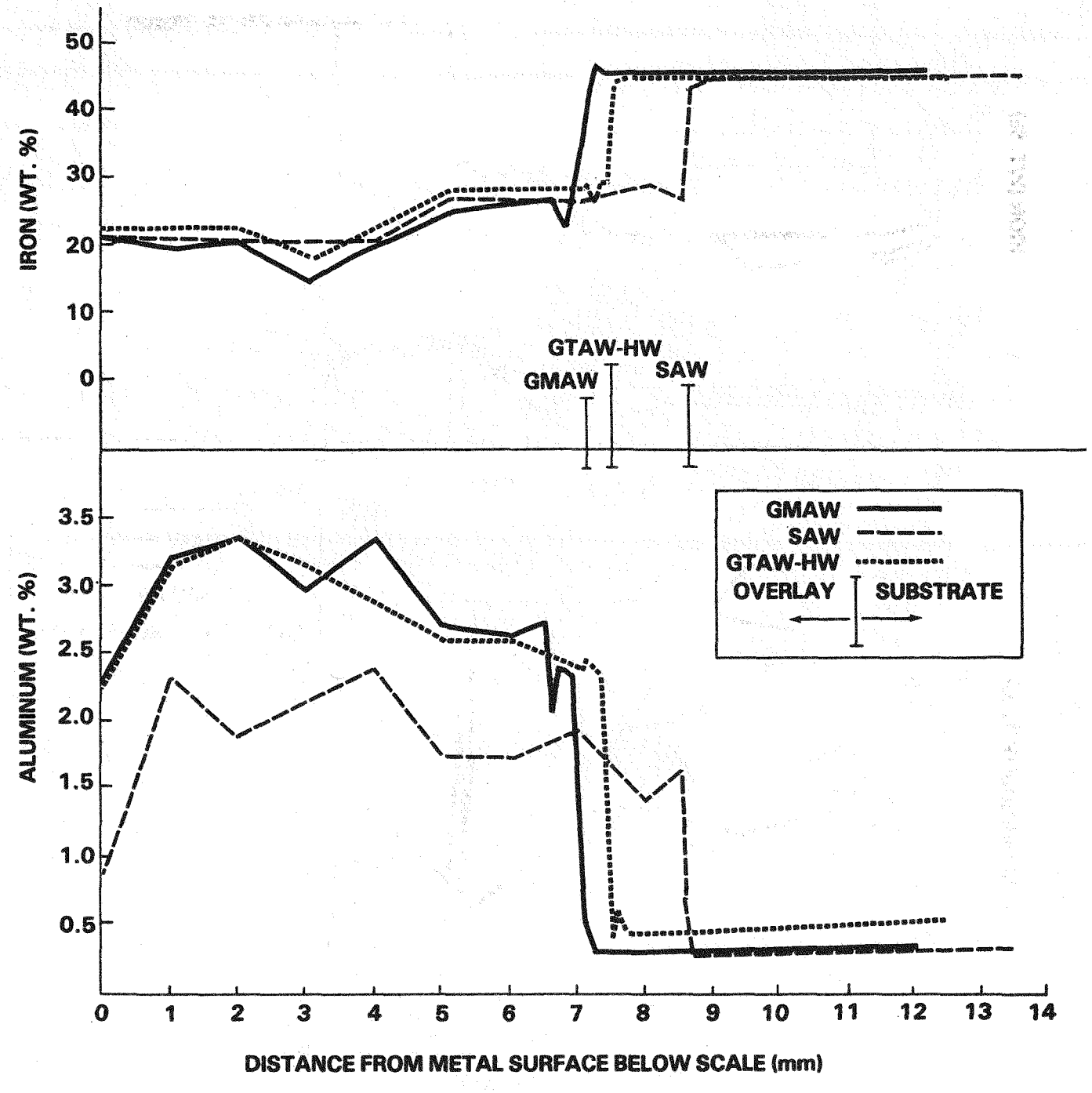


FIGURE 132. – EFFECT OF WELDING PROCESS ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 OVERLAYS ON INCOLOY ALLOY 800H AFTER EXPOSURE IN A CGA, DOUBLE LAYERS

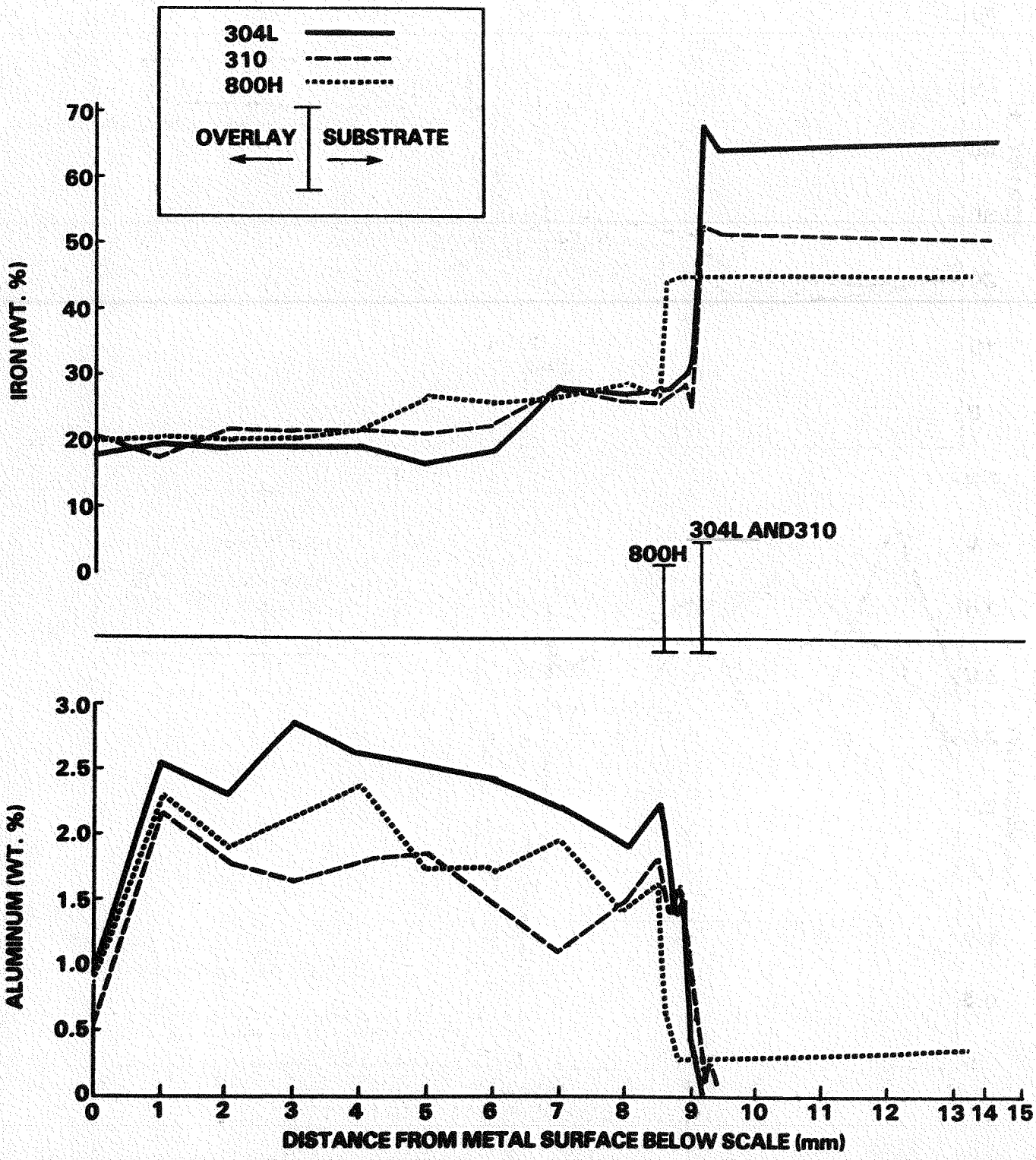


FIGURE 133. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, SAW PROCESS, DOUBLE LAYERS

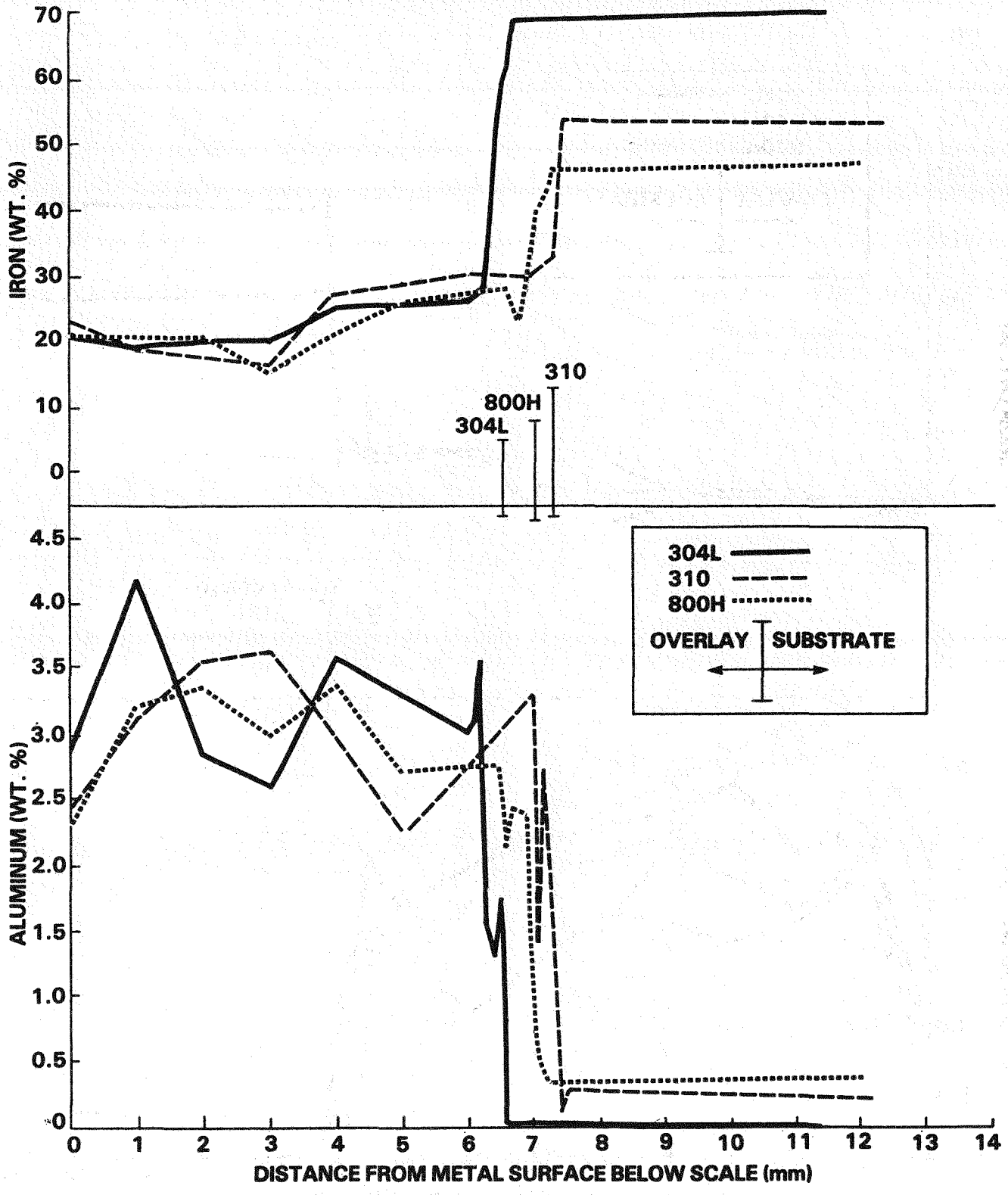


FIGURE 134. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, GMAW PROCESS, DOUBLE LAYERS

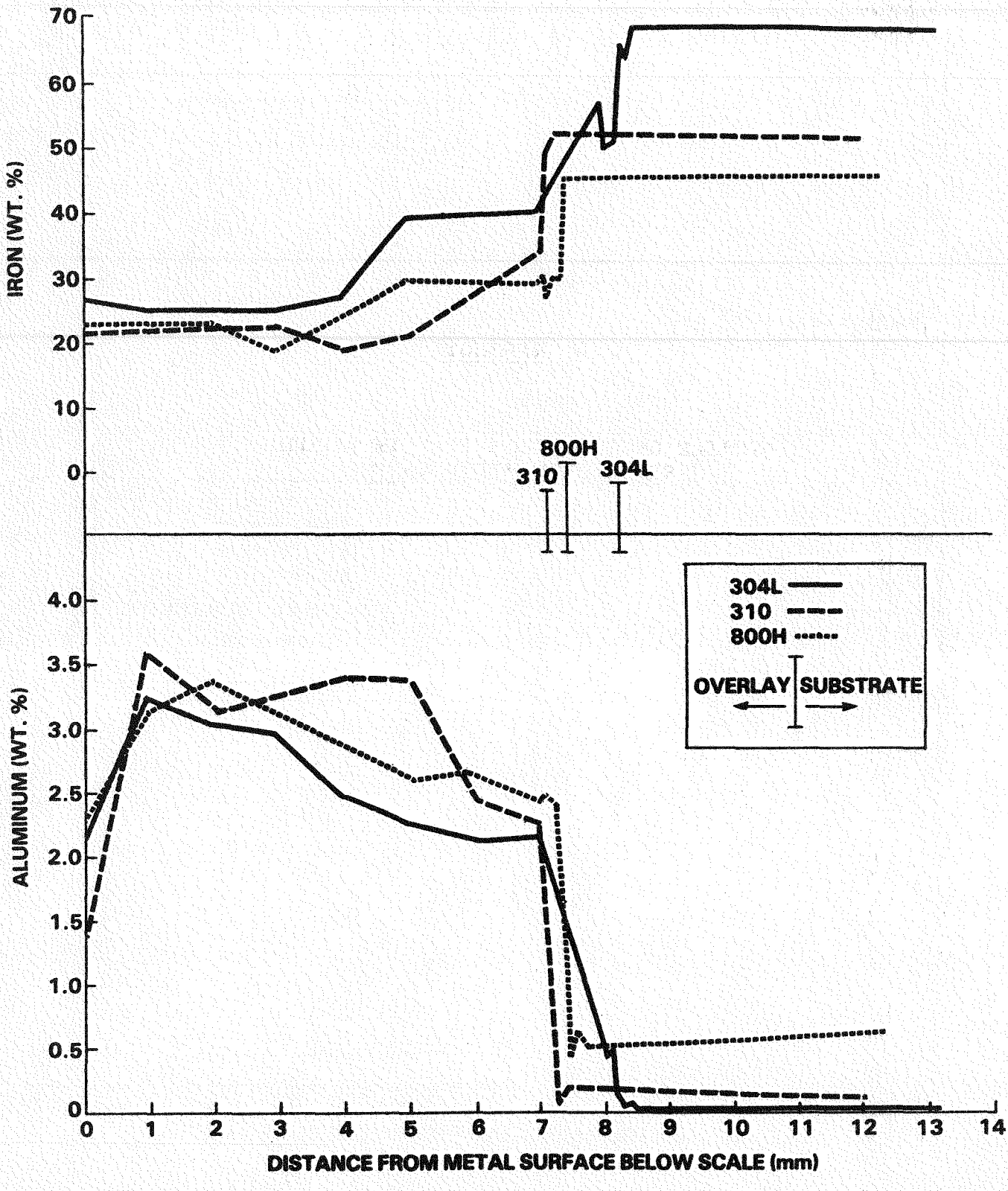


FIGURE 135. – EFFECT OF SUBSTRATE ON THE DISTRIBUTION OF IRON AND ALUMINUM IN R139 WELDMENTS AFTER EXPOSURE IN A CGA, GTAW-HW PROCESS, DOUBLE LAYERS

8.0 APPENDIX

DETAILS OF 1000-HOUR TEST IN A COAL GASIFICATION ENVIRONMENT

1.0 SUMMARY

A variety of weld overlay materials were exposed to a coal gasification mixture at 1800°F for a period of 1000 hours. The corrosion observed ranged from minor to severe, depending on the material. The facility description, test operation, and preliminary results are discussed in this report.

This exposure was conducted for the International Nickel Company, Inc., Suffern, New York, who also provided the test specimens and criteria for test conditions and who will perform the post-test metallurgical analyses.

1.1 Objective

The objective was to provide a controlled thermal/gaseous environment on a number of test specimens to allow metallurgical evaluation of corrosion to be made.

1.2 Test Conditions

Test Temperature:	1800°F
Pressure:	Local Atmospheric
Gas Environment:	12% CO_2
	18% CO
	24% H_2
	5% CH_4
	1% NH_3
	1% H_2S
	39% H_2O
Gas Exchange Rate:	Hourly
Duration:	1000 hours

2.0 TEST SETUP

2.1 Oven

The overall test facility is shown in Figure 1. The oven was housed within the large central box, and surrounded with vermiculite insulation. The controls for temperature and for commodity injection are on the left side. The commodity injection system was mounted on the face of the box, with the gas supply bottles on the right side.

A schematic of the oven configuration appears as Figure 2. The fiberblock insulation was stacked in place directly on the concrete floor. The lower section of the lightweight castable refractory was placed on the fiberblock as a support for the remaining oven assembly. The heater elements were cast directly into the refractory material. Redundant heaters were installed, since the heaters would not be serviceable with the oven at temperature. All connection wires were passed through the backside of the refractory into the vermiculite insulation area. The connecting wires were stranded nickel, and were attached using tubular stainless steel crimps.

The specimen holding box was constructed of 310 SS, and all closures were completely welded. The inlet pipe was vertical to allow the gas/liquid mixture to make its way quickly to the 1800°F area. The outlet pipe was on the side of the box, and a baffle forced the exhaust to be from the bottom or coolest area of the box. Extra pipes were included on the box as spares, in the event of any blockage during operation.

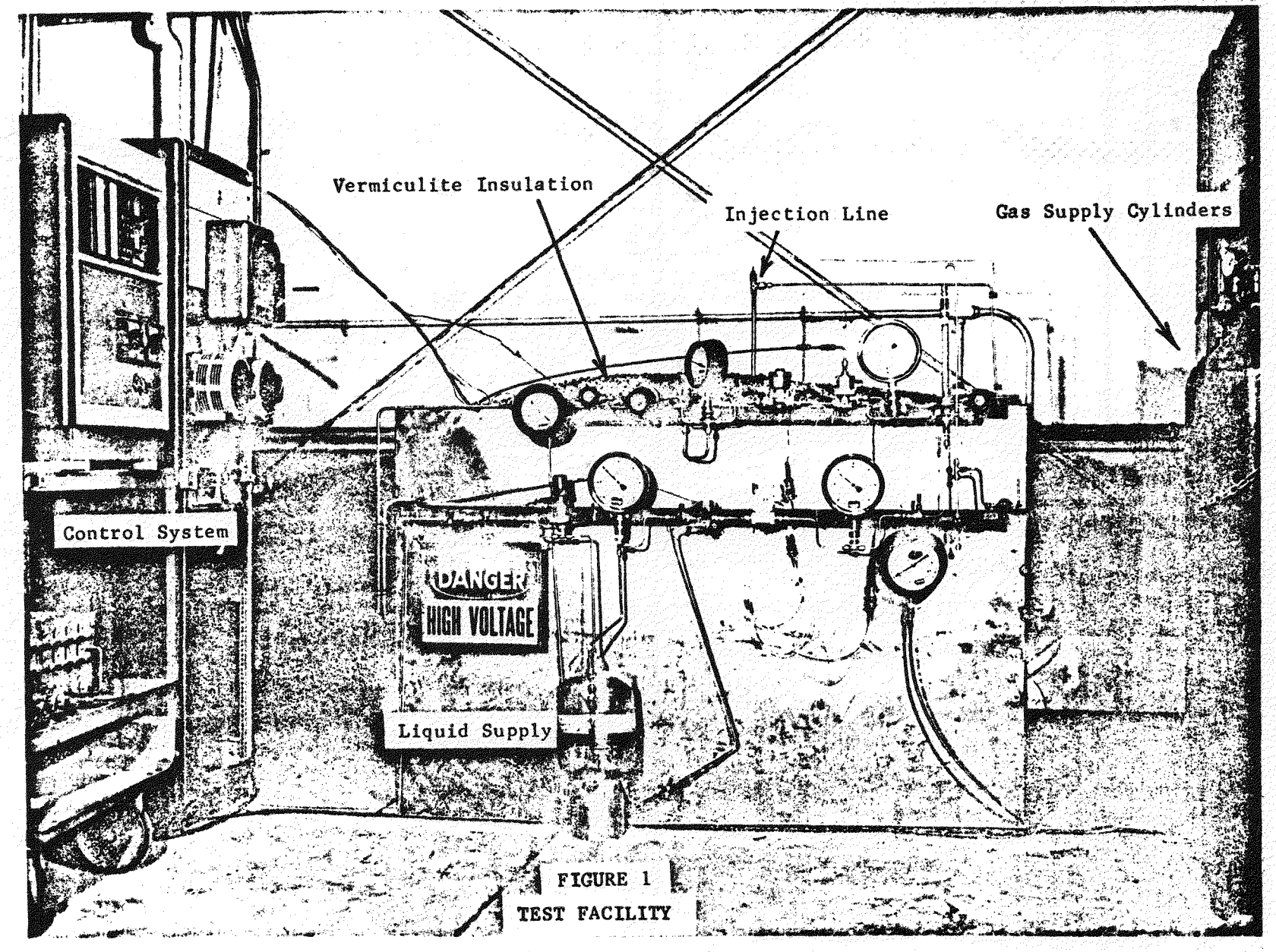


FIGURE 1
TEST FACILITY

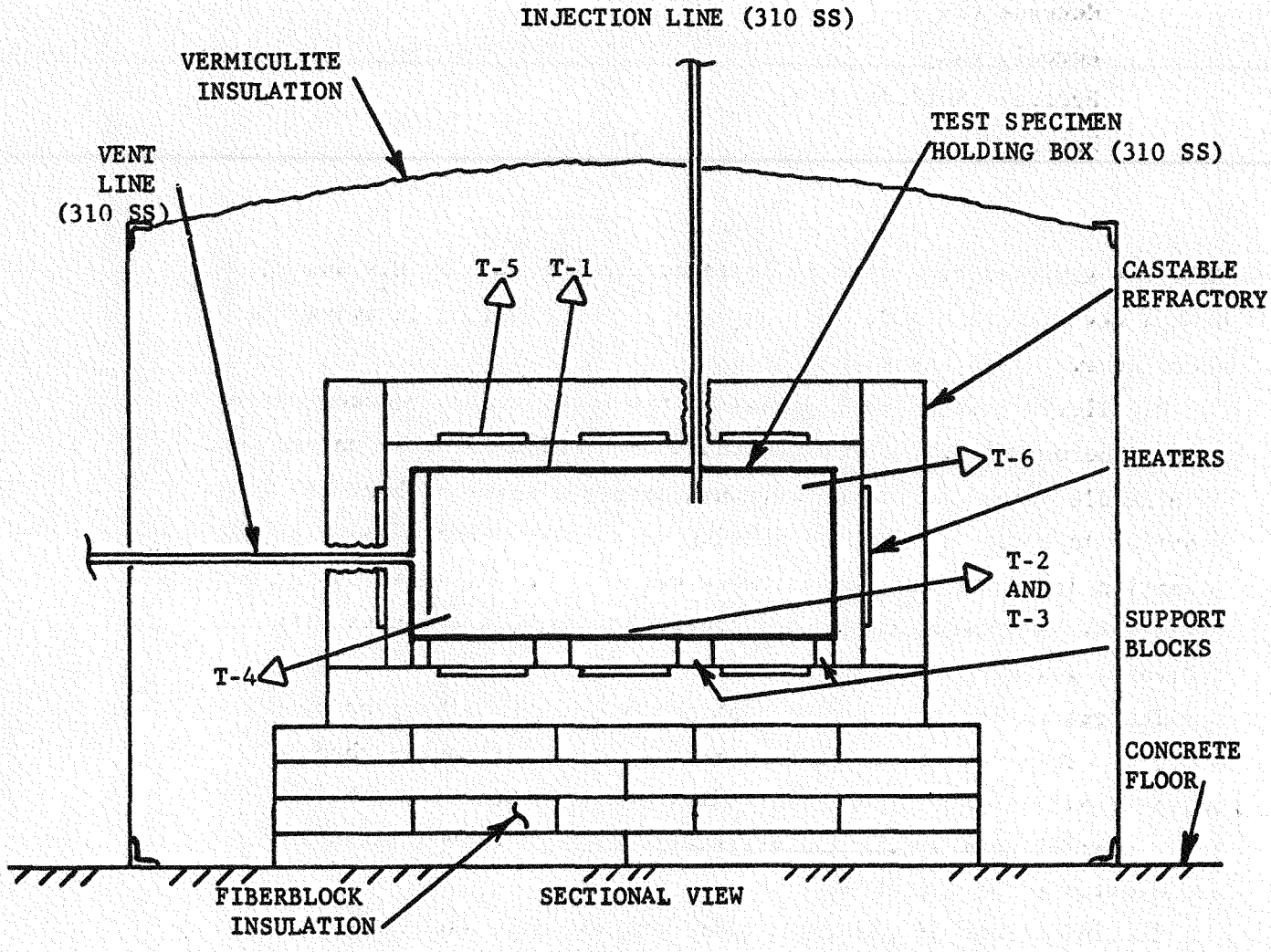


FIGURE 2

OVEN CONFIGURATION

2.2 Injection System

The desired gas composition in the specimen box was:

Carbon Dioxide (CO_2)	12%
Carbon Monoxide (CO)	18%
Hydrogen (H_2)	24%
Methane (CH_4)	5%
Ammonia (NH_3)	1%
Hydrogen Sulfide (H_2S)	1%
Water (H_2O)	39%
	100%

This was achieved by mixing a liquid consisting of H_2O, H_2S and NH_3 with a gas mixture of CO, CO_2, CH_4 and H_2. The injection system is shown schematically in Figure 3.

The liquid supply was a vessel of the mixed fluid, pressurized to 20 psig. The vessel outlet was controlled by tandem solenoid valves leading to a needle valve and flowmeter, then into the specimen box. HV-7 was provided to allow the initial setting of the HV-6 needle valve. The injection line into the specimen box was 1/8 inch diameter tubing with a small I.D. All materials in the liquid system were stainless steel, Teflon or glass.

The gas supply system used high pressure storage bottles of the gas mixture. This was regulated down to 20 psig, then routed through tandem solenoid valves into a control orifice and flowmeter into the specimen box. Most of this system was stainless steel, although corrosion was not anticipated to be a problem.

The injections of gas and liquid were to occur simultaneously one time each hour. The quantity injected was calculated to totally exchange the gas volume in the specimen box. An electronic timer was adjusted to provide the proper actuation duration for the four solenoid valves.

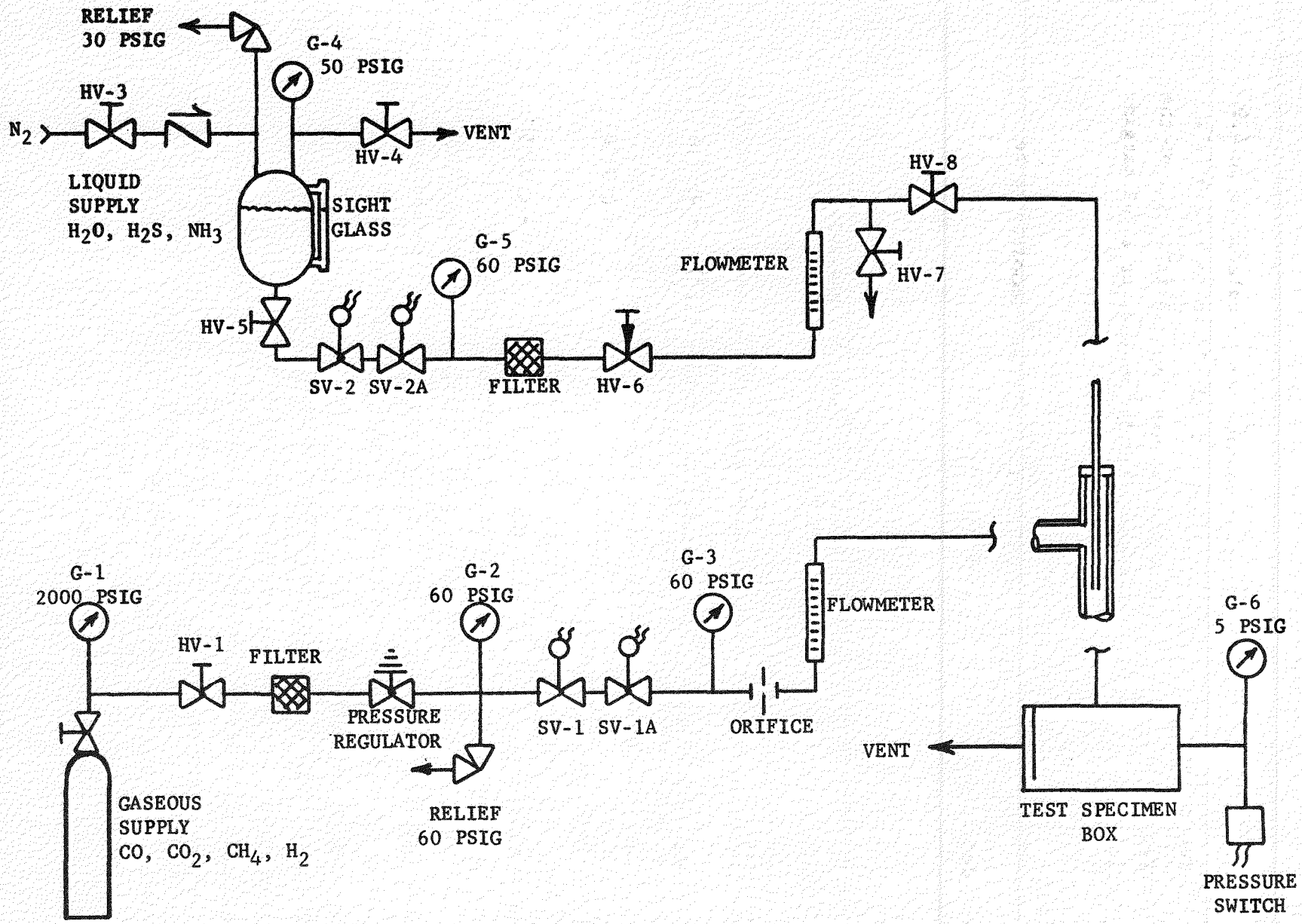


FIGURE 3

INJECTION SYSTEM SCHEMATIC

2.2.1 Test Volume

The free volume of the test chamber was calculated to be 4.9 ft^3. The volume of the test specimens was calculated to be 2.6 ft^3. The effective volume of the test chamber was then 2.3 ft^3. All of the injection rate calculations assumed a 3.0 ft^3 volume, or a 30% margin.

2.2.2 Gas Injection Calculations

The criteria required 59% of the injected commodity to be provided from the mixed gas supply, that is;

$$12\%\ CO_2 + 18\%\ CO + 24\%\ H_2 + 5\%\ CH_4 = 59\%.$$

$$(59\%)(3.0\ ft^3) = 1.77\ ft^3 \text{ replenished from gas supply}$$

Determine weight of gas to be injected:

Gas;	*Density (lb/ft^3)	x	Concentration	x	Volume (ft^3)	= Wt (lb)
CO_2;	$\frac{0.765}{35.13} = 0.0218$	x	0.203	x	1.77	= 0.00783
CO;	$\frac{0.765}{55.19} = 0.0139$	x	0.305	x	1.77	= 0.00750
H_2;	$\frac{0.765}{766.8} = 0.000997$	x	0.407	x	1.77	= 0.000718
CH_4;	$\frac{0.765}{96.35} = 0.00794$	x	0.085	x	1.77	= 0.00119
			1.000			0.0172 lb

$$* \text{ Density} = \frac{P(144)}{RT} = \frac{(12)(144)}{R(2260)} = \frac{0.765}{R}$$

Where P = pressure, lb/in^2 absolute
R = gas constant, ft lb/lbm ^{o}Rankine
T = temperature, ^{o}Rankine

For an injection duration of 8.4 seconds each hour, the gas flowrate required was:

$$\frac{0.0172}{8.4 \text{ sec}} = 0.00205 \text{ lb/sec}$$

This was calculated to require a control orifice of 0.082 inch I.D. with an inlet pressure of 20 psig.

2.2.3 Liquid Injection Calculations

The criteria required 41% of the injected commodity to be provided from the mixed liquid supply, that is: 39% H_2O + 1% H_2S + 1% NH_3 = 41%.

$$(41\%)(3.0 \text{ ft}^3) = 1.23 \text{ ft}^3 \text{ replenished from gas supply}$$

Determine weight of the liquid to be injected:

Liquid; Density (lb/ft^3) x Concentration x Volume (ft^3) = Wt (lb)

H_2O;	$\frac{0.765}{85.9}$ = 0.00891	x	.9512	x	1.23	=	0.0104
NH_3;	$\frac{0.765}{90.9}$ = 0.00842	x	.0244	x	1.23	=	0.0003
H_2S;	$\frac{0.765}{45.5}$ = 0.0168	x	.0244	x	1.23	=	0.0005
			1.000				0.0112 lb

For an injection duration of 8.4 seconds each hour, the liquid flowrate required was:

$$\frac{0.0112 \text{ lb}}{8.4 \text{ sec}} = 0.00133 \text{ lb/sec}$$

2.3 Power System

The heaters were operated from a three phase variable voltage control. A parallel wiring arrangement was used, to minimize the system voltage. The top, middle and bottom oven heaters were connected to separate phases, to allow individual control if excessive temperature differences were noted.

2.4 Instrumentation

A schematic indicating the location of the thermocouples used appears as Figure 4.

T-1, T-2, T-3 and T-4 were used to monitor oven temperature

T-5 was used as a heater over-temperature shutdown

T-6 was used as the primary control

All thermocouples were chromel-alumel, with 310SS, 1/8 inch diameter sheath material.

2.5 Test Specimens

Each of the test specimens consisted of a substrate material clad with a filler metal. Fourty-two of these were exposed to the coal gasification environment. The size of each specimen was approximately 11 x 6 5/8 x 1 1/2 inches, and each specimen weighed approximately 33 lbs. The various substrate materials, filler metal materials, and welding processes are listed on Table 1.

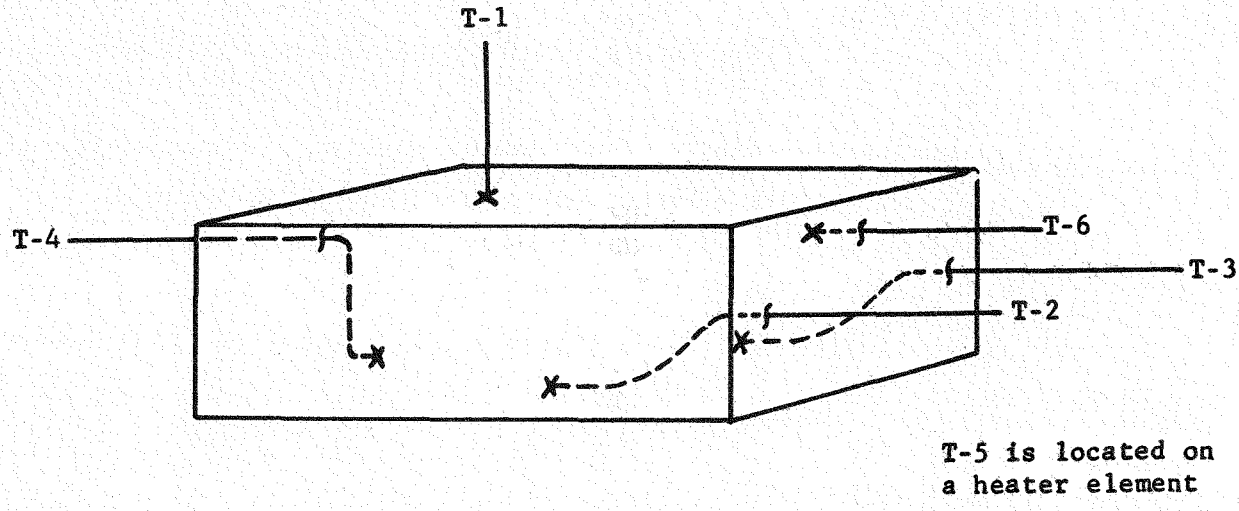


FIGURE 4

THERMOCOUPLE LOCATIONS

TABLE 1
TEST SPECIMEN MATERIALS

Specimen No.	Process(a)	Substrate	Filler Metal
6180	GMAW	304L	309
6181	GMAW	304L	309
6182	SAW	304L	309
6183	SAW	304L	309
6184	GTAW-HW	304L	309
6185	GTAW-HW	304L	309
6186	GMAW	304L	72(b)
6187	GMAW	304L	72
6188	SAW	304L	72
6189	SAW	304L	72
6190	GTAW-HW	304L	72
6191	GTAW-HW	304L	72
6192	GMAW	310	72
6193	GMAW	310	72
6194	SAW	310	72
6195	SAW	310	72
6196	GTAW-HW	310	72
6197	GTAW-HW	310	72
6198	GMAW	800H	72
6199	GMAW	800H	72
6200	SAW	800H	72
6201	SAW	800H	72
6202	GTAW-HW	800H	72
6203	GTAW-HW	800H	72
6204	GMAW	304L	R139
6205	GMAW	304L	R139
6206	SAW	304L	R139
6207	SAW	304L	R139
6208	GTAW-HW	304L	R139
6209	GTAW-HW	304L	R139
6210	GMAW	310	R139
6211	GMAW	310	R139
6212	SAW	310	R139
6213	SAW	310	R139
6214	GTAW-HW	310	R139
6215	GTAW-HW	310	R139
6216	GMAW	800H	R139
6217	GMAW	800H	R139
6218	SAW	800H	R139
6219	SAW	800H	R139
6220	GTAW-HW	800H	R139
6221	GTAW-HW	800H	R139

(a) GMAW = Gas Metal Arc
SAW = Submerged Arc
GTAW-HW = Gas Tungsten Arc with Hot Wire
(b) INCONEL Filler Metal 72

In addition to these clad specimens, small samples of various metals were also placed in the specimen box. Each of these measured approximately 1/4 in. x 1.0 in. x 1.0 in. Four each of 304L stainless steel, 310 stainless steel, and Incoloy 800H were tested.

The arrangement of the test specimens during their exposure was random, in order to balance any effects due to possible varying conditions throughout the specimen box. This arrangement is shown in Figure 5.

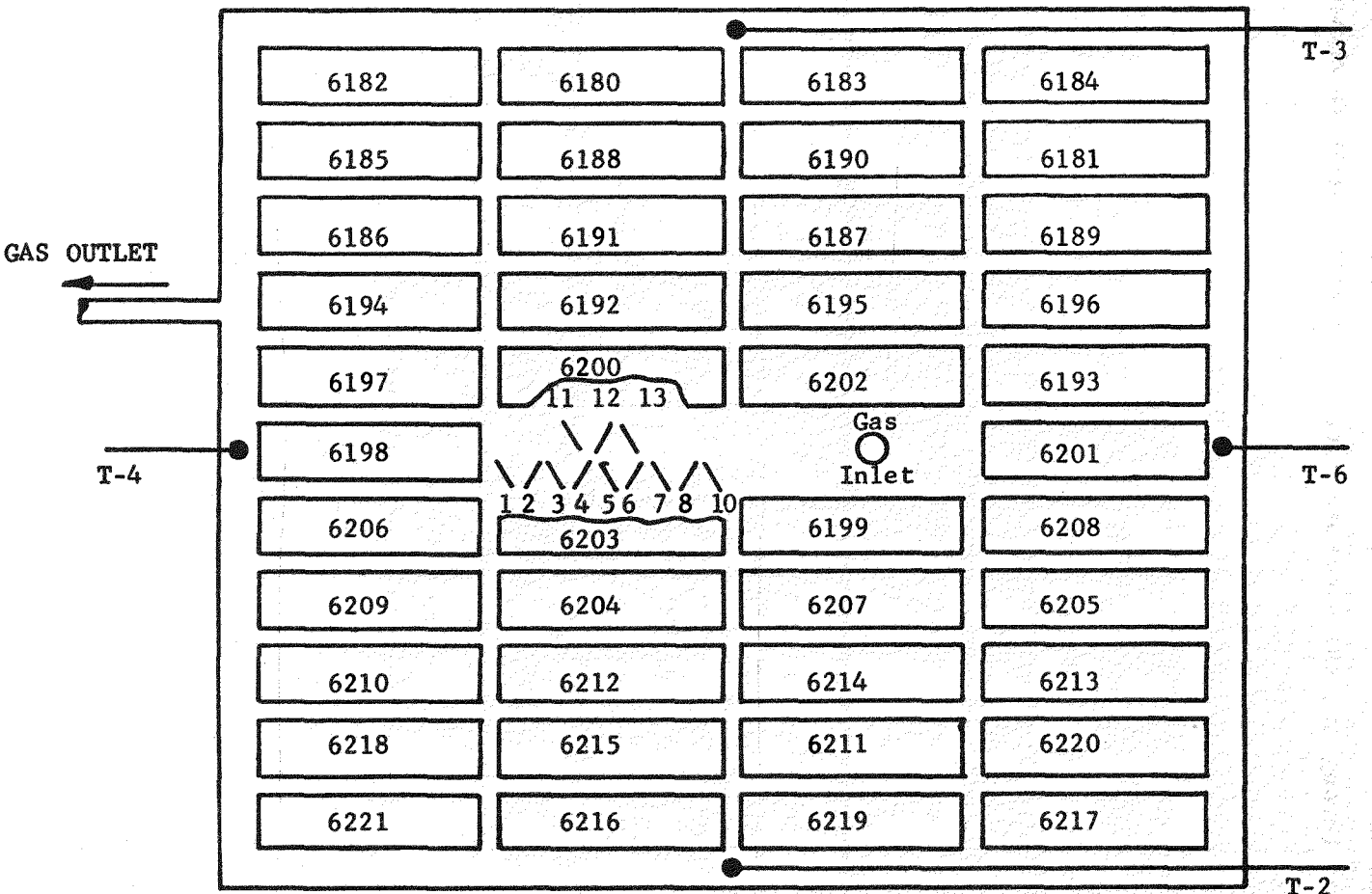


FIGURE 5

ARRANGEMENT OF SPECIMENS
(TOP VIEW)

3.0 TEST METHOD AND PROCEDURE

The test specimens were oriented in the oven with the 11 inch dimension vertical. As an added precaution against loss of identification, the identifying number was stamped into the lower surface substrate material of each specimen. The oven lid was then welded in place using a 310 stainless steel shielded metal arc weld, and the heaters and insulation were placed to complete the assembly.

A step-by-step startup, monitoring and shutdown procedure was used to ensure safety and test fidelity. All procedural aspects effecting specimen environment were discussed with the International Nickel Co. Inc. representative to ensure proper exposure.

The exposure was started by first purging the specimen box with gaseous argon to remove all normal atmospheric gases. The temperature was then slowly increased to 1800^{o}F, while maintaining the argon environment. The automatic cycling system controlling the liquid and gas injection was then started, which began the 1000 hour exposure duration. Initially, the injection duration was increased to exchange the volume several times to remove the argon and replace it with the test environment. The automatic cycling continued throughout the 1000 hour exposure, after which argon was again used to purge out all test gases.

The system was allowed to cool to room temperature, and, after removal of the insulation and heaters, the lid of the specimen chamber was removed by grinding away the weld material at its circumference.

The test specimens were removed and inspected, their identification was verified, they were photographed, and then prepared for shipment to the International Nickel Co., Inc. for evaluation.

4.0 TEST OPERATIONS HISTORY

A trial operation of the oven system was conducted from 11-8-78 through 11-13-78. This assured the capability of the system to achieve and maintain 1800°F. The lid of the specimen box was set into position, but was not welded for this checkout. At this time the liquid and gas injection systems were checked out; although no injection was directed into the specimen box.

The gas system was operated to verify the size of the control orifice by comparison to the flowmeter F-1. After satisfactory calibration of the orifice, the flowmeter was removed from the system.

The liquid system was operated to verify adjustment of the micrometer valve HV-6 by comparison to the flowmeter F-2. The flowmeter was left in the system throughout the test to verify that the HV-6 adjustment did not shift.

Following successful checkout of the oven and injection systems, the specimens were loaded, the lid was welded on, the heaters and insulation reassembled, and system heating was begun. The heaters were energized on 12-1-78, with an argon atmosphere maintained until 12-7-78. At this time the oven was at temperature and the injection system was activated. On 12-13-78, the injection logic was changed to inject a smaller quantity at 15 minute intervals. This was done to reduce the back pressure noted in the specimen box during the injection period. The total quantity of gas injected every hour was not changed.

On 12-17-78, the current readout on the system supplying power to the heaters in the oven walls was found to be zero. The other two systems, supplying power to the oven top and bottom, were increased slightly to compensate for the loss.

On 1-5-79, the temperature was found to be 300°F low, indicating a power outage the previous night. The specimen box was purged with argon, and the system temperature was again increased. On 1-6-79, the injection system was restarted. Also on 1-6-79, the upper heater bank became inoperative, leaving only the lower heaters. Again, the voltage was increased.

On 1-9-79, a portion of the lower heater bank also failed; so the voltage was increased on the remaining heaters. Although the differential temperature from the top to the bottom of the specimen box increased to nearly 60°F, the necessary voltage to the remaining heaters was still only 182 VAC compared to their 230 VAC rating. This proved to be the last heater problem, and the system continued operating in this mode until 1-20-79, when the injection and heating were terminated and the specimen box was purged with argon to terminate the 1000 hour exposure.

During the entire test period, the rate of usage of the liquid and gaseous supplies was monitored to assure a proper overall rate. The liquid usage was monitored by observation of the sight glass on the liquid supply vessel while the gas usage was calculated from pressure decay of the supply pressure cylinder.

The temperature history of the exposure is presented in Table 2.

TABLE 2

TEMPERATURE HISTORY

Date	T-1	T-2	T-3	T-4	
12-1-78	59	60	60	58	Purged with argon.
12-2-78	759	755	751	730	
12-3-78	1100	1096	1094	1086	
12-4-78	1350	1342	1345	1336	
12-5-78	1788	1783	1786	1778	
12-7-78	1804	1793	1792	1772	10 am; started injection, 1 hour frequency.
12-8-78	1807	1794	1791	1791	
12-9-78	1806	1778	1771	1797	
12-10-78	1808	1756	1751	1799	
12-11-78	1809	1742	1736	1801	
12-12-78	1789			1781	
12-13-78	1808	Note: T-2 and T-3 continued		1798	Changed to 15 min. injection frequency.
12-14-78	1806	to decrease		1796	
12-15-78	1811	until the end		1803	
12-16-78	1802	of the exposure,		1795	
12-17-78	1806	due to plug-in connectors		1799	Middle heater bank failed.
12-18-78	1789	becoming too		not read	
12-19-78	1814	hot.		1807	
12-20-78	1814			not read	
12-21-78	1816			1809	
12-22-78	1816			1808	
12-23-78	1811	-	-	1804	
12-24-78	1808			1802	
12-25-78	1809	-	-	not read	
12-26-78	1806			1800	
12-27-78	1809	-	-	1803	
12-28-78	1806			not read	
12-29-78	1809	-	-	not read	
12-30-78	1805			1800	
12-31-78	1810	-	-	1806	
1-1-79	1806			not read	
1-2-79	1805	-	-	1801	
1-3-79	1807			not read	
1-4-79	1809	-	-	not read	4 pm
1-5-79	1497			1483	7 am; power outage last night. Now on. Purged with argon. Lost upper heater bank.

1-6-79	1729	-	-	1776	1 pm; restarted injection.
1-7-79	1810	-	-	1829	
1-8-79	1802	-	-	1839	
1-9-79	1793			1835	Lost part of lower heaters.
1-10-79	1774	-	-	1826	
1-11-79	1778			1835	
1-12-79	1771	-	-	1830	
1-13-79	1761			1820	
1-14-79	1763	-	-	1821	
1-15-79	1761			1821	
1-16-79	1754			1814	
1-17-79	1754	-	-	1813	
1-18-79	1757			1816	
1-19-79	1759	-	-	1818	
1-20-79	1761	1417	1452	1821	8 am; purged with argon and turned power off.

* U.S. GOVERNMENT PRINTING OFFICE: 1981-740-145/1296