MASTER

APAE-72

METALLURGY AND CERAMICS

WELDED TRANSITION JOINT BETWEEN 2-1/4% Cr 1% Mo STEEL AND TYPE 316 STAINLESS STEEL

Sodium Components Design Project Research and Development Program — Final Report

August 15, 1960

Alco Products, Inc.
Schenectady, New York

UNITED STATES ATOMIC ENERGY COMMISSION • OFFICE OF TECHNICAL INFORMATION

DISCLAIMER

Printed in USA. Price $1.75. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

USAEC Office of Technical Information Extension
Oak Ridge, Tennessee

APAE-72

SODIUM COMPONENTS DESIGN PROJECT

RESEARCH AND DEVELOPMENT PROGRAM

WELDED TRANSITION JOINT BETWEEN 2-1/4% Cr 1% Mo STEEL AND TYPE 316 STAINLESS STEEL

FINAL REPORT

AUGUST 15, 1960

SUBMITTED TO

U.S. ATOMIC ENERGY COMMISSION
CHICAGO OPERATIONS OFFICE
ARGONNE, ILLINOIS

CONTRACT AT (11-1)-666

ALCO PRODUCTS, INCORPORATED
RESEARCH AND DEVELOPMENT DEPARTMENT
SCHENECTADY 5, NEW YORK

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

FIGURES

LIST OF FIGURES (CONT'D)

LIST OF TABLES

SUMMARY

An ALCO-designed steam generator, wherein the boiler, steam drum and superheater are integrated into one single unit, requires the welding of a transition joint between the 2-1/4% Cr - 1% Mo steel of the steam drum and the Type 316 stainless steel of the superheater. This research program was initiated to develop a practicable procedure for the welding of this transition joint and to evaluate the properties of the weld by mechanical testing and metallurgical evaluation.

After evaluating the technical aspects of the project and their relation to the fabrication of the generator, it was considered desirable to overlay the welding edge of the 2-1/4% Cr - 1% Mo steel with a suitable austenitic weld metal which would subsequently be welded to the Type 316 stainless steel of the superheater.

Austenitic stainless steel and high-nickel alloy weld metals were evaluated for the overlay, while only austenitic stainless steel weld metals were evaluated for the final weld joining the components. Completed welds were tested in accordance with the applicable requirements of the ASME Boiler and Pressure Vessel Code, and MIL-STD-271A (Ships), 2 Jan. 1959 specification for soundness.

It was concluded that Type 309 stainless steel weld metal deposited automatically by the submerged-arc process is completely satisfactory for cladding the 2-1/4% Cr - 1% Mo base metal and for making the final transition weld joining the steam drum and superheater sections of the generator. Supplementary mechanical tests, metallographic examinations and hardness surveys further attested to the adequacy of the quality of the transition joint resulting from the procedures developed by this program.

Based on the results of this investigation, a detailed fabrication and thermal treatment specification has been incorporated in this report for the welding of a transition joint between 2-1/4% - 1% Mo steel and Type 316 stainless steel.

INTRODUCTION

The proposed ALCO steam generator, designed to produce superheated steam using liquid sodium as a heating medium, consists of three conventional components: a boiler, a steam drum and a superheater. Conventional boilers and steam drums are generally designed and fabricated as individual components connected to the superheater by external piping. The proposed ALCO-designed system integrates the boiler, steam drum and superheater into one single unit, as schematically illustrated in Figure 1. Operating effectiveness and compactness are realized, as well as the elimination of the external piping system.

The materials of construction for the individual components of the steam generator were selected on the basis of maximum allowable design stresses required by the ASME Boiler and Pressure Vessel Code, Section VIII, for the particular operating temperatures, which range from 650°F to 1140°F. Type 316 stainless steel was, therefore, selected for all sections of the superheater, and 2-1/4% chromium - 1% molybdenum (hereafter referred to as Cr-Mo) alloy steel was chosen for the boiler and steam drum. While many other materials possess higher strength characteristics under the anticipated services conditions, other factors, including compatibility to high temperature sodium, heat treatment, weldability and physical properties, also required consideration. It was concluded that the properties of the selected materials were the most applicable for the service intended.

To fabricate the integrated steam generator, it is necessary to produce a transition joint between the Cr-Mo and the austenitic stainless steel having metallurgical and mechanical properties that would assure satisfactory service performance of the unit. This depended in part upon the proper location of the joint with respect to the integrated unit. The necessary design parameters were developed through careful stress analysis which determined the best location for the transition joint. At this location the transition joint would be subjected to a nominal design temperature of 700°F.

The objective of this research program was to develop a practicable procedure for welding a transition joint between heavy forged sections of Cr-Mo steel and Type 316 austenitic stainless steel, and to evaluate the mechanical and metallurgical properties of the resulting welded joint.

This report covers the work conducted on this program, the results obtained and the conclusions reached.

PROJECT MATERIALS

BASE MATERIAL

The Cr-Mo steel base materials used for this investigation were 1-inch and 4-1/2 inch thick forged plates having the mechanical properties set forth in Table 1. The chemical compositions from the mill test reports and Alco check analyses are shown in Table 2. These forgings were received in the normalized and tempered condition.

The Type 316 stainless steel material used for this program was 1-inch thick hot rolled plate and 4-1/2 inch thick forged plate. All material was annealed and pickled. The mechanical properties from the mill test reports are given in Table 1. The chemical analyses from the mill test reports and the Alco check analyses are shown in Table 2.

WELDING ELECTRODES

The coated electrodes used for the weld-metal overlay evaluation were of two general classification: high-nickel alloys and austenitic stainless steel. The high nickel alloy electrodes were Arcos 14/75 Cb, Inco Weld "A", Inco BP-85 and Champion 50/10/15. The austenitic stainless steel electrodes were Arcos Chromend HC 309-15. Chemical compositions of the Weld-metal overlays and the nominal compositions indicated by the applicable ASTM Specifications are listed in Table 3.

BARE WIRE & FLUX

Submerged-arc deposited overlays were made using Drawalloy Type 309 stainless steel, 1/8-inch diameter wire and Arcosite S4 welding flux. The chemical composition of the resulting deposited weld metal is given in Table 3.

The bare filler wires used for submerged-arc welding the transition joint in 1-inch and 4-1/2-inch thick materials were Drawalloy Type 316 and Type 309 stainless steel, 5/32-inch diameter. Arcosite S4 flux was emploued throughout this investigation for all submerged-arc welding. The chemical compositions of the filler wires are listed in Table 4.

WELDING EQUIPMENT

Miller "Gold Star", 300 amp, AC-DC, rectifier-type, and Lincoln, 900 amp, motor-generator welding machines were used for manual metal-arc welding of overlays and submerged-arc welding, respectively.

Welding current and voltages were recorded on Esterline-Angus meters.

A Linde "Unionmelt UE" submerged-arc welding head, mounted on a Linde "CM 37" carriage, was used for overlays and groove welding the transition joint.

A manually operated positioner was used for indexing the test plates.

Welding preheat was applied with an oxy-acetylene preheating torch, and measured with a surface contact pyrometer.

Subcritical heat treatment was conducted in a muffle-type electric heat-treating furnace.

TESTS OF WELD METAL OVERLAYS ON 2-1/4% CHROMIUM - 1% MOLYBDENUM STEEL

Design and stress analyses, along with an evaluation of the manufacturing sequence for fabricating the ALCO steam generator, resulted in locating the transition joint about 20 inches from the spherical Cr-Mo steam drum. (Refer to Figure 1.) In making this transition between the large diameter, heavy wall (54 inches O.D. x 5 inches thick) Cr-Mo steam drum and the Type 316 superheater, careful consideration was given to the materials and the method of fabrication to provide a joint having the best metallurgical properties. This is essential to assure a sound, strong joint with complete integrity to meet the anticipated service conditions where the design temperature and pressure for the transition joint area are 700^{o}F and 2200 psi respectively.

The header section of the superheater during operation is exposed to a steam environment that may carry a low concentration of chloride ions, which can be conducive to localized chloride deposits of sufficient concentration to cause stress corrosion cracking of the Type 316 stainless steel material. An Inconel weld overlay will thus be deposisted over the stainless steel extending beyond the transition joint and terminating on the Cr-Mo forged transition section, in order to eliminate the chloride stress corrosion cracking hazard.

During the past 15 years, there has been a substantial number of important technical articles written on the joining of dissimilar materials, such as austenitic stainless steel and the hardenable Cr-Mo steels, using an austenitic weld metal.(1)(2)(3)(5)(6) (Refer to Bibliography).

After evaluating the technical aspects of these references and their relation to the fabrication of the steam generator, as well as fabricating and other engineering factors, it was considered desirable to overlay one end of the Cr-Mo transition forging with a suitable austenitic weld metal for subsequent welding to the Type 316 superheater section. The inside surface of the transition forging could thus be overlaid with Inconel to cover several inches of the Cr-Mo steel, as well as the inside surface of the buttered transition end. Upon completion of the transition joint weld, the Inconel overlay would be completed, thus providing the required protective cladding.

The overlaid transition forging can then be thermally treated at a temperature sufficiently low to restrict, or prevent, carbon migration from the Cr-Mo steel to the austenitic weld metal, but still be high enough to reduce the hardness and improve the ductility in the heat affected zone of the Cr-Mo steel resulting from applying the weld overlays. Since the operating temperature of the steam generator at the transition joint will be somewhat below the design temperature of 700^{o}F, detrimental carbon diffusion is not expected to occur during the serice life of the unit.

The ASME Boiler and Pressure Vessel Code, Section VIII, permits the use of welded austenitic stainless steel vessels without post weld thermal treatment. The overlaid Cr-Mo transition section can thus be welded to the Type 316 superheater section, the Inconel cladding completed on the inner weld joint surface, and the unit put into service without subsequent thermal treatment.

The final closing weld would be made between the Cr-Mo transition section and the Cr-Mo steam drum, followed by a local post weld thermal treatment using an induction heater.

The objectives of this phase of the investigation were:

1. To develop a procedure for depositing a suitable austenitic stainless steel weld overlay on the Cr-Mo steel.

2. To determine a suitable post weld thermal treatment to obtain optimum metallurgical properties and strength of the transition joint between the weld overlay and the Cr-Mo steel base material.

3. To evaluate the influence of preheat level on the metallurgical and mechanical properties of the weld metal overlay and fusion zone of the Cr-Mo steel base material.

TEST MATERIALS

Base Metals: The ferritic base material used for the overlay evaluation was 1 inch thick, Cr-Mo forged steel plate in the normalized and tempered condition. The mechanical properties and chemical composition are given in Tables 1 and 2, respectively. The surface of the material to be overlaid was thoroughly cleaned to remove mill scale and other weld contaminators prior to welding.

Weld Metals: The initial tests were directed toward determining the most suitable and practicable welding process and weld metal for the overlay. The weld metals were deposited by the manual metal-arc process using Arcos Chromend HC-309 (Type E309-15), Arcos Chromend 14/75 (Type E3N12), Inco Weld A (Type E3N12), Inco BP-85, and Champion 50/10/15 coated electrodes.

The submerged-arc welding process was used for automatically depositing austenitic weld metal overlays. The uncoated filler wire was Drawalloy 309 (Type ER309), used with Arcosite S4 welding flux. The wire composition is given in Table 4.

The chemical composition of the weld metal deposited by these electrodes is given in Table 3.

EVALUATION OF WELDING PROCESS AND WELD METAL COMPOSITION

This series of tests was specifically directed toward determining several austenitic stainless steel and high-nickel weld metal alloys suitable for producing an overlay on Cr-Mo steel that would demonstrate suitable weld metal soundness and mechanical properties by meeting the ASME Boiler and Pressure Vessel Code side-bend test requirements. The automatic submerged-arc process has been extensively used by ALCO and other manufacturers for overlays, as well as for transition joint welding.

The high-nickel base alloys have often been considered desirable for joining ferritic to austenitic materials, especially for equipment operating cyclically at temperatures of 1000°F, or above.[2] These weld metals have a lower thermal expansion than austenitic stainless steel weld metal, as well as good creep-rupture strength. The influence of these factors, however, is not pronounced for the conditions of operating the steam generator under consideration. However, it was possible that, if the nickel base weld metal alloys showed better metallurgical and mechanical properties than the austenitic stainless steel alloys, the transition joint, as well as the cladding of the internal vessel surface, could be fabricated with them.

Preliminary screening tests were thus conducted on several austenitic stainless steel and high-nickel alloy weld metals by making guided side bend tests on specimens in the as-welded conditions. Weld metals qualifying would be subjected to further evaluation.

Welding Procedure for Weld Overlay Tests: The Cr-Mo forged steel plates, 1 inch thick, were cut to a standard size of 12 x 6 inches for all tests. All plates for this specific series of tests were preheated with an oxyacetylene torch to 400°F and placed in the flat position on asbestos for overlay welding. This preheat level is within the range generally used for commercial fabrication of this composition of steel and is conducive to keeping the degree of underbead hardening to a reasonable level to prevent underbead cracking as well as permit screening tests to be made in the as-welded condition.

Weld overlays deposited by the manual metal-arc process consisted of two passes, about 3/8 inch thick, whereas only one weld pass was required for the automatic submerged-arc process to produce an overlay 1/4 inch thick. The temperature of the test plates during overlaying did not exceed the preheat temperature of 400°F by more than 50°F. The overlaid test plates were cooled to room temperature (70°F) in still air. The conditions for depositing the weld metal on each test plate are given in Table 5.

Evaluation of Weld Overlays: The overlaid test plates, in the as-welded condition, were cut transversely to the direction of welding. The specimen size and method of testing were in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. Prior to bending, all specimens were polished on the side to be subjected to the maximum bending stresses (outside), etched and examined at 10 diameters with a stereoscopic microscope. No significant defects were observed in any of the test specimens.

The side bend specimens were bent 180° to the full extent of the testing jig and again examined for ruptures on the stressed surface. Both the manually and automatically deposited Type 309 weld metal overlays bent with completely satisfactory results. The manually deposited Inco BP-85 high nickel alloy overlay showed equally satisfactory results. The manually deposited Inco Weld-A, high nickel alloy overlay, showed minor fissures of negligible extent, and the test results were considered satisfactory.

Further tests were conducted with these weld metal overlays for investigating the influence of preheat and post-weld thermal treatment on the overall metallurgical and mechanical properties of over laid Cr-Mo steel.

The overlays deposited by the Arcos 14/75 and Champion 50/10/15 electrodes showed extensive fissuring upon bending, and were deleted from further consideration in this program. Side bend test result details are given in Table 5.

A chemical analysis was made of each weld metal overlay by analyzing millings taken from the surface of the test samples. The analyses are given in Table 3.

INFLUENCE OF POST-WELD OVERLAY THERMAL TREATMENTS

The chemical composition of 2-1/4% chromium - 1% molybdenum steel classifies this type of material as an air-hardening steel. Upon welding, the area immediately under the deposited weld metal, generally referred to as the "underbead zone", is heated above the upper critical temperature, thus putting all the chemical elements into a solid solution. As the distance from the fusion line increases, the temperature reached becomes lower. This decreases the percentage of the elements in the solid solution. Below the lower critical temperature (about 1425°F), the constituents do not go into solution and a tempering (softening) action occurs. The rate at which the partial, or complete, solid solution cools through the critical temperature range, determines the hardness that will obtain in the "underbead zone". The mass of the base material and its temperature during welding have a pronounced influence on the rate of heat dissipation away from the fusion and "underbead zone". Although preheating prior to welding substantially retards the cooling rate of the "underbead" metal, the practicable preheat level may not be sufficiently high to prevent an undesirably high degree of hardness to occur, because of a martensitic structure formation. Under adverse conditions of stress caused by restraint or service conditions, the hardened area having excessively high strength accompanied by low ductility is apt to crack upon welding, or in service. To reduce this undesirable hardness to a reasonable level of about the same hardness as the normalized and tempered Cr-Mo base material, a post weld thermal treatment is considered essential.

A post weld thermal treating temperature for welded Cr-mo steel that is considered optimum by ALCO, as well as other fabricators, is 1325 -1375°F for a minimum period of 1-1/2 hours per inch of wall thickness at the welded joint, followed by cooling at a sufficiently slow rate to prevent stresses and to meet the ASME Boiler and Pressure Vessel Code requirements. This thermal treatment tempers the hard "underbead" area, and relieves residual stresses imposed during welding. Unfortunately, when austenitic weld metal is applied to a ferritic steel and heat treated, the carbon migrates from the ferritic steel into the austenitic steel. This can result in a depletion of carbon on the Cr-Mo side of the fusion line and a concentration of carbon on the austenitic side. Although carbon migration is not expected to occur at the operating temperature maintained in the area of the transition joint, it was still considered necessary to determine the post-weld subcritical heat treating temperature that would provide the best mechanical properties, microstructure and proper hardness at the weld joint without causing an undue amount of carbon diffusion.

Testing Procedure: A portion of each of the test plates overlaid with various weld metals qualified by the screening tests was used for the post-weld overlay thermal treatment tests. The qualified overlays having been deposited automatically using Type 309 austenitic steel weld wire and Arcosite S4 flux and manually deposited with Arcos Chromend HC-Type 309, Inco BP-85 and Inco Weld A coated electrodes were used.

To evaluate the influence of the post weld heating temperature and holding time on underhead hardness, ductility, carbon migration and general metallurgical structure, the various test sections were heated to the temperature shown below and held for a period of 24 hours. This time is arbitrarily more than twice the heating cycle period expected during manufacturing, and should be representative of the maximum condition that would be encountered in the finished steam generator.

SUB-ARC TYPE 309	ARCOS CHROM-HC TYPE 309	INCO BP-85	INCO WELD-A
1100°F	----------	------	--------
1200°F	----------	------	--------
1300°F	1300°F	1300°F	1300°F
1350°F	1350°F	1350°F	1350°F

After thermal treatment, the test plates were machined into standard side bend specimens, and sections were mounted for metallographic evaluations and hardness surveys.

Evaluation of Thermal Treatments: The side-bend test results for each of the overlaid and heat treated specimens were essentially the same as reported for the specimens bent in the as-welded condition. (Refer to Table 5.). With the exception of minor fissuring in the Inco A weld overlay as before, the outer stressed surfaces of the other specimens were completely free of ruptures or other deficiencies for all post-weld temperatures evaluated.

Careful examination of the "underbead zone" of all bend-test specimens did not reveal any deficiencies in this area or the base material per se. These good results were expected as the underbead hardness of the Cr-Mo base material was substantially reduced and the ductility enhanced over the "as-welded" bend-test specimens.

From the side-bend test results of the Cr-Mo steel overlaid with austenitic stainless steel and high-nickel alloy weld metal, it was concluded that post welding thermal treatment ranging from 1100 to 1350°F did not have a detrimental influence on the mechanical properties of the overlaid weld metal, the fused interface, or the underbead zone of the base metal.

A metallographic examination was made of the weld metal, fusion line and "underbead" zone from each overlaid sample given a post-weld thermal treatment indicated on page 10. These structures were compared with the structure of as-welded specimens. In general, carbon migration from the Cr-Mo base metal to the austenitic weld overlay occurred for all specimens given a post-weld thermal treatment. Representative photomicrographs showing the degree of carbon migration at the 1100°F, 1200°F, and 1300°F temperature levels are shown in Figures 2, 3 and 4. By comparing Figures 3B and 4, it is apparent that at the 1300°F temperature treatment, the width of the diffused carbon zone is considerably greater for the high-nickel BP-85 overlay than for the automatically deposited Type 309 austenitic stainless steel overlay. These results are consistent with the results obtained by Christoffel and Curran (3) and their theory that "Carbon in solution crosses the fusion line from the low alloy material into the high alloy material. The prime driving force which causes the carbon to migrate is the alloy difference between the two steels which results in a lower energy for carbon in the high alloy steel at a high-carbon concentration than in the low carbon steel at a lower concentration. A measure of the magnitude of this driving force is the difference in carbon concentration on the high alloy and low alloy side of the fusion line."

Comparison of Figures 3A and 3 B further shows that 1200°F is about the practical limit of post-weld thermal treatment for keeping the carbon migration to a minimum. At the 1300°F level, there is a double band of carbon concentration with a low carbon band in between them (Figures 3B and 4). Thus from a carbon migration standpoint, the high nickel alloys do not offer any advantage over the austenitic stainless steels for the transition joint overlay.

In the fabrication of austenitic stainless steels, it is an established metallurgical principal that at least 3% delta ferrite in the austenitic matrix is necessary to obtain a sound, crack-free weld (7). At elevated temperatures in the magnitude required for post-weld thermal treatment of the Cr-Mo steel, the delta ferrite transforms to the hard sigma phase. The degree of sigma formation depends upon the amount of available delta ferrite, and the temperature and the time at temperature. Figure 5 is a series of photomicrographs of automatically deposited Type 309 austenitic weld overlay in the as-welded condition and after thermal treatments of 1100°F, 1200°F, and 1300°F for 24 hours. Very little sigma has formed at 1100°F, partial transformation has taken place at 1200°F, and complete transformation is indicated at the 1300°F temperature level.

Regardless of the degree of sigma formation, the side-bend tests results did not show that the sigma formed was detrimental to the mechanical properties and ductility of the austenitic overlay. Since the steam generator will operate considerably below the sigma-forming temperature, the possibility of long term detrimental effects can thus be disregarded. From a practical post-weld thermal treatment procedure standpoint, 1200°F again appears to be the maximum desirable limit to keep the formation of sigma phase to a practical minimum.

<u>Diamond Pyramid Hardness</u> surveys using a 10 kg load on a Vickers hardness tester were made across the automatically deposited Type 309 weld metal and into the 2-1/4% Cr - 1% Mo base material. The measurements were made to determine the influence that post weld thermal treatments at 1100°F, 1200°F and 1300°F had on the underbead hardness, the weld, fusion zone and base material. The results of these surveys are given in Table 6 and Figure 6.

These data show there is no significant influence of thermal treatment on underbead hardness of the Cr - Mo steel until a temperature of 1200^{O}F has been reached, (Figure 6C). At the 1200^{O}F level, there is a well defined drop in the underbead hardness of the Cr - Mo steel but no significant change in the hardness of the Type 309 weld metal. At 1300^{O}F, a further decrease occurs in underbead hardness approaching the hardness level of the base material, (Figure 6D). The hardness of the austenitic Type 309 overlay, however, increases about 50 DPN which is attributed to the complete transformation of delta ferrite to sigma phase shown in Figure 5.

Knoop hardness measurements were made at the fusion line interface area for a more accurate hardness study as shown in Figure 7 and Table 7. The beneficial aspects of the 1200^{O}F thermal treatment in reducing underbead hardness in the Cr - Mo steel without a detrimental increase in the Type 309 weld overlay is clearly illustrated.

INFLUENCE OF PREHEAT TEMPERATURE ON WELD OVERLAYS

This part of the investigation was concerned with an evaluation of the influence of preheat temperature on the properties of Cr - Mo steel overlayed with automatically deposited Type 309 weld metal. Since the various tests in this phase of the investigation indicated that an automatically deposited Type 309 austenitic weld metal was suitable for the transition overlay, only this type overlay was investigated from the preheat standpoint.

Often times during fabrication of heavy steel sections, such as the transition forging, it is difficult to maintain close preheat temperatures during welding. It is thus desirable to know the practicable working range of temperatures that can be tolerated for proper control on the deposition of the weld metal as well as for preventing excessive underbead hardness and possible cracking. The function of the preheat, therefore, is to retard the cooling rate of the portion of the Cr - Mo steel heated in excess of the lower critical temperature and especially the immediate fusion zone heated above the upper critical temperature.

Testing Procedure: Type 309 weld metal was automatically deposited on 1 inch thick Cr - Mo steel by the submerged arc process using the same procedure given in Table 5. Prior to welding, the test plates were preheated to 70^{O}F, 200^{O}F, 400^{O}F and 600^{O}F respectively. Heat build up during welding did exceed the preheat temperature by more than 50^{O}F. After welding, the over layed test plates were cooled in still air to 70^{O}F, then processed into specimens for side-bend tests, microexamination and hardness surveys in the as-welded condition.

Evaluation of Preheat Influence: All side-bend specimens, bent 180° to the full extent of the testing jig, were completely satisfactory with no evidence of fissures or other deficiencies. Representative bend test specimens are shown in Figure 8.

A metallographic examination was made of a weld fusion zone section cut from specimens welded at each preheat level. A representative photomicrograph of the Type 309 weld metal, the fusion line and the heat-affected zone of the Cr - Mo base material is shown in Figure 9. The martensitic structure in the underbead zone is normal for Cr - Mo steel permitted to cool to 70°F after welding. The variation in the degree of preheat, however, did not show any significant influence on either the weld metal or base metal structures. Microhardness tests made with a Knoop indenter at a distance of about .0005 inch from the fusion line into the Type 309 weld metal showed a very narrow hard band having a hardness ranging from 350 to 400 Knoop hardness number which appeared to be independent of the preheat level. (Refer to Figure 9). This hardness is attributed to the dilution of the austenitic stainless steel with the Cr - Mo base metal and is not considered detrimental as evidenced by the satisfactory side-bend tests of as-welded specimens. By referring back to Figure 7, it will be observed that this local hardness band is softened by post weld thermal treatment. However, the formation of the sigma phase is thus introduced which obscures the true mechanism of the final actual hardness level.

Figure 10 illustrates a series of Vickers hardness surveys (10 kg load) made across the fusion zone of welded specimens preheated to 70°F, 200°F, 400°F and 600°F and cooled to room temperature after welding. An increase in preheat temperature increases the width of the hardness band in the underbead heat-affected zone of the Cr - Mo base material but it does not appear to affect the hardness level. These results suggest that little benefit would be expected by preheating above 400°F. For overlaying the unrestrained transition section, a drop in preheat to 200°F does not appear detrimental to good welding conditions and the satisfactory metallurgical and mechanical properties.

GENERAL CONCLUSIONS OF PRELIMINARY WELD-OVERLAY TESTS

From the preliminary tests of weld-metal overlays on the Cr - Mo steel, the following general conclusions were reached:

1. Type 309 austenitic stainless steel is suitable for the transition overlay. Automatic deposition of the Type 309 by the submerged-arc process has both economic and welding control benefits to make it

more desirable than manual overlays for this size and mass of material.

2. The high nickel Inconel BP-85 coated electrode is suitable for manual deposition of the weld cladding overlay on the inside of the transition joint for protection of the stainless steel against chloride stress corrosion action.

3. A post-weld thermal treatment of 1200^{O}F was found to be the best compromise for adequate reduction of underbead hardness, minimum formation of sigma phase in the Type 309 weld metal and a minimum of migration. Completely satisfactory side bend tests of manually and automatically deposited Type 309 weld metal and manually deposited BP-85 weld metal overlays on Cr - Mo steel showed that the mechanical properties, especially ductility and reasonably uniform hardness, were adequate for the transition overlay.

4. A preheat temperature of 400^{O}F was considered practicable and conducive to good welding practice to provide a transition overlay having good mechanical and metallurgical properties. No detrimental results from cracking would be expected in permitting the overlaid transition forging to cool slowly and uniformly to 70^{O}F prior to effecting the post-weld thermal treatment at 1200^{O}F.

TESTS TO DEVELOP THE WELDING PROCEDURE FOR COMPLETION OF THE TRANSITION-WELD JOINT

In welding dissimilar materials together, such as the Type 316 stainless steel of the superheater to the austenitic overlay (stainless steel or high nickel), it is considered good practice to use a filler metal providing a chemical composition and mechanical properties as close as possible to either, or both, of the component materials being joined. Since the transition section of the steam generator (Fig. 1) is amenable to automatic welding, effort on this phase of the investigation was directed toward establishing an automatic submerged arc procedure for welding the final 5-inch thick joint.

Previous research by Alco has demonstrated that lower residual stresses develop in heavy butt-weld joints welded automatically than by manual methods. This is attributed to more uniform heat distribution and better bead contour control of the weld deposit. Unless it is mandatory to thermally treat a welded austenitic joint for critical dimensional stability, it has been Alco's practice, based on extensive experience, to leave such joints in the as-welded condition. This practice is approved by the ASME Boiler and Pressure Vessel Code. (This does not include the overlay weld on the Cr-Mo steel which will be thermally treated at 1200^{O}F prior to making the final transition weld).

Since this portion of the investigative program was predicated on the use of automatic welding, initial screening tests were made using both Type 309 and Type 316 stainless steel filler wires. At the time this investigation was conducted, there was not a satisfactory high nickel filler wire commercially available for automatic welding of heavy butt joints. Consequently, the preliminary screening tests were directed toward evaluating the ability of the procured heats of Type 309 and Type 316 weld wires to weld Type 316 stainless steel to itself as well as dissimilar metal butts joints consisting of Type 316 stainless steel on one side and Cr - Mo steel having Type 309 and BP-85 weld overlays for the other faying surfaces.

PROCEDURE

The 1-inch thick 2-1/4% Cr -1% Mo forged steel plates and the 1-inch thick Type 316 wrought stainless steel plates having mechanical properties and the chemical compositions given in Tables 1 and 2, respectively, were used for this phase of the investigation program.

One edge of the Cr - Mo plates were given a 10 degree level, then overlaid manually with either Arcos Chromend HC-Type 309 or INCO BP-85 weld metal. The overlay thickness of 3/8 inch, required three weld passes. A preheat of 400°F was used but no post-weld thermal treatment was given to the overlaid plates.

The faying surfaces of the Type 316 and overlaid Cr - Mo steel materials were machined to provide a "U" type butt joint having a 20-degree included angle, a 1/4-inch root radius and a 3/8-inch root land. The assembled plates were welded to a 2-inch thick backing plate to provide high restraint during welding the test joints. Welding was done in the flat position by the automatic submerged arc process using the following welding conditions:

Welding Wires:	5/32 inch diameter Drawalloy ER-309
	5/32 inch diameter Drawalloy ER-316
Welding Flux:	Arcosite S4 (Arcos Corp.)
Welding Power:	Direct Current Reverse Polarity
Arc Amperage:	375-425
Arc Volts:	30-32
Nominal Travel Speed:	18 inches per minute
Preheat:	70 deg. F.
Postheat:	None

The welded joints were given a cursory evaluation based on visual examination and dye-check tests of random weld beads during welding and macroexamination of at least three cross sections from each test plate.

DISCUSSION OF RESULTS

Qualification of Type 316 and Type 309 Filler Wires: The chemical composition of the filler wires given in Table 4 was calculated into chromium and nickel equivalents to determine the amount of delta ferrite expected in the austenitic matrix, from plotting these data on the Schaffler Constitution Diagram (7) The Type 316 weld metal indicated about 2% delta ferrite where as the Type 309 weld metal showed about 7%.

To check the ability of the Type 316 and Type 309 weld wires to produce a sound weld in the completely austenitic Type 316 forged plate 1-inch thick, "U"-groove butt-weld tests were made as described under "Procedure" above. The weld made with Type 316 wire cracked extensively as shown in Figure 11A. Calculation of the delta ferrite content based on a chemical analysis of the metal in the joint indicated the weld metal was almost 100% austenitic. This particular heat of Type 316 filler wire was thus rejected as unsuitable for further welding tests. The negative results of these tests, however, emphasize the necessity for establishing a thorough knowledge of the chemical, metallurgical and weld-ability characteristics of each heat of Type 316 material and Type 316 filler wire to be used in fabricating the superheater per se.

The butt joint of Type 316 stainless steel automatically welded with the Type 309 filler wire was x-rayed and found completely sound and free of any cracks as illustrated in Figure 11B. The delta ferrite content of the weld metal was calculated at 7%. Alco, as well as other fabricators and investigators have found from experience that a minimum of 3% delta ferrite is required in the deposited austenitic stainless steel weld metal to prevent cracking. As the join restraint is increased, there should also be an increase in the delta ferrite content. The Type 309 filler wire was thus considered qualified for further testing.

Type 316 Stainless Steel Welded to BP-85 Weld Overlay: The Type 316 stainless steel plate was automatically welded to the BP-85 deposited weld overlay using Type 309 filler wire. The deposited weld showed extensive cracking typified by Fig. 11C. This procedure was not pursued further as the literature, as well as past ALCO experience, have established that a weld composition approacing 15% chromium and 35% nickel is prone to cracking. (4)(8) These tests, however, clearly demonstrate that extreme caution will be required to make certain that in welding the final transition joint with austenitic weld metal, the Inconel overlay on the internal surfaces must not be penetrated.

Type 316 Stainless Steel Welded to Type 309 Weld Overlay: The Type 316 stainless steel plate was automatically welded to the Type 309 weld overlay using Type 309 filler wire. X-ray and macroexamination of several cross sections of the joint showed it to be free of cracks. However, there were some random slag inclusions evident, as shown in Figure 11D. During the welding of this test plate, it was found necessary to locate the position of the filler wire considerably closer to the bevel of the Type 316 plate than it was for the side having the Type 309 overlay on Cr - Mo steel. Such compensation eliminated the erratic weld metal deposition and assured good fusion of the weld into the base materials.

Since most of the weld metal was sound, four side bend specimens were made from sound locations and tested. Results were completely satisfactory with no deficiencies or fissuring indicated upon bending 180 deg. This procedure and the properties of the deposited weld metal were therefore considered suitable to justify making a full-size transition joint using 4-1/2-inch thick material.

FINAL TRANSITION JOINT EVALUATION

This portion of the investigation integrates all of the technology previously developed and reported herein for welding the transition joint for the steam generator. A test plate of sufficient thickness and size was welded to simulate the conditions encountered during fabrication of the transition joint and to provide data on the mechanical and metallurgical properties of the weldment.

PROCEDURE

The Type 316 and the 2-1/4% Cr - 1% Mo materials used for this final qualification test were 4-1/2 inch-thick forged plates. Their mechanical properties and chemical compositions are given in Tables 1 and 2, respectively. The composition of the Type 309 weld wire used for overlaying the Cr - Mo steel and welding the transition joint is given in Table 4.

The procedure for overlaying the faying edge of the 4-1/2-inch thick Cr- Mo test plate with Type 309 weld metal is given in Fig. 12 and Table 9. Sufficient weld metal was deposited to provide an overlay that would finish 3/8-inch beyond the Cr - Mo base material. The overlaid plate was thermally treated at 1200 deg. F. for six (6) hours and cooled in a closed furnace to room temperature. The faying surfaces of the Type 309 overlaid Cr - Mo steel and the Type 316 plate were machined to provide the transition joint shown in Fig. 12. The test plate, having overall dimensions of 12 inches long by 12 inches wide, was welded to a 2 inch thick backing plate to provide restraint to the joint during welding.

The conditions for submerged-arc welding the transition joint are given in Table 9. Specific attention was given to the proper location of the welding wire with respect to the faying surfaces to obtain consistment arc action and good uniform fusion. The electrode offset from the faying surface of the Type 316 plate was held between 3/16 and 1/4 inch while the offset for the overlay side was held at 1/2 inch.

After the "U" groove was welded, the test plate was cut away from the restraining plate. The backside of the joint was machined through the initial root pass and the resulting groove was welded to complete the test plate.

The completed test plate was X-rayed and the soundness and quality was well within the applicable standard, MIL-STD-271A (SHIPS), 2 Jan. 1959, set for the steam generator.

The test plate was then machined into side bend, transverse tentile, and all-weld-metal cylindrical .505-inch diameter tensile specimens. The dimensions of the specimens and the testing procedures were in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. Two cross sections of the joint were prepared for metallographic examination and hardness measurements.

DISCUSSION OF RESULTS

Side-Bend Tests: The thickness (4-1/2 inches) of the simulated transition joint was tool large to utilize side bend specimens incorporating the entire cross section of the joint. Two standard size specimens taken from the top of the weld, two from the center and two from the bottom were considered sufficiently representative to reflect the ductility, weld metal soundness, fusion zone integrity and general joint quality. All side bend specimens were bent the full 180 degrees without any deficiencies indicated as shown in Figure 13.

All-Weld-Metal Tensile Tests: One standard cylindrical .505-inch diameter all-weld-metal tensile specimen was made from each of the top, center, and bottom locations of the transition groove weld. The results of these static tensile tests, given in Table 10 and averaged below, are considered satisfactory for the purpose of this evaluation.

Yield strength, psi	58,900
Ult. tensile, psi	82,900
Elong. % in 2 inches	32.3
Type fracture	Irreg. shear
Delta Ferrite content, %	6.5

A typical fracture speciment is shown in Figure 13.

Prior to fabrication of the steam generator transition joint, it is recommended that the heat of Type 309 wire used, be properly qualified to assure that the weld deposited meets the requirements of ASTM A371-53T-Type 309 as well as having at least 5% delta ferrite calculated from the chemistry of the deposited weld metal.

Reduced-Section Tensile Tests: Three reduced-section, transverse-tensile test specimens taken from the top, center, and bottom sections of the transition joint were tested in static tension. The test results given in Table 10, are summarized as follows:

	Tran. Tension Test	A182-F316 Min. Req.	A182-F22 Min. Req.
Yield strength, psi	49,000	30,000	40,000
Ult. tensile, psi	77,700	75,000	70,000
Elong, % in 2 inches	54.3	40	20
Fracture location	Type 316 Base Metal		

A photograph of the fractured specimens is incorporated in Fig. 13.

The test results are considered satisfactory and show that the overall strength of the transition joint exceeds the ASTM requirements for the component base materials. The strength of the weld metal per se was 82,900 psi, as discussed under "All weld metal tensile tests". It is considered beneficial from an overall functional standpoint to have the mechanical properties of the weld metal in such a transition joint slightly higher but as close to the mechanically properties of the component materials as possible.

There is no technical significance for the fracture occurring in the stainless steel rather than the Cr - Mo base metal, except that the particular heat of Type 316 material used for this test had lower strength properties than the particular heat of Cr - Mo steel used.

Metallurgical Evaluation and Hardness Measurements: A cross section of the final 4-1/2-inch thick transition joint weld is shown in Figure 14. The initial width of the Type 309 weld metal overlay on the Cr - Mo steel was 3/8 inches. While this thickness was adequate for laboratory tests, it is recommended that the overlay thickness at the transition joint for the steam generator be increased to at leat 5/8-inch. This will permit a greater range of fabricating tolerances and permit application of the Inconel overlay on the inner surface of the overlay and the Cr - Mo steel without the risk of being penetrated when making the final transition weld. It will also keep the influence of the heat-of-welding within the austenitic weldmetal overlay and sufficiently far away from the hardenable Cr - Mo steel.

A metallographic examination was made of a series of specimens representing the Type 309 overlay on the Cr - Mo steel, the Type 309 overlay and Type 309 groove weld interface and the Type 316 base material to Type 309 groove weld area. Representative microstructures of these areas are illustrated in Figure 15. It is considered significant that the band formed by carbon migration is narrower than that observed on the preliminary tests (Figure 3). This is due to the shorter holding time of 6 hours at 1200 deg. F. rather than 24 hours for the post-weld thermal treatment. The Cr - Mo steel adjacent to the overlay fusion zone showed a slight grain growth which is normal for a silicon killed steel of this type. Hardness surveys made across the same areas represented by the photomicrographs are also plotted in Figure 15. The fusion zone hardness at the Cr - Mo overlay interface is slightly higher than obtained from the preliminary tests (figure 6C) which is also attributed to the shorter holding time of 6 hours at 1200 deg. F. rather than 24 hours. The hardness of the Type 309 overlay is essentially the same as before (Figure 6C) indicating the degree of sigma formation was essentially of the same order of magnitude.

The type 309 weld metal in the groove joint clearly revealed delta ferrite in the austenitic matrix. The amount of delta ferrite was determined to be 6.5% from the results of chemical analysis and plotting the calculated chromium - nickel equivalents on the Schaeffler Diagram. The weld metal hardness of about 200 Diamond Pyramid Hardness Number (Vickers) is compatible with the hardness of weld metal from the same heat of wire used for the overlay tests (Figures 6 and 10).

The microstructure of the annealed Type 316 base material has completely austenitic thus confirming the delta ferrite calculations based on chemical compositions and the Schaeffler diagram. Figure 15 shows that the hardness of the Type 316 base material in the heat affected zone as well as the unaffected material is essentially the same as the transition weld at about 200 DPH.

Complete hardness measurements are tabulated in Table 11.

CONCLUSIONS:

The procedure for welding and thermal treatment of the transition-weld joint between 4-1/2-inch thick Type 316 stainless steel and 2-1/4% Cr - 1% Mo steel was determined to be completely satisfactory on the basis of having exceeded the minimum requirements of Section IX of the ASME Boiler and Pressure Vessel Code by a wide margin. Supplementary mechanical tests, metallographic examinations and hardness surveys further attested to the adequacy of the quality of the transition joint resulting from the procedures developed by this investigative program.

The only basic factor recommended for modification, to provide a wider latitude for commercial fabrication, is an increase in the overlay thickness to 5/8 inch to make certain the Cr - Mo material is not adversely influenced from the heat developed during welding of the transition joint. This increase of thickness will also provide more tolerance for the Inconel overlay on the inner vessel surface in order to avoid penetration of it during the welding of the transition joint.

PROCEDURE SPECIFICATION FOR FABRICATING THE TRANSITION JOINT

A detailed procedure specification for fabricating the transition joint between the heavy wall 2-1/4% Cr - 1% Mo steam drum and the Type 316 superheater for the steam generator shown in Figure 1, is contained in the Appendix of this report.

The successful development and prototype testing of this procedure meets the stated objective of this program and thus completes the investigation.

FABRICATION OF PROTOTYPE TRANSITION JOINTS FOR THERMAL CYCLING TESTS

In order to demonstrate the reliability of the transition joint under temperature cycling conditions that could conceivably be encountered in service, a prototype assembly was fabricated under normal shop manufacturing conditions using the procedures developed from this investigative program and detailed in the Appendix.

Two ring forgings of 2-1/4% chromium - 1% molybdenum steel were welded to each end of a Type 316 stainless steel forged ring. The component rings were essentially 30 inches in diameter, 4 inches thick and 8 inches long. The prototype assembly thus contained two transition joints for evaluation as shown in Figure 16.

The joints were X-rayed after half of the transition weld was deposited and again after it had been completed. The soundness of the weld joint was satisfactory for both series of radiographs and well above the minimum limits of acceptability set forth in MIL-STD-271A (Ships), 2 Jan. 1959.

The prototype assembly was subjected to a thermal cycling test consisting of heating to 880 deg. F. in a period of 45 minutes. Cooling was accomplished by applying a fine spray of water until a temperature of 300 deg. F. was reached in a period of 80 minutes. At the time this report was written, 21 cycles had been completed with no evidence of failure. Other details and the results of this test will be contained in a separate report.

CONCLUSIONS

1. Practicable welding and thermal procedures have been developed for making a transition joint between the Type 316 stainless steel of the superheater and the 2-1/4% chromium - 1% molybdenum steel of the steam drum in order to complete fabrication of the steam generator. The complete fabrication procedure is given in the Appendix of this report.

2. The mechanical and metallurgical properties of the welded transition joint produced by the developed procedures and meeting the x-ray requirements of MIL-STD-271A (Ships), 2 Jan. 1959, are considered adequate to more than accommodate the stress requirements at the transition joint area designed to operate at 700 deg. F and 2200 psi. Guided-side-bend tests, transverse-tensile tests, all-weld-metal cylindrical tensile tests, hardness surveys, x-ray and complete metallographic examinations were used for evaluating the properties of welded transition joints.

3. Type 309 weld wire and Arcosite S4 flux, having a chemical composition suitable for depositing a weld metal by the automatic submerged-arc process having 6.5% delta ferrite in the austenitic matrix, was suitable for making the weld overlay as well as the final transition-joint weld. An overlay thickness that will finish to a minimum thickness of 5/8 inch, after machining to provide the contour for the final transition weld, is recommended.

4. A post-weld thermal treatment of 1200 deg. F. for the weld overlay was found to be the best compromise for adequate reduction of underbead hardness in the 2-1/4% chromium - 1% molybdenum steel, minimum formation of sigma phase in the Type 309 weld metal and a minimum of carbon migration across the weld interface.

   No post-weld thermal treatment is considered necessary for the final transition-weld joint. This practice is approved under Section VIII of the ASME Boiler and Pressure Vessel Code and Code Case Ruling No. 127ON-1, dated Sept. 18, 1959.

5. A preheat temperature of 400 deg. F on the 2-1/4% Cr - 1% Mo steel transition ring prior to applying the Type 309 weld overlay is considered practicable and conducive to good welding practice to obtain a transition overlay having satisfactory mechanical and metallurgical properties. Slow and uniform cooling of the overlaid transition ring to 70 deg. F will not be detrimental to the weldment.

6. The high nickel (Inconel) BP-85 electrode, is suitable for manual deposition of the weld cladding on the inner surface of the transition joint for protection against chloride stress corrosion action. This overlay should be deposited after deposition of the Type 309 weld metal on the faying surface so that it can extend at least 1/4-inch on to the Type 309 overlaid metal. Type 309 and BP-85 overlays are both amenable to the 1200 deg. F post-weld thermal treatment. Caution must be exercised during welding of the root portion of the final transition-joint in order to avoid penetration of Type 309 weld metal into the BP-85 Inconel overlay as cracking will result.

BIBLIOGRAPHY

1. Rutherford, J. J. B., "Welding Stainless Steel to Carbon or Low-Alloy Steel", The Welding Journal 38 (1), Research Supplement 19-s to 26-s (1959).

2. Tucker, J. T. Jr. and Eberle, F. "Development of a Ferritic-Austenitic Weld Joint for Steam Plant Application", The Welding Journal 35 (11), Research Supplement 529-s to 540-s (1956).

3. Christoffel, R. J., and Curran, R. M., "Carbon Migration in Welded Joints at Elevated Temperatures", The Welding Journal 35 (9), Research Supplement 457-s to 468-s (1956).

4. Thomas, R. D., "Welding of High-Alloy Castings", The Welding Journal 34 (1), Research Supplement 27-s to 32-s (1952).

5. Emerson, R. W., and Hutchinson, W. R., "Welded Joints Between Dissimilar Metals in High-Temperature Service", The Welding Journal 31 (3), Research Supplement 126-s to 140-s (1952).

6. Carpenter, O. R., and Jessen, N. C., "Some Considerations in the Joining fo Dissimilar Metals for High-Temperature High-Pressure Service", ASTM Proceedings (50) pp 809 to 857 (1950).

7. Schaeffler, A. L., "Welding Dissimilar Metals with Stainless Electrodes", Iron Age (July 1, 1948).

8. Rozet, D., Campbell, H. C., Thomas, R. D., "Effect of Weld Metal Composition on the Strength and Ductility of 15% Cr - 35% Ni Welds", The Welding Journal 27 (10), Research Supplement 481-s to 491-s (1948).

APPENDIX

PROCEDURE FOR WELDING A TRANSITION JOINT BETWEEN 2-1/4% CHROMIUM - 1% MOLYBDENUM STEEL AND TYPE 316 STAINLESS STEEL

1.0 GENERAL:

1.10 The procedure for welding a transition joint between 2-1/4% cr - 1% Mo steel and Type 316 stainless steel which follows is given in three parts.

1.20 Part I covers the welding of the Type 309 stainless steel overlay on the end of the 2-1/4% Cr - 1% Mo transition section.

1.30 Part II covers the welding and the thermal treatment of the high-nickel-alloy (Inconel) overlay deposited on the inner surface of the transition from the 2-1/4% Cr - 1% Mo base metal and the stainless steel overlay on the end of the transition section.

1.40 Part III covers the groove welding of the overlaid 2-1/4% Cr - 1% Mo transition section to the Type 316 stainless steel base material.

2.0 PART I: WELDING THE STAINLESS OVERLAY ON THE 2-1/4% Cr - 1% Mo STEEL TRANSITION SECTION

2.10 PROCESS: The welding shall be done by the submerged-arc process.

2.20 BASE MATERIAL: The base material shall be of 2-1/4% Cr - 1% Mo nominal composition (ASTM A387-57T Grade D or A182-58T-F22). The run-off tabs or rings may be fabricated from 2-1/4% Cr - 1% Mo material or from a plain low-carbon deoxidized steel.

2.30 ELECTRODE WIRE AND WELDING FLUX: The electrode wire shall conform to ASTM A371-53T ER 309 specifications and have a deposited all-weld-metal delta ferrite content of 5 per cent minimum. The welding flux used shall be Arcosite S4 (Arcos Corp.)

2.40 WELDING CURRENT: D.C. straight polarity shall be used.

2.50 PREPARATION: The welding edge of the base material shall be machined with a 10° bevel as shown in Figure A. All scale, grease and paint, or other contaminators shall be removed from the surface to be welded.

2.60 PREHEAT: The base material and run-off tabs and rings shall be preheated to a temperature of $400^{\circ}F$ before welding and a minimum interpass temperature of $300^{\circ}F$ shall be maintained during welding. In the event that the overlay welding on the 2-1/4% Cr - 1% Mo steel must be interrupted the following procedure shall be followed:

2.61 If less than two completed layers have been applied, the component shall have the preheat held at $400^{\circ}F$ until welding is resumed.

2.62 After two or more layers have been applied, the component may be covered with asbestos and cooled slowly to not lower than $70^{\circ}F$.

2.63 The component must be preheated uniformly to $400^{\circ}F$ before the welding is resumed.

2.70 WELDING CONDITIONS: The overlay shall consist of a minimum of three identical layers of weld metal, which altogether will provide a layer of stainless steel 5/8" minimum thickness on the beveled surface after machining. Additional layers of weld metal shall be deposited along the I.D. edge of the bevel to allow for the bottom radius and root land as shown in Figure A. The welding conditions used shall be as outlined in Table A.

2.71 OVERLAY INSPECTION: The overlay shall have a soundness capable of meeting the X-ray quality requirements of MIL-STD-271A (SHIPS), 2 Jan. 59 specifications.

2.80 MACHINING: The overlay shall be machined to a 10° J-bevel with a 1/4" bottom radius and 3/8" land as shown in Figure A.

2.90 POST-HEAT TREATMENT: See Part II of this procedure specification.

3.0 PART II: INCONEL OVERLAY

3.10 Following completion of the overlay welding and machining of the J-bevel, the inner surface of the transition joint shall be cleaned to remove scale and oil from the surface to be welded, and clad with suitable high-nickel alloy (Inconel) weld metal. This cladding shall be applied to cover the inner surface of the overlay-base metal interface, and shall extend a minimum of 1/4 inch on the Type 309 overlay and a minimum of 1/2 inch on the Cr - Mo base material.

3.20 POST-HEAT TREATMENT: The overlaid transition section with the Inconel cladding shall be thermally treated be heating uniformly to a temperature of 1200^{o}F and holding at temperature for 1-1/2 hours per inch of thickness, then furnace cooled in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code (1959).

4.0 PART III: GROOVE WELDING OF THE STAINLESS STEEL TRANSITION JOINT

4.10 PROCESS: The welding shall be done by the automatic submerged-arc welding process.

4.20 BASE MATERIAL: The base material shall consist of the Type 309 overlaid and the Inconel clad 2-1/4% Cr - 1% Mo material and stainless steel material conforming to ASTM A240-58T Type 316 or, ASTM A182-58T-F316 specifications.

4.30 ELECTRODE WIRE AND WELDING FLUX: The electrode wire shall conform to ASTM A371-53T ER309 specifications and have a deposited all-weld-metal delta ferrite content of 5 percent minimum. The welding flux used shall be Arcosite S4 (Arcos Corp.)

4.40 WELDING CURRENT: D.C. reverse polarity shall be used.

4.50 PREPARATION: The abutting edges of the base material shall be J-beveled with a 10^{o} bevel angle, 1/4-inch radius and a 3/8-inch land as shown in Figure A. All grease, oil, paint and other surface contaminators shall be removed from the welding groove and adjacent surfaces.

4.60 FIT-UP: Joints shall be fitted tightly and accurately and tack welded on the I.D. of the joint using coated Type 309 stainless steel welding electrodes. Proper care shall be taken to confine the tack welds to the area of the stainless overlay and stainless base metal. Welding on the 2-1/4% Cr - 1% Mo base material and the Inconel cladding is not permitted. A backing strip shall not be used.

4.70 PREHEAT: A preheat of 70°F minimum shall be used for tacking and welding the joint. The interpass temperature shall be 300°F maximum.

4.80 WELDING CONDITIONS: The welding conditions, diameter of electrode wire, and the current and voltage ranges required during welding are listed in Table A. The welding arc shall be broken only in a manner which will prevent crater cavities. Weld beads shall merge smoothly with one another and with the base material. Extra precautions will be required in correctly placing each weld bead because of the influence exerted on the arc by the ferritic Cr - Mo material. Offsetting the electrode 1/2-inch away from the Type 309 stainless overlay and 1/4-inch away from the Type 316 material should be helpful.

When one-half of the welding in the groove is completed, the backside of the joint shall be machined or ground to sound metal (back chipping is not permitted) and the proper number of beads deposited to fill the groove.

The width of the backside groove shall not be greater than 1/2-inch in order to assure that the final backside cover passes shall be clear of the Inconel cladding.

The outside cover passes shall merge uniformly with the stainless steel overlay and stainless steel base material, and shall be clear of the transition interface between the Cr - Mo material and stainless overlay by at least 1/4-inch. The weld reinforcement shall be within that specified by the applicable specification.

Peening the weld for mechanical stress relief is not permitted.

4.90 POST-HEAT: No post-weld thermal treatment shall be applied to the transition joint after completion of welding.

5.0 INSPECTION:

5.10 The half-completed weld and the fully-completed weld shall be X-rayed in accordance with, and meet the requirements for soundness set forth in the MIL-STD-271A (SHIPS), 2 Jan. 1959 specifications.

5.20 In the event that a defect is observed in the overlay of the transition weld after partial or complete X-ray inspection, the welded girth seam shall be cut apart, the repair made in the overlay (using the preheat precautions of Item 2.60), and the overlaid component re-heat treated as set forth under Item 3.20 of this specification.

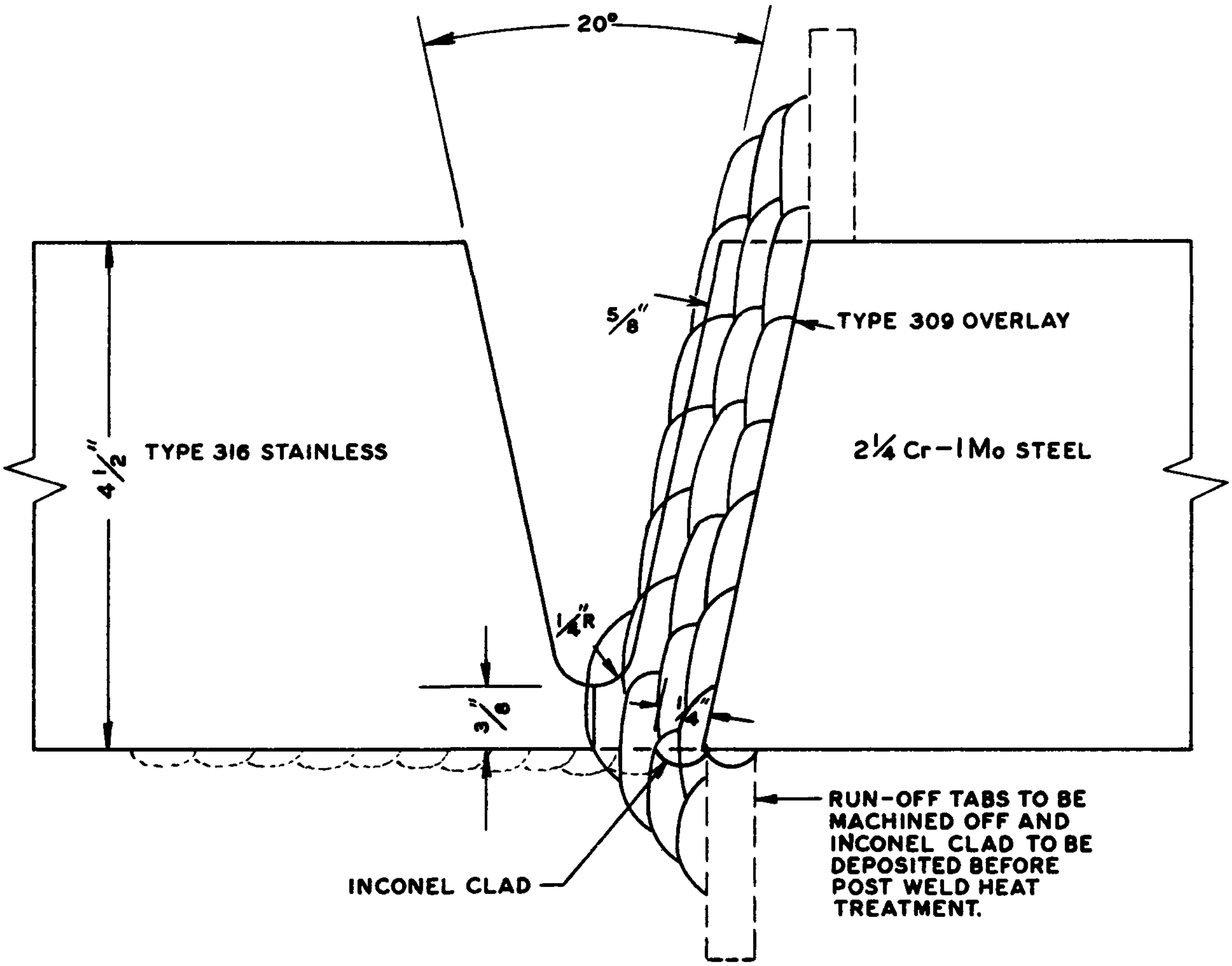


FIGURE A. DESIGN DETAILS REQUIRED FOR MAKING THE TRANSITION WELD.

PROCEDURE FOR WELDING A TRANSITION JOINT BETWEEN 2-1/4% CHROMIUM - 1% MOLYBDENUM STEEL AND TYPE 316 STAINLESS STEEL

TABLE A.

CONDITIONS FOR WELDING THE OVERLAY

Welding Process	Automatic submerged-arc
Welding position:	Flat
Electrode wire:	ER 309 1/8" dia.
Flux:	Arcosite S4 (Arcos Corp.)
Preheat:	400°F
Interpass Temp:	300-400°F
Current:	DCSP
Arc amps:	300-325
Arc volts:	39-41
Travel speed:	6-1/2 ipm
Post heat:	1200°F - 1-1/2 hr/inch

CONDITIONS FOR WELDING THE GROOVE JOINT

Welding process:	Automatic submerged-arc
Welding position:	Flat
Electrode Wire:	ER 309 5/32" dia.
Flux:	Arcosite S4 (Arcos Corp.)
Preheat:	70°F min.
Interpass Temp:	300°F max.
Current:	DCRP
Post heat:	None

Passes	Arc Amps	Arc Volts	Speed ipm
1	390-410	31-32	15
2-8	475-525	31-32	12
9-29	475-525	31-32	10
30-42	500-550	31-32	8
Cover and backside	450-475	31-32	15

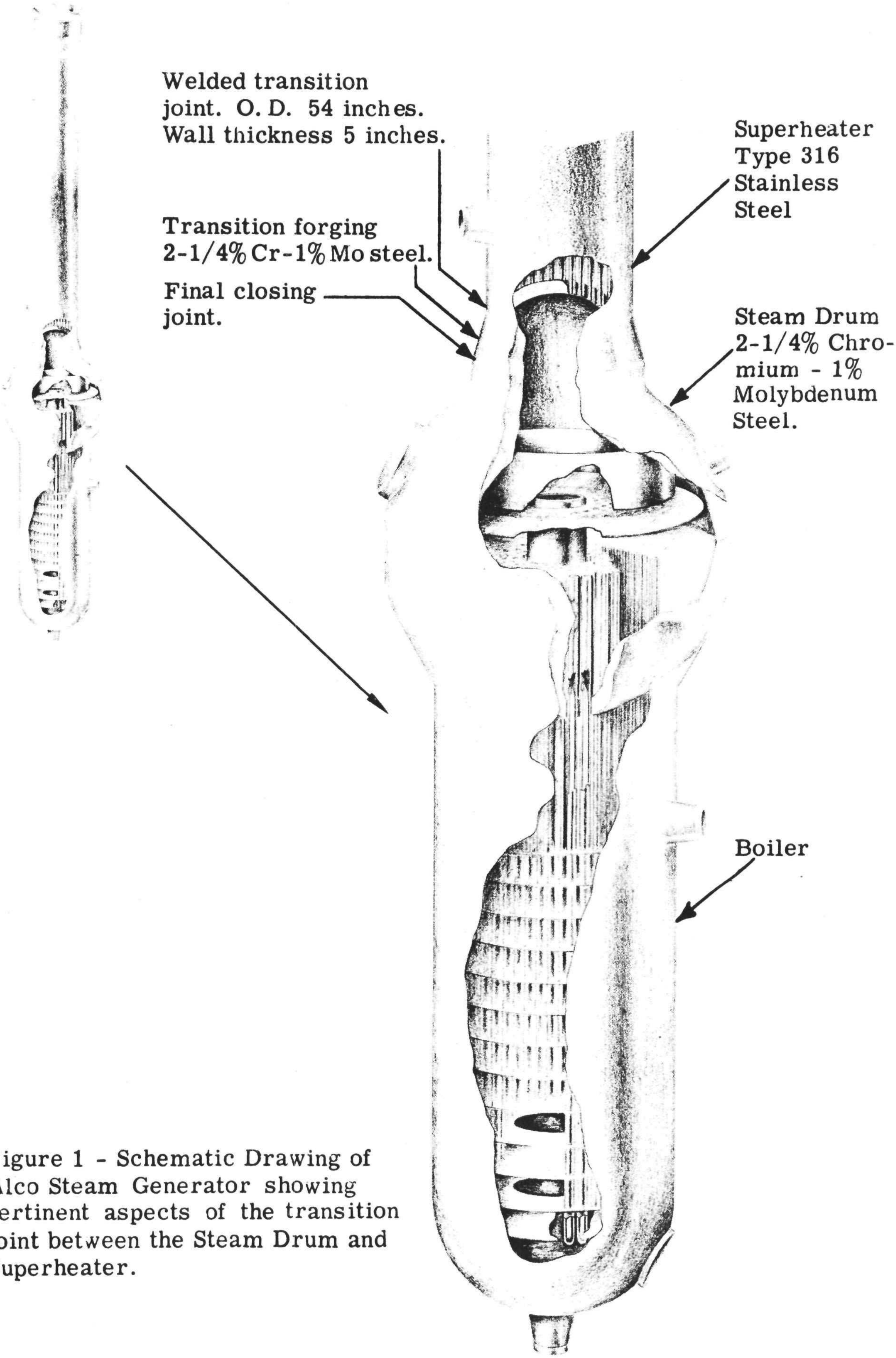
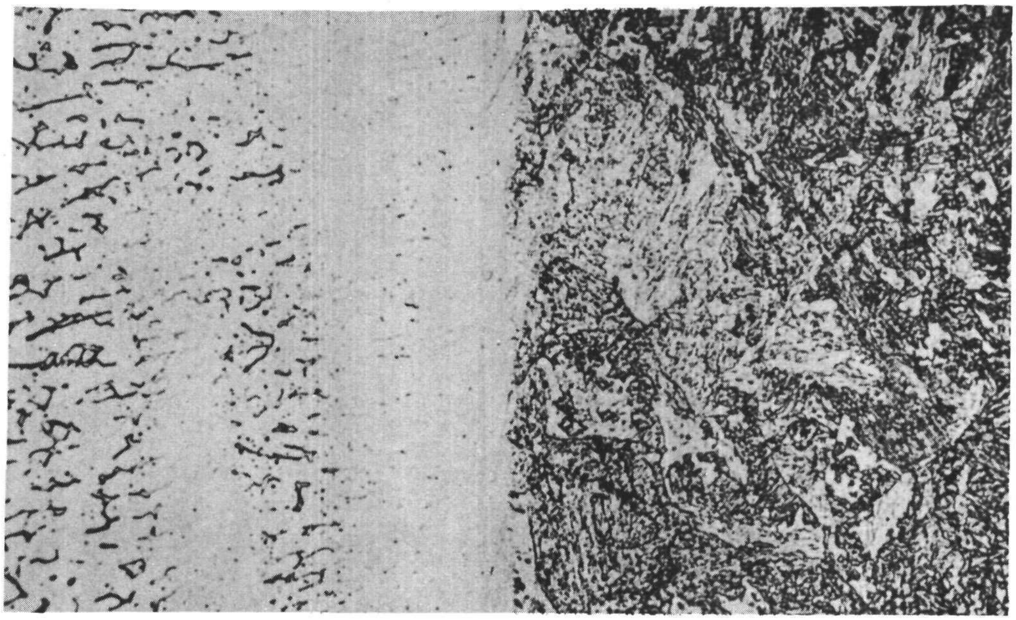
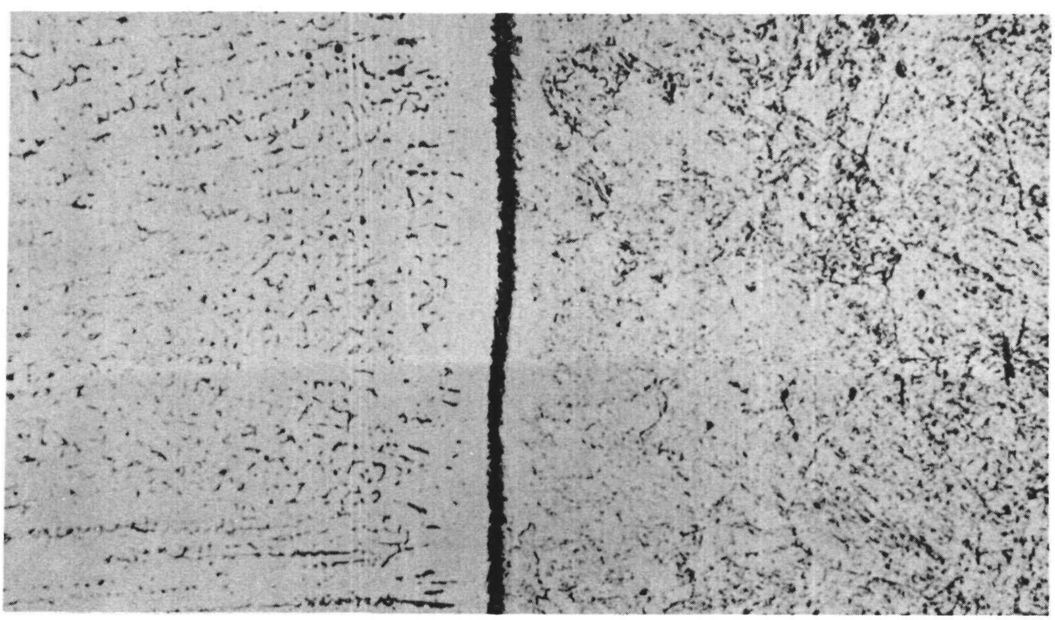


Figure 1 - Schematic Drawing of Alco Steam Generator showing pertinent aspects of the transition joint between the Steam Drum and Superheater.



13045 A

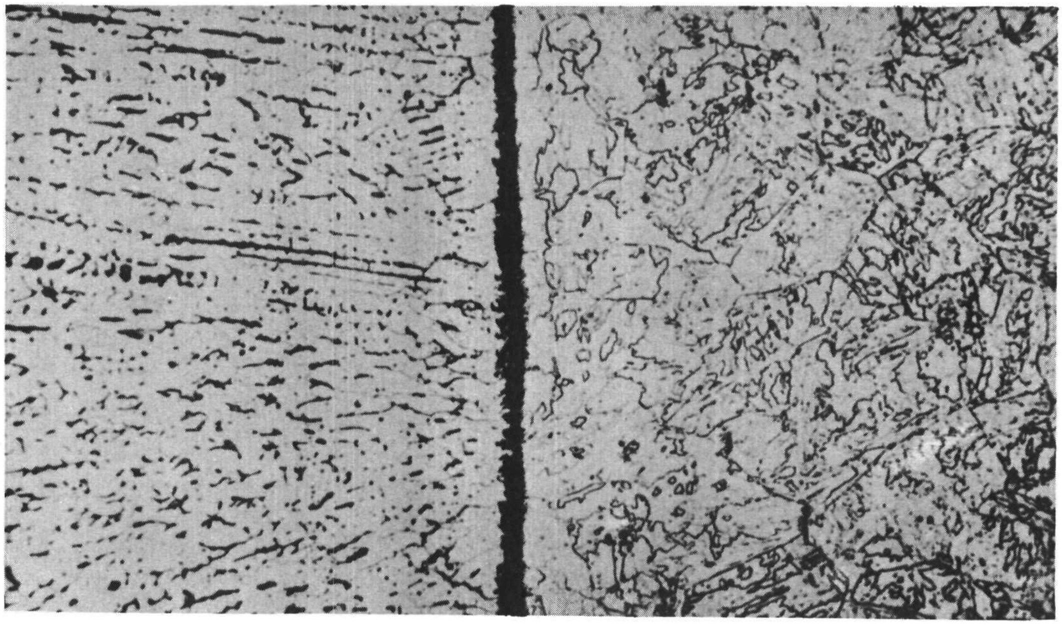
A. As-Welded Condition



13085 C

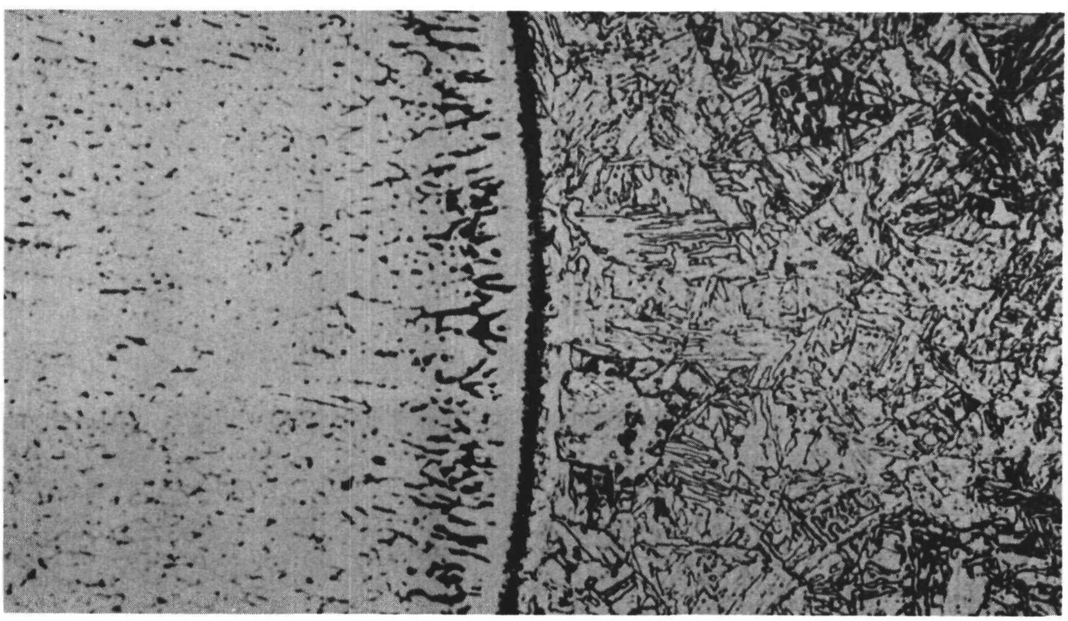
B. Treated 1100^{O}F, 24 hrs.

Figure 2 - Photomicrographs of automatically deposited type 309 weld overlay on 2-1/4% Cr-1% Mo steel showing influence of thern.al treatment on carbon migration Mag. 250 X. Etchant - chromic acid and picral.



13085 E

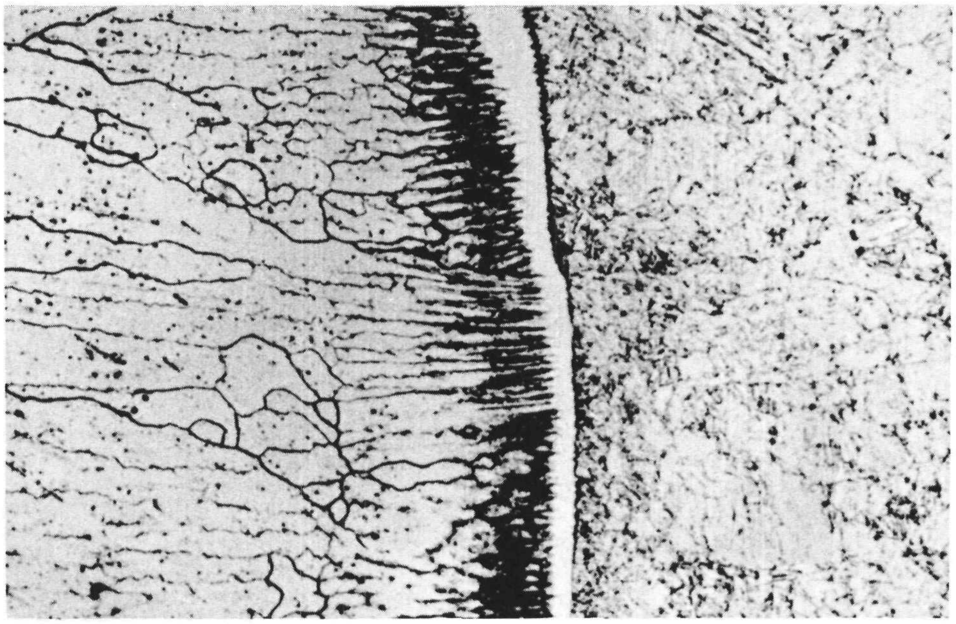
A. Treated 1200°F, 24 hrs.



13045 B

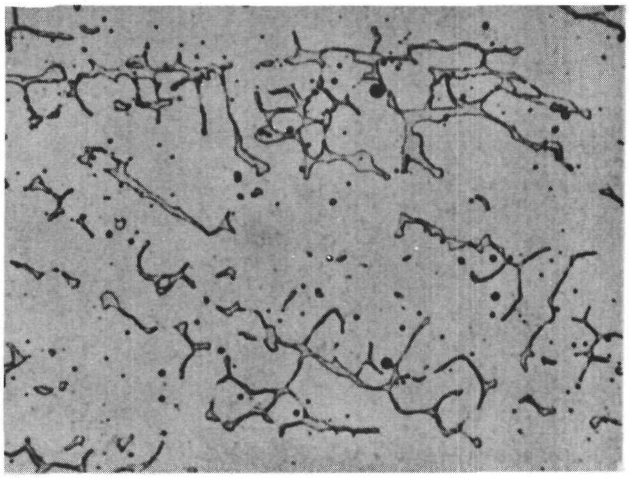
B. Treated 1300°F, 24 hrs.

Figure 3 - Photomicrographs of automatically deposited type 309 weld overlay on 2-1/4% Cr-1% Mo steel showing influence of thermal treatment on carbon migration. Mag. 250 X. Etchant - chromic acid and picral.



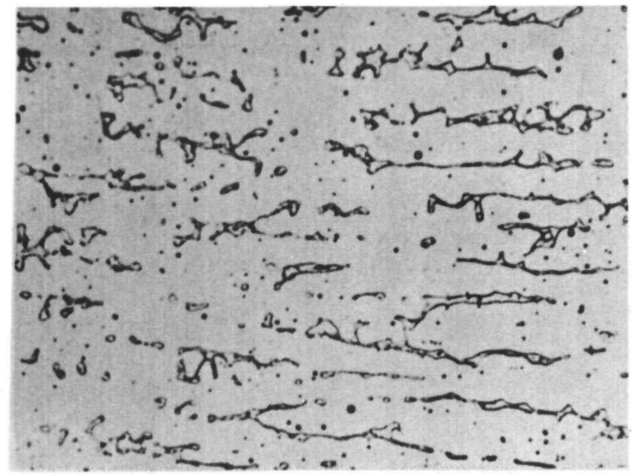
13136 A

Figure 4 - Photomicrograph of manually deposited BP-85 weld overlay on 2-1/4% Cr-1% Mo steel showing carbon migration after thermal treatment at 1300°F for 24 hrs. Mag. 250 X. Etchant - chromic acid and picral.



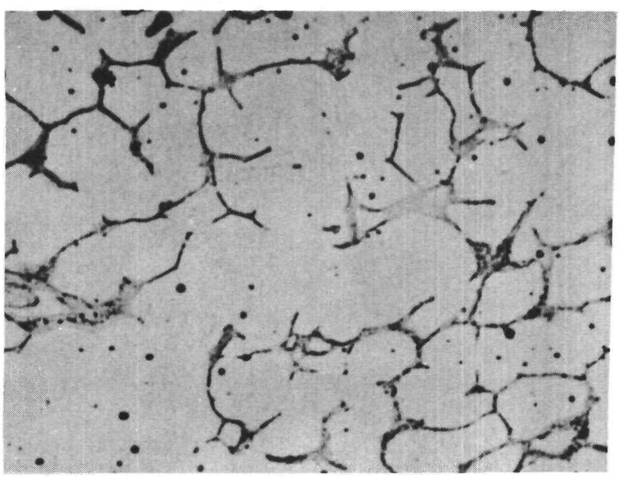
13049 D

A. As-welded condition.



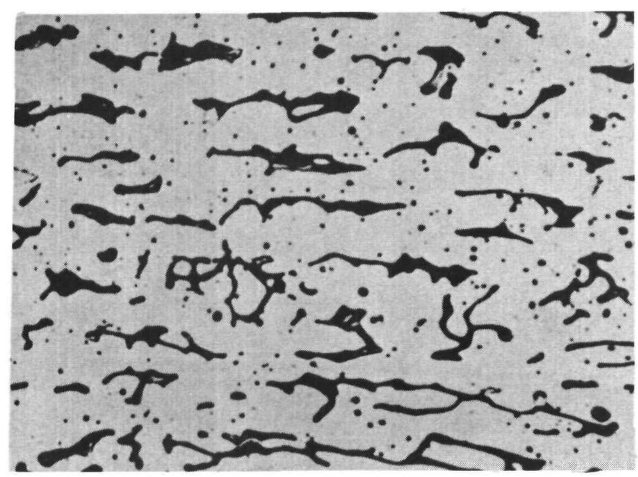
13089 H

B. Treated at 1100^{O}F, 24 hrs.



13049 B

C. Treated 1200^{O}F, 24 hrs.



13089 G

D. Treated 1300^{O}F, 24 hrs.

Figure 5 - Photomicrographs of automatically deposited type 309 weld metal showing transformation of delta ferrite to sigma resulting from various post-weld thermal treatments. Mag. 500 X. Etchant 20% HCL.

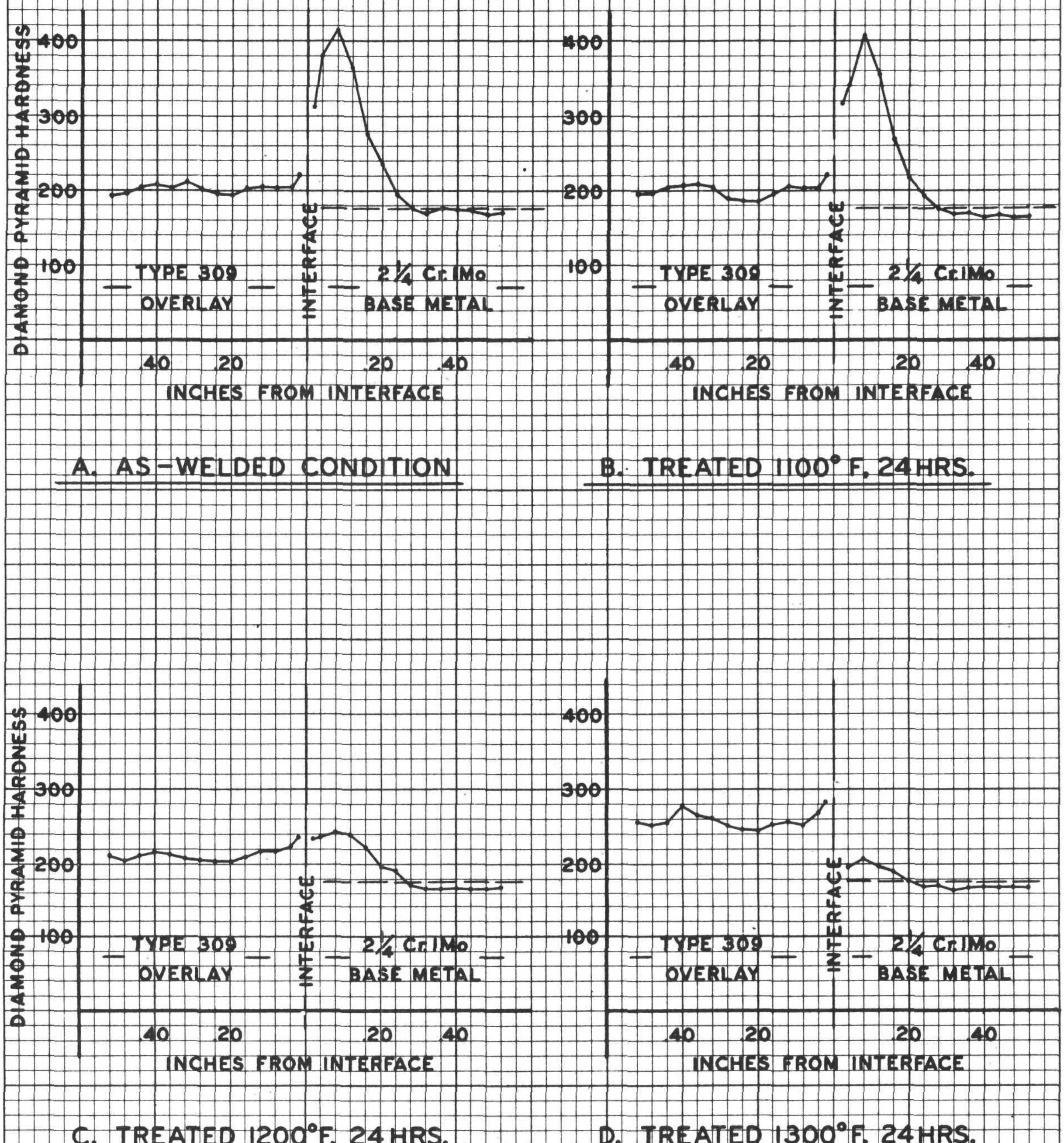


FIGURE 6. DIAMOND PYRAMID HARDNESS SURVEYS OF AUTOMATICALLY DEPOSITED TYPE 309 WELD OVERLAY ON 2¼ Cr. IMo STEEL THERMALLY TREATED AT SEVERAL TEMPERATURES. FROM TABLE 6. NOMINAL BASE METAL HARDNESS 175 DPH

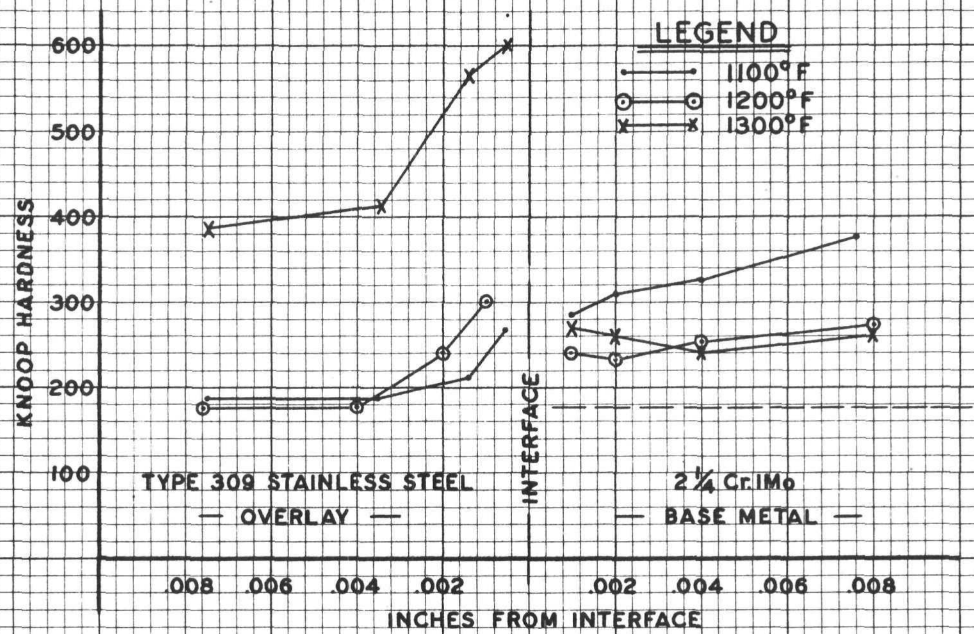
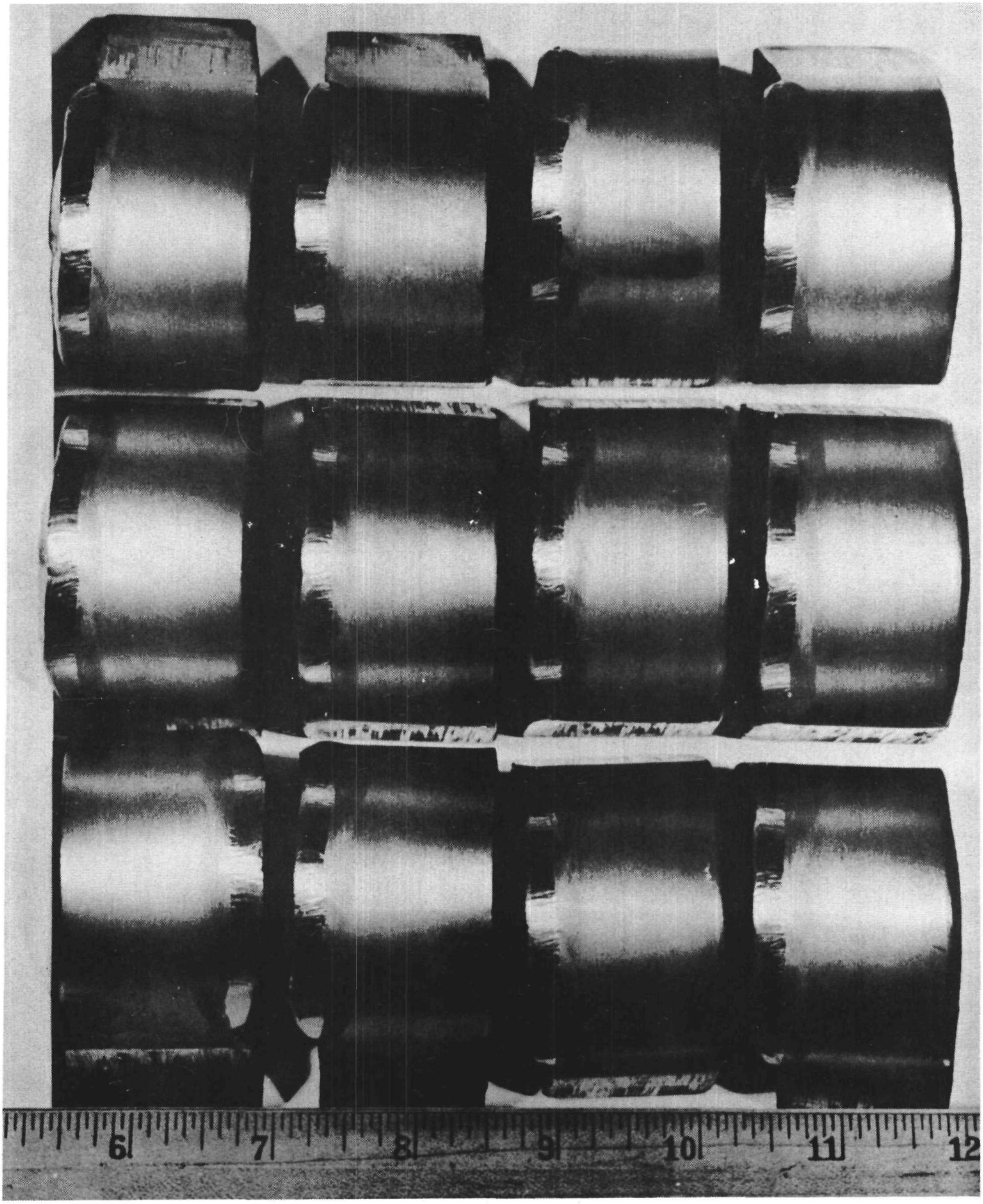
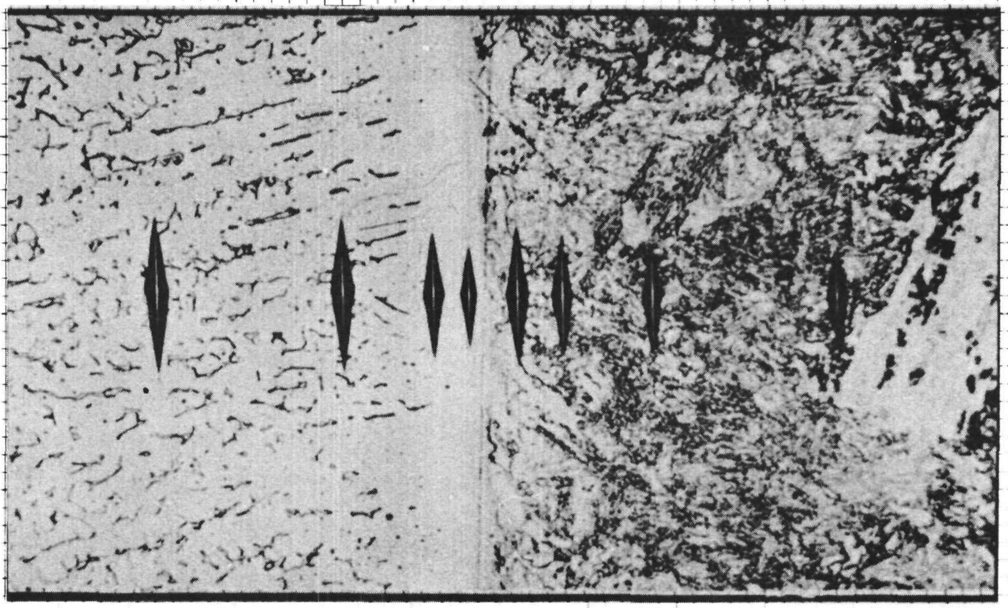


FIGURE 7. KNOOP HARDNESS MEASUREMENTS OF FUSION ZONE OF AUTOMATICALLY DEPOSITED TYPE 309 WELD OVERLAY ON 2 1/4 Cr. 1Mo STEEL THERMALLY TREATED AT SEVERAL TEMPERATURES. FROM TABLE 7. NOMINAL BASE METAL HARDNESS 173 KHN.



670

Figure 8 - Side bend speciments of 2-1/4% Cr-1% Mo steel preheated to several temperature levels then overlaid with automatically deposited type 309 austenitic stainless steel weldmetal. Tested as-welded.



13033 D

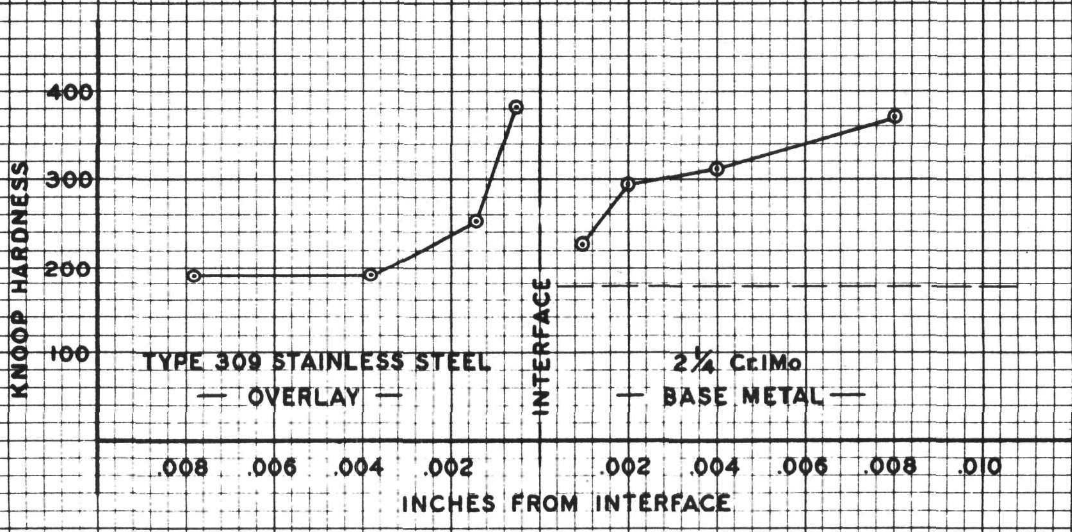


FIGURE 9. PHOTOMICROGRAPH OF FUSION ZONE OF AUTOMATICALLY OVERLAID TYPE 309 WELD METAL ON 2¼% Cr.-1% Mo STEEL PREHEATED TO 400°F AND COOLED TO 70°F AFTER WELDING. HARDNESS VALUES ARE TYPICAL FOR ALL PREHEAT LEVELS INVESTIGATED. MAG. 250X ETCHANT-CHROMIC ACID AND NITAL. NOMINAL BASE METAL HARDNESS 173 KHN.

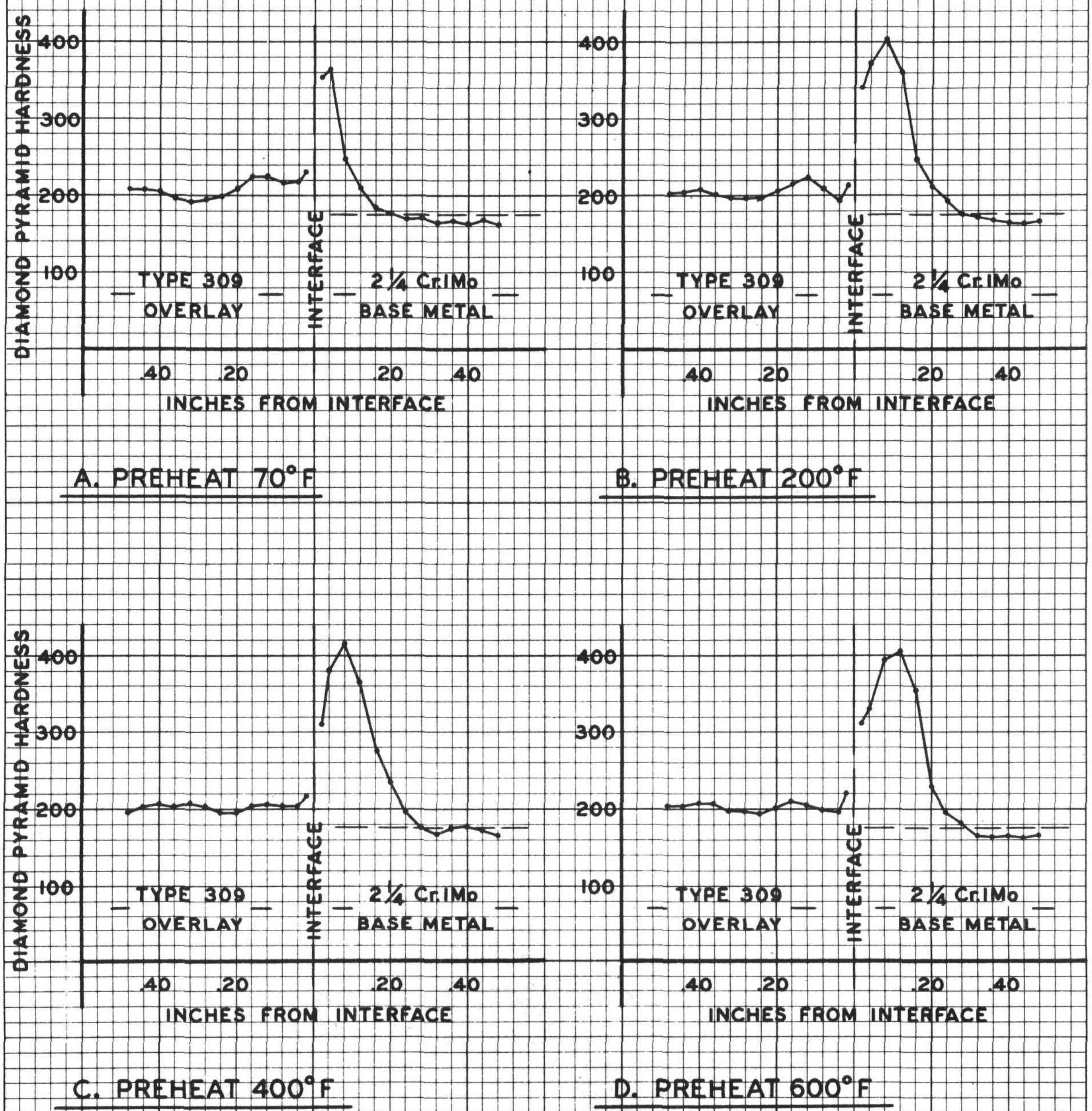
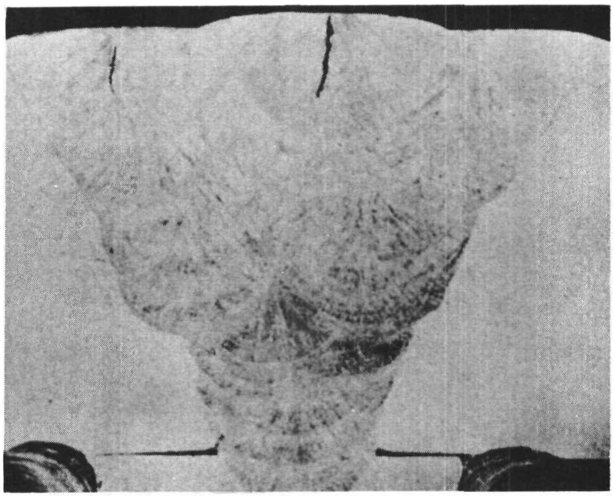
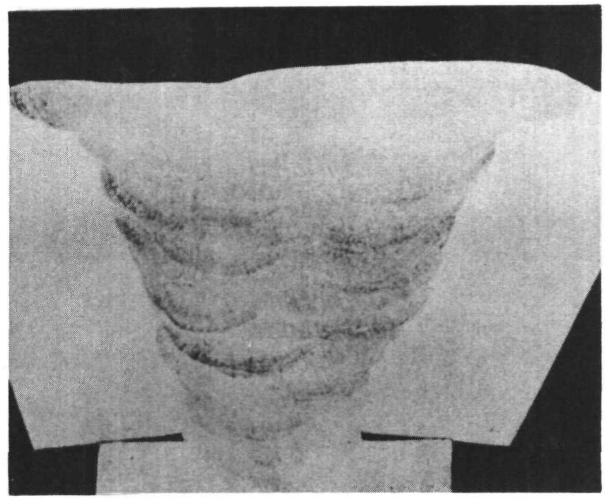


FIGURE 10. VICKERS HARDNESS SURVEYS OF AUTOMATICALLY DEPOSITED TYPE 309 OVERLAYS ON 2 1/4 Cr.-1% Mo STEEL PREHEATED TO SEVERAL TEMPERATURES AND COOLED TO 70°F AFTER WELDING. FROM TABLE 8. NOMINAL BASE METAL HARDNESS 175 DPH.



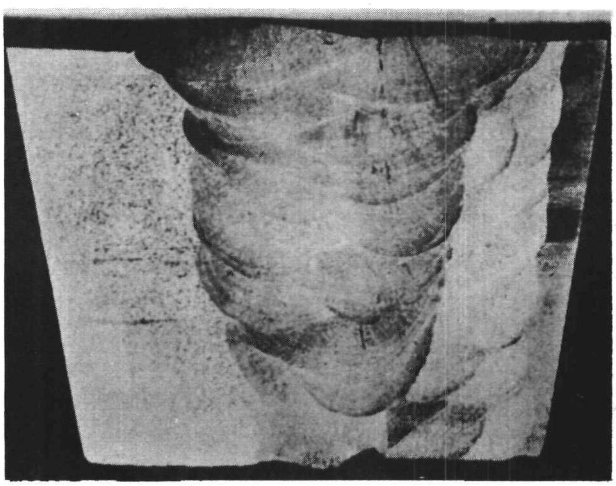
864 D

A. Type 316 plate welded with type 316 wire, weld metal deposited is 100% austenitic



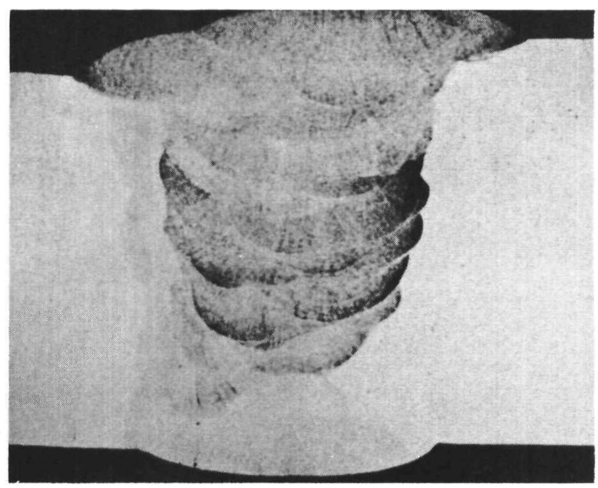
864

B. Type 316 plate welded with type 309 wire, weld metal deposited has 7% delta ferrite



864 E

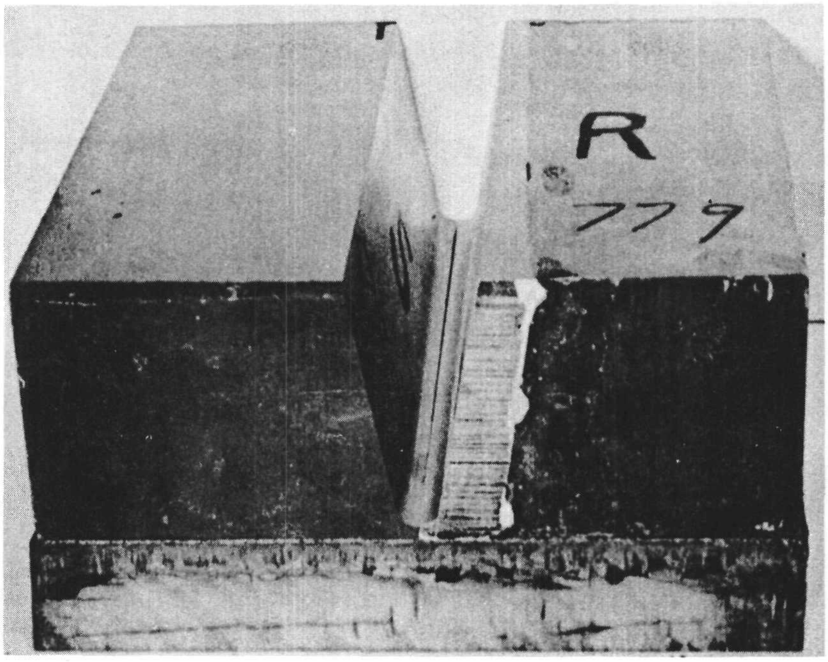
C. Joint of type 316 and BP-85 overlay welded with type 309 wire



864 B

D. Joint of type 316 and type 309 overlay welded with type 309 wire

Figure 11 - Photomacrographs of butt weld joints made using the base materials and weld wires indicated. Mag. 2 X. Etchant - chromic acid.



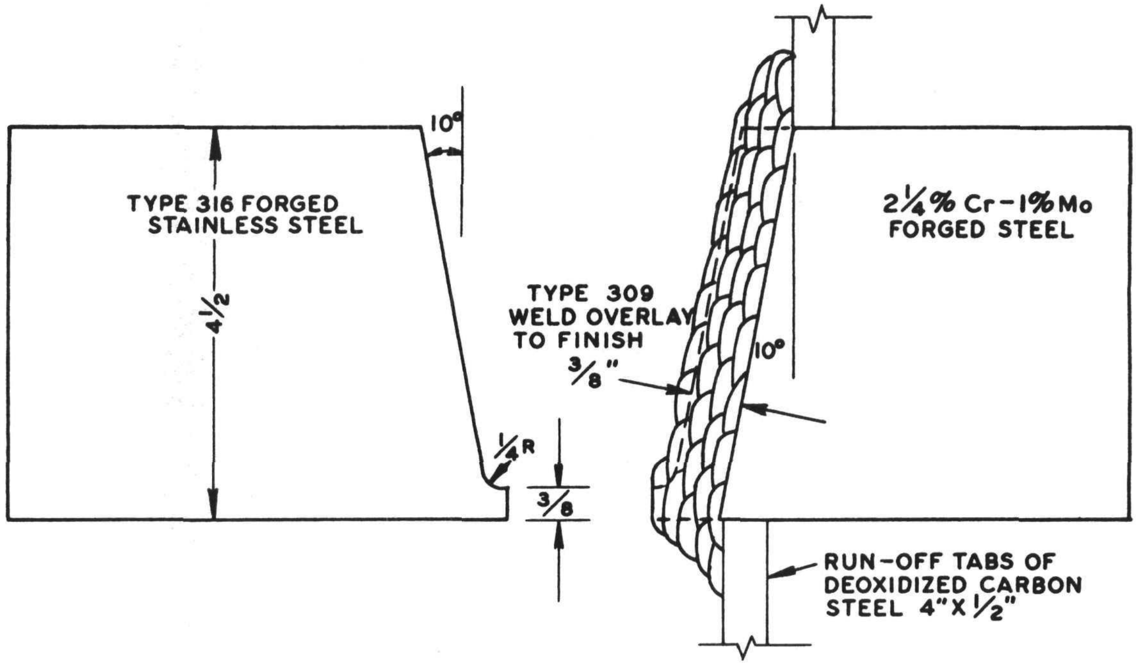
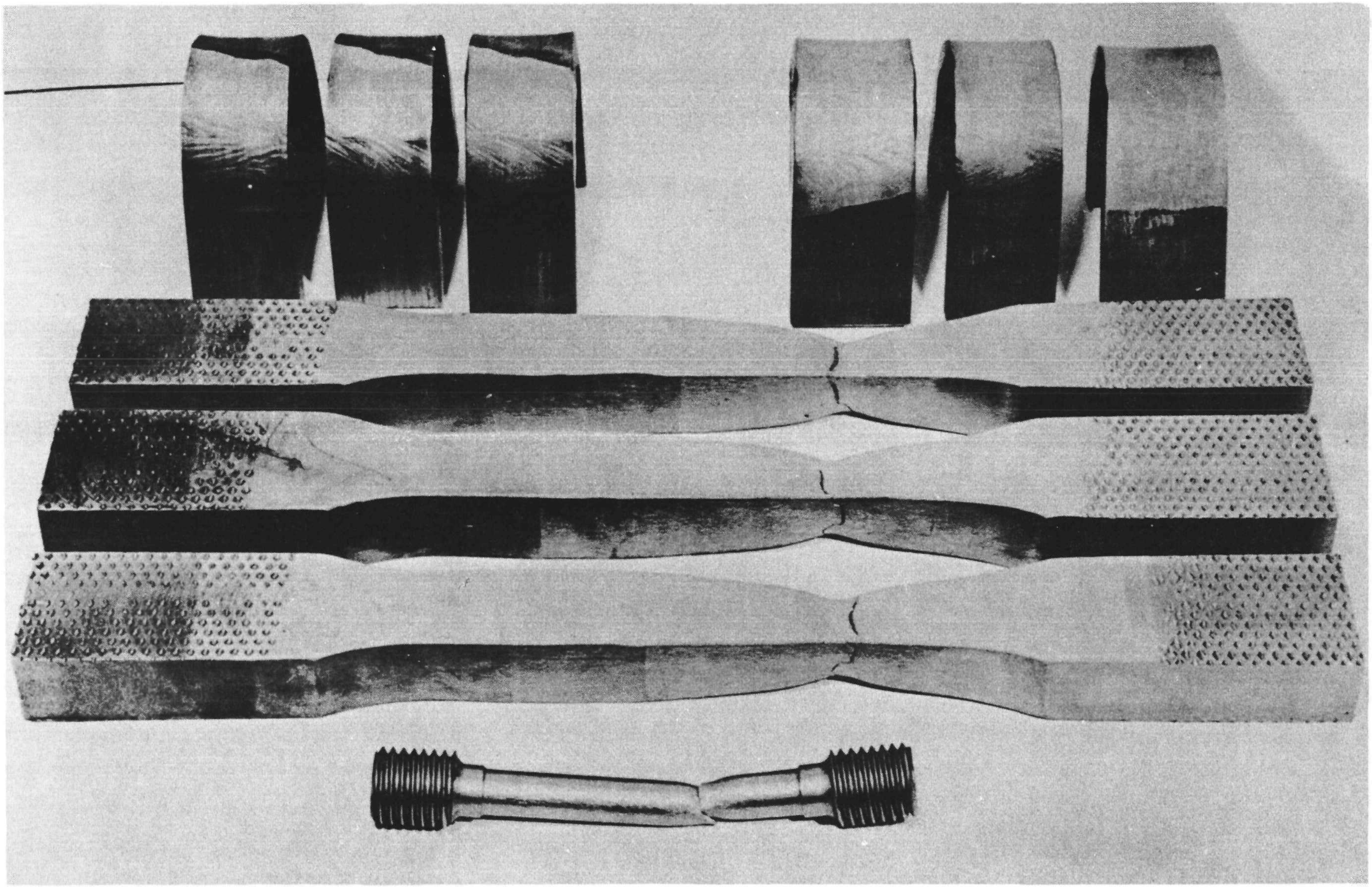
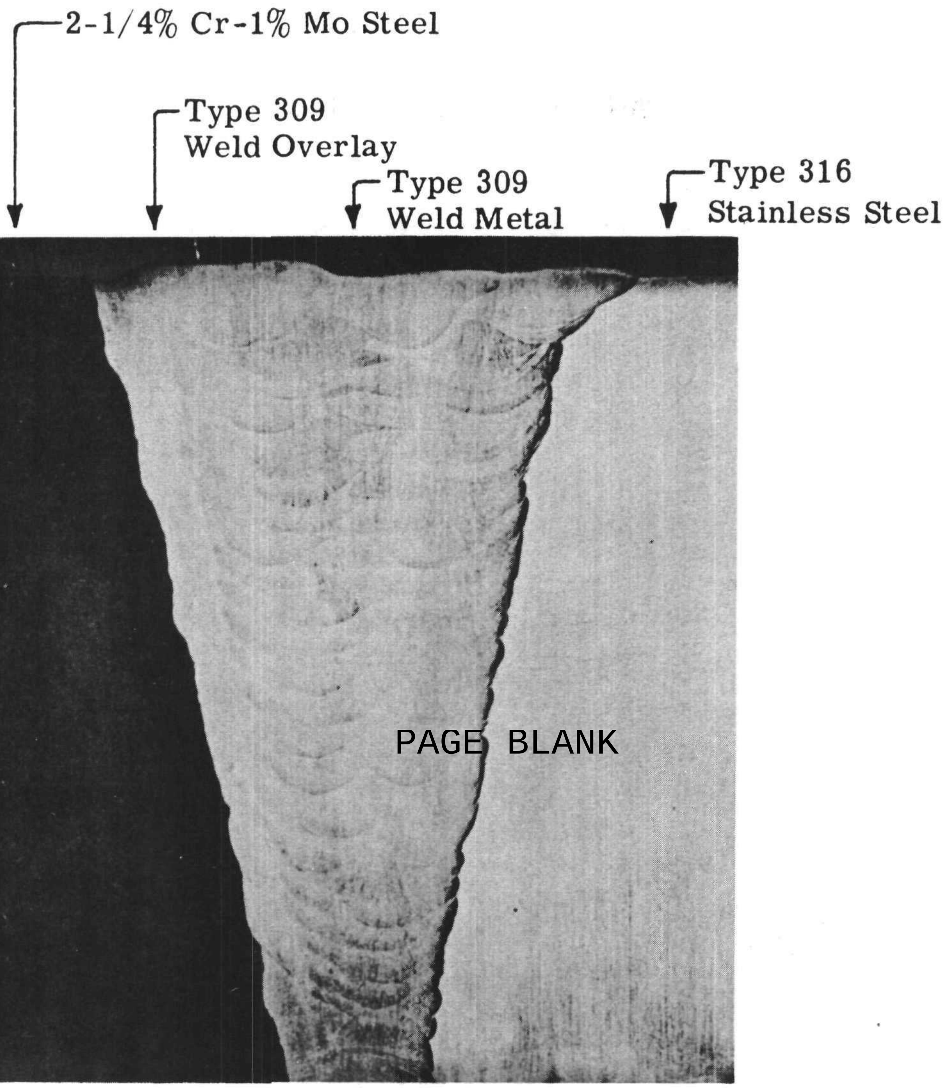


FIGURE 12. DETAILS OF TRANSITION JOINT BETWEEN TYPE 316 FORGED STAINLESS STEEL AND 2¼Cr-1%Mo FORGED STEEL.



784

Figure 13 - Photograph of specimens machine from the final 4-1/2-inch transition joint and subjected to guided side bend, transverse tensile and all-weld tensile tests. Mag. 1/2 X.



817 A

Figure 14 - Photomacrograph of a cross section of the final transition joint between type 316 stainless steel and 2-1/4% Cr-1% Mo steel. Mag. 1 X. Etchant - chromic and oxalic acid.

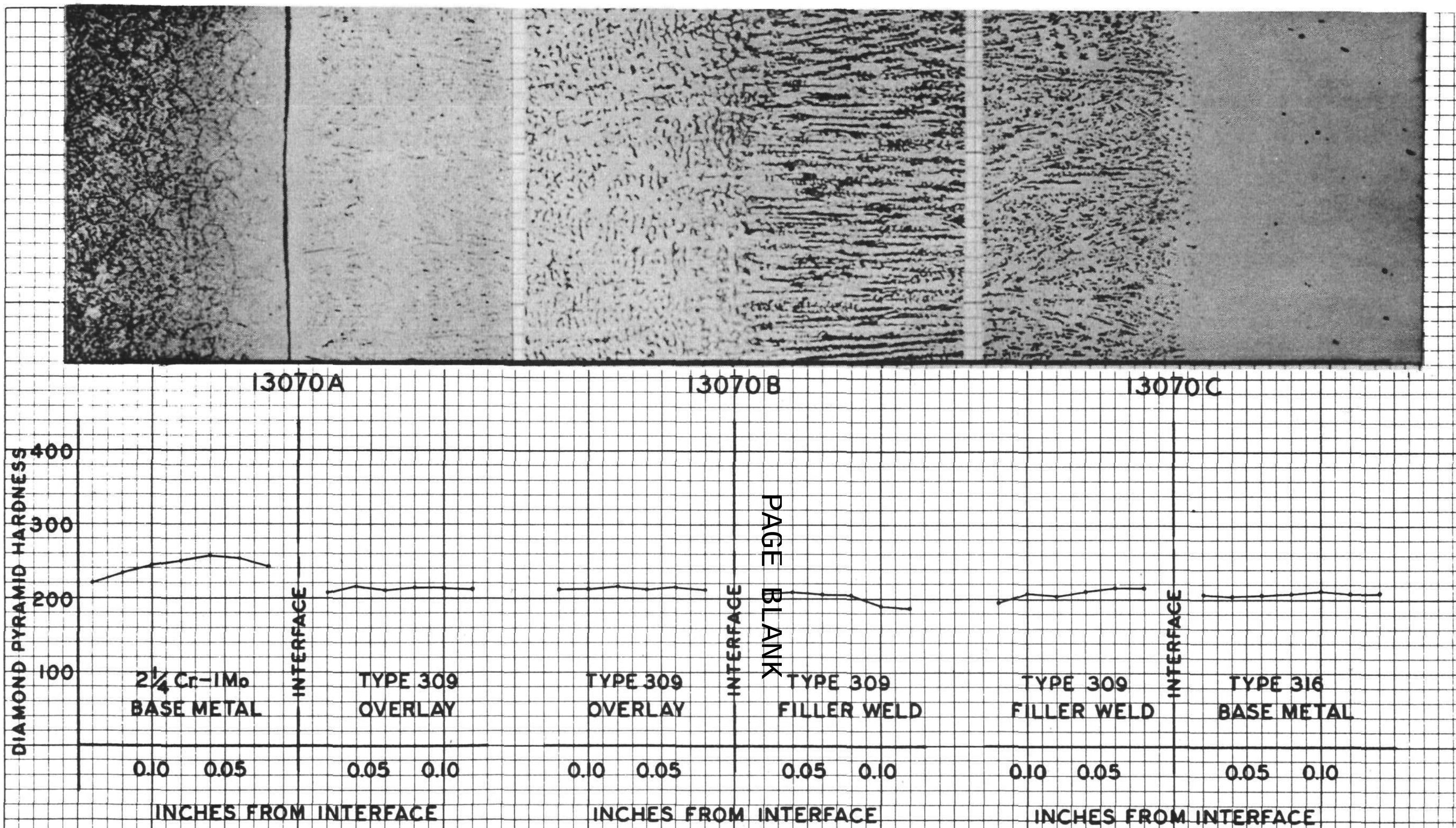


FIGURE 15. PHOTOMICROGRAPHS AND VICKERS HARDNESS SURVEYS ACROSS THE THREE INTERFACE AREAS COMPRISING THE FINAL TRANSITION - JOINT WELD. POST WELD THERMAL TREATMENT AT 1200°F FOR 6HRS. MAG. 100X. ETCHANT PICRAL AND CHROMIC ACID.

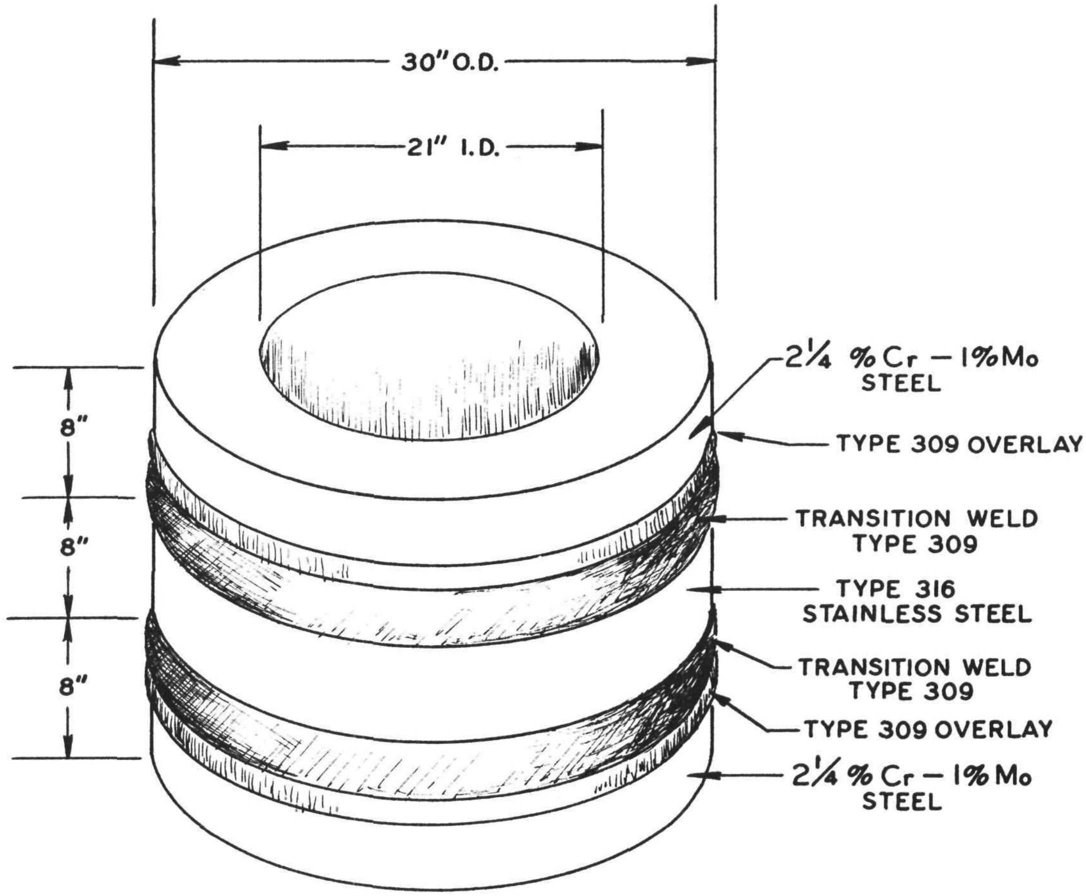


FIGURE 16. PROTOTYPE ASSEMBLY FOR THERMAL CYCLING TESTS CONTAINING TWO TRANSITION WELDS.

TABLE 1

MECHANICAL PROPERTIES OF BASE MATERIALS*

Material	Yield strength, psi .2% offset	Ult. tensile strength, psi	El. % in 2"	Reduction of Area %	Hardness Brinell
2-1/4 Cr - 1 Mo Forged Plates					
McInnes Steel Co. Ht. # 6633 1" thick	53000	82000	31	72.5	170
McInnes Steel Co. Ht. #50044 4-1/2" thick	51000	79000	32	73.5	179
ASTM A182 - 58T - F22 Min. Requirements	40000	70000	20	30	201 max.
Type 316 Stainless Plates					
Benedict Miller Inc. Ht. #34653 1" thick	45520	82730	54	---	163
ASTM A240 - 58T - Type 316 Min. Requirements	30000	75000	40	---	217 max.
Type 316 Stainless Forging					
Benedict Miller Inc. Ht. #67550 4-1/2" thick	37800	82100	60	---	163
ASTM A182 - 58T - F316 Min. Requirements	30000	75000	45	50	---

* Mill test report data.

TABLE 2

CHEMICAL COMPOSITION OF BASE MATERIALS

Material	ELEMENTS - PERCENT								Remarks
	C	Mn	P	S	Si	Ni	Cr	Mo	
2-1/4 Cr - 1 Mo Forged Plates									
McInnes Steel Co.	.12	.41	.013	.032	.30	-------	2.27	.98	Mill
Ht. #6633 - 1" thick	.12	.47	.010	.034	.28	-------	2.33	.89	Alco check
McInnes Steel Co.	.11	.50	.009	.020	.30	-------	2.22	1.00	Mill
Ht. #50044 - 4-1/2" thick	.12	.52	.005	.019	.29	-------	2.17	1.00	Alco check
ASTM A182 - 58T - F22 Requirements	.15	.30-.60	.040	.040	.50	-------	2.-2.50	.90-1.10	ASTM *
Type 316 Stainless Plates									
Benedict Miller Inc.	.028	1.73	.026	.013	.13	13.10	17.70	2.35	Mill
Ht. #34653 - 1" thick	.042	---	----	----	---	12.61	17.62	2.47	Alco check
ASTM A240 - 58T - Type 316 Requirements	.08	2.00	.045	.030	1.00	10-14.0	16-18.0	2-3.0	ASTM *
Type 316 Stainless Forging									
Benedict Miller Inc.	.054	1.65	.020	.014	.53	13.15	17.24	2.09	Mill
Ht. #67550 - 4-1/2" thick	.064	---	----	----	---	13.09	17.45	2.37	Alco check
ASTM A182 - 58T - F316 Requirements	.08	2.00	.040	.030	1.00	10-14.0	16-18.0	2-3.0	ASTM *

* Single values shown are maximum percentages.

TABLE 3

CHEMICAL COMPOSITION OF WELD-METAL OVERLAYS (1)

Welding Electrode	ASTM-AWS Class	Elect. dia.	C	Mn	P	S	Si	Ni	Cr	Fe	Other	Remarks
			ELEMENTS - PERCENT									
Stainless Steel Arcos Chromend HC E309-15 (Manual)	ASTM A298-55T type E309	3/16"	.062 .15	1.87 2.50	.027 .04	.018 .03	.43 .90	13.40 12-14.00	23.80 22-25.00	bal. bal.		Alco check ASTM Spec.
Drawalloy 309 Overlay by Submerged-arc	ASTM A371-53T ER309	1/8"	.070	1.35	---	---	.87	12.50	22.50	---		Alco check
High Nickel Inco BP-85 (Manual)	None	5/32"	.054	8.30	.014 NOT AVAILABLE	.009	.62	65.67	13.39	8.82	1.81 Cb	Alco check ASTM Spec.
Inco Weld A (Manual)	ASTM B295-54T E3N12	3/16"	.050 .15	1.45 1.50	.017 ---	.004 .015	.33 .75	71.50 68.00*	14.80 13-17.00	9.16 11.00	2.42 Cb .50 Cu 1.50-4.00 CbTa	Alco check ASTM Spec.
Arcos Chromend 14/75 (Manual)	ASTM B295-54T E3N12	3/16"	.056 .15	1.18 1.50	--- ---	.010 .015	.43 .75	71.60 68.00*	14.72 13-17.00	8.10 11.00	2.14 CbTa .50 Cu 1.50-4.00 CbTa	Alco check ASTM Spec.
Champion 50/10/15 (Manual)	None	5/32"	.165	1.14	--- NOT AVAILABLE	---	.38	45.96	7.99	43.62	.70 CbTa	Alco check ASTM Spec.

(1) The chemical analyses were made from millings taken from the surface of weld-overlay test-specimens.

All ASTM values shown with an asterisk (*) are minimum values, all others are maximum.

TABLE 4

CHEMICAL COMPOSITION OF STAINLESS STEEL BARE WELDING WIRE

PAGE BLANK

Type of Wire	ELEMENTS - PERCENT								Remarks
	C	Mn	P	S	Si	Ni	Cr	Mo	
Type 309									
Alloy Rods Co. Drawalloy 309 Ht. #48017 - 1/8" dia.	.04	1.75	.025	.008	.49	13.70	24.36	-----	Alco check
Alloy Rods Co. Drawalloy 309 Ht. #17625 - 5/32" dia.	.05	1.83	.031	.023	.46	13.98	24.12	-----	Alco check
ASTM A371 - 53T - ER 309 Requirements	.12	1-2.5	.03	.03	.60	12-14.0	23-25.0	-----	ASTM *
Type 316									
Alloy Rods Co. Drawalloy 316	.05	1.92	.025	.010	.43	13.29	18.96	2.31	Mill
Ht. #16507B - 5/32" dia.	.05	1.95	----	----	.44	13.44	19.28	2.46	Alco check
ASTM A371 - 53T - ER 316 Requirements	.08	1-2.5	.03	.03	.60	12-14.0	18-20.0	2-2.5	ASTM *

* Single values shown are maximum percentages.

TABLE 5

WELDING CONDITIONS FOR WELD OVERLAYS ON 2-1/4% Cr-1% Mo STEEL AND PRELIMINARY BEND-TEST RESULTS

Welding Electrode	Arc Amps	Arc Volts	Side-Bend Specimen	Bend-Test Results
Manual Metal Arc Process				
Arcos Chromend HC-E309 3/16" dia.	180	25/27	1	OK 100% sound
			2	OK 100% sound
Arcos Chromend 14/75 3/16" dia.	160	25/27	1	NG 8 fissures in weld
			2	NG 4 fissures in weld
Inco Weld A 3/16" dia.	160	25/27	1	OK 1 fissure in weld
			2	OK 2 fissures in weld
Inco BP85 - 5/32" dia.	130	24/26	1	OK 100% sound
			2	OK 100% sound
Champion 50/10/15 5/32" dia.	135	25/27	1	NG 8 fissures in weld
			2	NG 5 fissures in weld
Automatic Submerged-Arc Process				
Drawalloy 309-1/8" dia.	300/325	39/41	1	OK 100% sound
			2	OK 100% sound

Constant Welding Conditions

Welding Current: DCRP for manual metal-arc process.
DCSP for submerged-arc process.
Preheat: 400°F
Post-Weld Thermal Treatment: None

TABLE 6

VICKERS HARDNESS SURVEYS OF AUTOMATICALLY DEPOSITED TYPE 309 WELD OVERLAY ON 2-1/4% Cr - 1% Mo STEEL THERMALLY TREATED AT SEVERAL TEMPERATURES.

Material	Inches from Interface	POST-WELD THERMAL TREATMENT AS — WELDED DPH	24 hrs 1100°F DPH	24 hrs 1200°F DPH	24 hrs 1300°F DPH
Type 309	.520	193	197	212	257
Stainless	.480	197	198	207	251
Steel	.440	201	201	212	257
Overlay	.400	208	206	215	265
	.360	201	208	214	264
	.320	208	201	209	260
	.280	201	190	204	251
	.240	195	188	201	245
	.200	195	188	201	245
	.160	201	197	209	251
	.120	205	204	218	257
	.080	201	201	218	251
	.040	205	204	221	264
	.020	218	221	236	282
INTER FACE					
	.020	312	319	236	199
	.040	380	342	238	197
	.080	413	405	244	207
	.120	363	357	241	197
	.160	278	266	222	188
	.200	235	218	199	178
	.240	196	192	191	171
	.280	178	178	175	171
	.320	172	169	169	163
	.360	179	172	169	167
	.400	176	165	171	170
	.440	173	168	168	169
2-1/4 Cr - 1 Mo	.480	168	164	168	170
Steel	.520	172	166	171	169

TABLE 7

KNOOP HARDNESS SURVEYS OF AUTOMATICALLY DEPOSITED TYPE 309 WELD OVERLAY ON 2-1/4% Cr - 1% Mo STEEL THERMALLY TREATED AT SEVERAL TEMPERATURES.

Material	Inches from Interface	POST-WELD THERMAL TREATMENTS 24 hrs. 1100°F KHN	24 hrs. 1200°F KHN	24 hrs. 1300°F KHN	6 hrs.** 1200°F KHN
Type 309 Stainless Overlay	.0080	---	178	---	---
	.0075	184	---	390	290
	.0040	---	178	---	---
	.0035	184	---	412	260
	.0020	---	240	---	---
	.0015	217	---	566	295
	.0010	---	300	---	---
	.0005	270	---	601	332
INTERFACE					
	.0005	---	---	---	---
	.0010	286	240	278	296
	.0015	---	---	---	---
	.0020	312	234	262	296
	.0035	---	---	---	---
	.0040	324	250	254	232
2-1/4 Cr - 1 Mo Steel	.0075	---	---	---	---
	.0080	377	272	268	332

** Comparative hardness data from Type 309 overlay on 4-1/2-inch thick Cr-Mo steel section used for final qualification tests.

TABLE 8

VICKERS HARDNESS SURVEYS OF AUTOMATICALLY DEPOSITED TYPE 309 WELD OVERLAYS ON 2-1/4% Cr - 1% Mo STEEL PREHEATED TO SEVERAL TEMPERATURES AND COOLED TO 70°F AFTER WELDING.

Material	Inches from Interface	PREHEAT TEMPERATURES 70°F DPH	200°F DPH	400°F DPH	600°F DPH
Type 309 Stainless Steel Overlay	.480	207	201	197	201
	.440	207	203	201	203
	.400	201	207	208	208
	.360	196	201	201	208
	.320	191	199	208	199
	.280	191	195	201	197
	.240	196	198	195	197
	.200	207	207	195	201
	.160	221	218	201	208
	.120	221	222	205	203
	.080	216	210	201	199
	.040	217	196	205	196
	.020	228	213	218	222
INTERFACE					
	.020	354	342	312	312
	.040	363	373	380	334
	.080	247	405	413	394
	.120	209	363	363	405
	.160	183	251	278	357
	.200	179	210	235	228
	.240	170	194	196	197
	.280	173	179	178	181
	.320	164	175	172	167
	.360	167	171	179	165
	.400	162	168	176	167
2-1/4 Cr - 1 Mo Steel	.440	167	165	173	163
	.480	161	167	168	167

TABLE 9

PROCEDURES FOR FABRICATING THE FINAL TRANSITION-WELD JOINT

CONDITIONS FOR WELDING THE OVERLAY:

Welding process	:	Automatic submerged-arc
Welding position	:	Flat
Electrode Wire	:	ER 309 1/8" dia.
Flux	:	Arcosite S4 (Arcos Corp.)
Preheat	:	400^{o}F
Interpass temp.	:	300-400^{o}F
Current	:	DCSP
Arc amps	:	300-325
Arc volts	:	39-41
Travel speed	:	6-1/2 ipm
Post-heat	:	1200^{o}F - 6 hrs.

CONDITIONS FOR WELDING THE GROOVE JOINT

Welding process	:	Automatic submerged-arc
Welding position	:	Flat
Electrode wire	:	ER 309 5/32" dia.
Flux	:	Arcosite S4 (Arcos Corp.)
Preheat	:	70^{o}F
Interpass temp.	:	300^{o}F max.
Current	:	DCRP
Post-heat	:	None

Passes	Arc amps	Arc volts	Speed ipm
1	390-410	31-32	15
2-8	475-525	31-32	12
9-29	475-525	31-32	10
30-42	500-550	31-32	8
Cover and backside	450-475	31-32	15

TABLE 10

MECHANICAL TEST RESULTS AND ALL-WELD-METAL CHEMICAL ANALYSIS FINAL 4-1/2"-THICK TRANSITION-WELD TEST PLATE

SIDE BEND TESTS

Six guided side-bend specimens bent 180^{o} without defects.

REDUCED SECTION TENSILE TESTS

Specimen	Yield psi	Tensile psi	% Elong. in 2"	Fracture
Top	49840	78830	54.5	stainless base metal
Centre	49190	76620	60.0	" " "
Bottom	47880	77610	48.5	" " "
Average	48970	77680	54.5	
ASTM Minimum Requirements				
A182-58T-F316	30000	75000	40	
A182-58T-F22	40000	70000	20	

ALL-WELD-METAL TENSILE TESTS

Specimen	Yield psi	Tensile psi	% Elong. in 2"	Fracture
Top	59750	81140	28.0	Irreg. shear
Centre	59125	80680	32.5	" "
Bottom	57860	86800	36.5	" "
Average	58910	82870	32.3	
ASTM Minimum Requirements				
A371-53T-309	-----	80000	35	
A371-53T-316	-----	80000	30	

CHEMICAL ANALYSIS OF ALL-WELD METAL

C%	Mn%	Si%	P%	S%	Cr%	Ni%	Delta Ferrite
.05	1.50	1.02	.031	.023	22.37	13.90	6.5%

TABLE 11

VICKERS HARDNESS SURVEY ACROSS FINAL 4-1/2"-THICK TRANSITION-JOINT WELD

Material	Inches from Interface	Diamond Pyramid Hardness	Material	Inches from Interface	Diamond Pyramid Hardness	Material	Inches from Interface	Diamond Pyramid Hardness
2-1/4 Cr-1 Mo	.220	180	Type 309	.220	---	Type 309	.220	183
Steel	.200	175	Stainless	.200	208	Stainless	.200	193
	.180	181	Overlay	.180	216	Filler-Weld	.180	197
	.160	198		.160	212		.160	198
	.140	211		.140	216		.140	192
	.120	235		.120	212		.120	198
	.100	243		.100	212		.100	208
	.080	250		.080	218		.080	203
	.060	257		.060	212		.060	210
	.040	256		.040	216		.040	218
	.020	241		.020	212		.020	218
Interface -----	-----	-----	-----	-----	-----	-----	-----	-----
	.020	208		.020	204		.020	206
	.040	216		.040	208		.040	202
	.060	212		.060	204		.060	205
	.080	216		.080	204		.080	208
	.100	212		.100	190		.100	212
	.120	212		.120	187		.120	208
	.140	218		.140	185		.140	210
	.160	212		.160	187		.160	204
Type 309	.180	216	Type 309	.180	183	Type 316	.180	202
Stainless	.200	212	Stainless	.200	191	Stainless	.200	192
Overlay	.220	---	Filler-Weld	.220	187	Base-Metal	.220	187