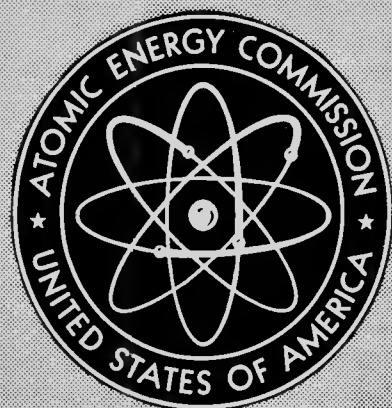


MASTER



NYO-9725

ELECTRODES FOR WELDING TYPE 347 STAINLESS STEEL

Summary Report

By

T. J. Moore

R. B. Gunia

July 31, 1961

Arcos Corporation
Philadelphia, Pennsylvania

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Summary Report
Electrodes for Welding Type 347 Stainless Steel

by

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R. B. Gunia,
United States Steel Corporation

Presented on behalf of the Advisory Subcommittee
on Welding of Stainless Steel, High Alloys Committee,
Welding Research Council.

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Work performed under Contract No. AT(30-1)-1233

July 31, 1961
Arcos Corporation

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ABSTRACT

In a ten-year study of filler metal compositions and techniques for welding columbium-stabilized 18-8 stainless steel, seven electrode compositions have been evaluated. The correct choice among these electrodes will depend on the temperature, surroundings, and other conditions of service.

The study began with a survey of welding fabricators to determine the frequency and types of weld metal cracking experienced by American industry. Once the problem was defined, a program was outlined to develop suitable weld metal compositions to join Type 347 for various types of service.

Tests used in the evaluation of these various experimental weld metals included:

- 1) Segmented circular groove cracking tests; the results were evaluated by statistical analysis.
- 2) Production welding qualification tests.
- 3) Corrosion tests, in nitric acid and in copper sulfate-sulfuric acid.
- 4) Tensile tests and notched-bar impact tests, at ambient and sub-zero temperatures, after various heat treatments.
- 5) Tests at elevated temperatures.
 - a) Tensile.
 - b) Stress rupture.
 - c) Hot-ductility.

In the early part of this program it was confirmed that weld metals containing ferrite are highly resistant to hot-cracking and fissuring. However, one undesirable effect of ferrite-bearing weld metal is the tendency for the ferrite phase to transform to the brittle sigma phase, during service at elevated temperature. In order to avoid the ferrite-to-sigma transition, it would be highly desirable to use fully austenitic Type 347 welds, if such electrodes could be developed for production welding. Accordingly, high-carbon Type 347 and high-manganese Type 347 electrodes were included in the development and testing program.

Tests of a partially ferritic Type 308L weld indicated that this composition was the most corrosion resistant of the compositions tested. The ability to retain notch-toughness after exposure to elevated temperatures and the retention of notch-toughness at extremely low temperature (on the order of -320°F) were higher than those obtained with any other composition. The principal drawback to the Type 308L weld deposit was its low elevated temperature strength, compared with Type 347 material.

Later in the development program the elevated temperature properties of the partially ferritic Type 308L weld metal were improved considerably by additions of nitrogen. Partially ferritic and fully austenitic high-nitrogen 308L compositions were investigated, and it was shown that their stress rupture properties at 1200°F are equivalent to Type 347 base material. At 1000°F the high-nitrogen 308L welds were below or on the low side of the Type 347 scatterband of stress rupture data.

A new electrode developed by the Babcock and Wilcox Company, containing 16% chromium, 8% nickel, 2% molybdenum (16-8-2), has properties which suggest its use in certain applications.

The corrosion tests conducted during the course of this project revealed extremely high corrosion rates after aging in the 800 to 1050°F temperature range. This alarming behavior was exhibited by both the 347 compositions and the Type 308L weld metal. Since the corrosion resistance of the Type 308L weld metal otherwise was the most promising of the compositions tested, the time-temperature parameters affecting the corrosion of 18-8 weld metals were further investigated. The danger zone at 800°F begins at 1000 hours. Progressively decreasing peak corrosion rates occur, at shorter and shorter times, as the temperature is raised.

DEDICATION

The Advisory Subcommittee, which directed the work reported herein, began its work and continued for several years under the chairmanship of Dr. Vsevolod N. Krivobok. His untimely death in 1958 brought to a close a brilliant career in metallurgy as a student, teacher, research worker, and consultant.

This Russian-born scientist served in both the academic and industrial communities with distinction over a period of many years. After completing his education at Harvard (B.S. '21, Met. E. '22, Sc. D. '24), he joined the Metals Laboratory at Carnegie Institute of Technology. In 1929, he became associate professor of metallurgy, and in 1932, professor of metallurgy at Carnegie Tech. Concurrent with this academic tour of duty, he was also Associate Director of Research of Allegheny Steel Company in Brackenridge, Pa., 1932-1940. In 1940, he severed the academic ties and became Chief Metallurgist of Lockheed Aircraft Company, Burbank, California. In 1944, he joined the Development and Research group of International Nickel Company, in New York where he had charge of the stainless steel section until his death.

Dr. Krivobok was a pioneer in research into the stainless steels in the United States. In 1934, he presented the ASM Campbell Memorial Lecture which appropriately dealt with stainless steels.

Those of us who were privileged to work closely with him knew him as a forceful leader and teacher, a wise counselor, a kindly man, and a dear friend. With his pleasing personality, his rare gift of humor, and the wisdom he had acquired through wide experience, he was an eminent figure among his fellows. His contributions to the science of metallurgy, particularly in the field of stainless steel, are written in the records of the technical societies to which he belonged where they will remain as an inspiration to the many young men who will follow the profession he loved.

To his memory we humbly dedicate this paper.

Advisory Subcommittee

R. B. Gunia, Chairman

W. O. Binder	T. J. Moore
H. C. Campbell	M. A. Scheil
F. W. Davis	R. D. Thomas, Jr.
W. B. DeLong	R. D. Wylie
C. R. Mayne	

HISTORY AND CREDITS

by F. W. Davis

Difficulties in the welding of Type 347 stainless and defects appearing in heavy welded equipment led the High Alloys Committee of the Welding Research Council to appoint a subcommittee in March 1950 to review some promising work that was being conducted by International Nickel Company and Arcos Corporation. The subcommittee was later asked to prepare a comprehensive program of research on the welding of Type 347 stainless steel which might be sponsored by the High Alloys Committee. The members of this subcommittee were V. N. Krivobok, Chairman, R. D. Thomas, Jr., M. A. Scheil, W. O. Binder, R. B. Gunia, and A. L. Schaeffler, Secretary. Such a report was presented in October 1950.

At the next High Alloys meeting in March 1951, it was noted that the shortage of columbium had developed so rapidly that little was available for other than military applications. It was recommended that the outlined program be postponed until a better appraisal of the supply of columbium could be made.

Directly after this meeting, F. W. Davis of the Division of Reactor Development, U.S. Atomic Energy Commission, proposed that if the subcommittee would direct the program the necessary funds would be contributed by the Commission. Davis was made a member of the subcommittee and the program started. Further changes in the subcommittee have included the addition of William B. DeLong, the replacement of Secretary A. L. Schaeffler by, first, Lorin K. Poole and, later, by Thomas J. Moore. On the decease of Chairman V. N. Krivobok, R. B. Gunia was appointed in his place. At present the members of the Advisory Subcommittee are R. B. Gunia, Chairman, W. O. Binder, H. C. Campbell, F. W. Davis, W. B. DeLong, C. R. Mayne, M. A. Scheil, R. D. Thomas, Jr., R. D. Wylie, and T. J. Moore, Secretary.

The present report summarizes nearly a decade of intensive work and is published now because the studies have achieved their original aim--to determine electrodes, welding techniques and post treatments which will produce sound, strong and corrosion resistant joints for high-temperature service.

Much credit is due to the companies listed below for the materials and services which they have provided gratis to this A.E.C.-sponsored program:

E. I. duPont deNemours & Company, Inc.
 International Nickel Company
 A. O. Smith Corporation
 Babcock and Wilcox Company
 Electro Metallurgical Company (Union Carbide Metals Co.)
 United States Steel Corporation

Summary Report
Electrodes for Welding Type 347 Stainless Steel

INTRODUCTION

The work summarized in this report began in 1950. The project, sponsored by the Atomic Energy Commission, covered numerous aspects of a problem that originated much earlier. This introduction describes the situation that existed when this study was undertaken.

The corrosion resistant ferrous alloys that have come to be known as stainless steels evolved from a series of scientific investigations of metals and alloys that began early in the 19th Century. The history of their development is outlined to some extent in Thum's "The Book of Stainless Steels" and Zappfe's "Stainless Steels." Commercial production in the United States started about 1924 and has continued to increase each year since that time.

The advantages of these alloys for the economical solution of corrosion problems were recognized in those early days, but technical difficulties with the steels were numerous. For example, these alloys would permit modifications in many chemical processes if they could be successfully welded. The phenomenon of carbide precipitation was not understood and incidents of rejection at both the producers' mills and the fabricators' shops were numerous. By a process of education and experience, these problems were solved and extensive research programs were initiated by the producers. Technological advances in production methods were also developing and one of the first solutions to the welding problems in these alloys was the reduction of the carbon content to .08% maximum from the earlier .15% to .20% level.

Further work culminated in the discovery that additions of titanium or columbium would "stabilize" the alloys and eliminate the harmful effects of carbide precipitation. Bain, Aborn, and Rutherford developed a theory of the effect which gained wide acceptance. They also suggested that material with .02% carbon or less would be free of the condition. Technological advances in melting made it possible to produce steel with carbon very near the required maximum about 1940 when the .03% maximum carbon grades such as 304L and 316L were first produced commercially.

The titanium and columbium stabilized materials were widely used during World War II. Much of this material was used in sheet and strip form, fabricated by forming and welding into aircraft exhaust systems. Increasing usage of the stabilized alloys for heavy plate sections occurred in this period, also. Fabrication of vessels from heavy plates was rather commonplace and it was during this time that first reports of welding difficulties were

noted. Most such vessels were fabricated from the columbium-bearing grades because tests in boiling 65% nitric acid reflected more favorable behavior than those on the titanium stabilized material.

Also, during this period, a great deal of elevated temperature testing was performed which demonstrated that the columbium stabilized material possessed high temperature creep and stress rupture properties superior to those of most of the alloys in the 18-8 family.

With the increased usage of the columbium stabilized grade, particularly for heavy-walled welded vessels, the problems with welds in the 347 grade apparently became more serious. However, no data were available at that time to indicate the nature or extent of these problems.

Simultaneously with these metallurgical and technological advances, the development of nuclear energy was moving ahead and culminated in the first successful chain reaction in the early 1940's. When these efforts were successful, the atomic energy field opened at a rapid rate. Materials of construction were examined for potential use in this field, and it is significant that the 18-8 Cb grade was selected for the internal reactor parts because it possessed two necessary qualities, i.e., resistance to corrosion by nitric acid and its successful application in welded units.

In the late 1940's, the problems encountered in using 18-8 Cb for welded structures were reviewed by a number of interested groups but no broad programs of investigations were initiated. About 1948, International Nickel and Arcos became interested because many engineers and scientists concluded that welds themselves were responsible for the difficulties. Naturally, the study of the problem started with a look at the weld metal. After several months of work, the two companies felt that their observations were of enough general interest and of such significance that the problem should be given to an industry committee to pursue. In this manner in 1949, the problem was first discussed in the High Alloys Committee of the Welding Research Council. This group agreed that the problem was of the type that should be studied by the Committee and a subcommittee was appointed to review the work already completed and suggest further studies.

Thus, in 1950, the Subcommittee actually began to work with the emphasis directed toward the development of material composition ranges that would deposit a weld free from defects. Because the AEC used rather substantial quantities of this stainless grade, the Commission expressed its interest in the problem and ultimately awarded a contract for the study to the Arcos

Corporation. The work on the contract began in 1951 and the contract was closed in 1961.

It is difficult to look back over a decade and reconstruct the discussions that began with the appointment of the Advisory Subcommittee and even more difficult to recall in detail all the ramifications and modifications that were reviewed and adopted by the Subcommittee. However, the manner in which the observations were reported as the work progressed has made it possible to view the entire program objectively.

As is indicated in the Summary Report that follows, the Subcommittee objectives of developing suitable electrode compositions for the welding of Type 347 were attained. At least three compositions of electrode will perform as required depending on the characteristics needed or specified for any particular application. In addition, interesting data were recorded relating to the high temperature and low temperature behavior of the compositions developed in this program. The statistical study reported herein is of considerable interest since it represents one of the first technical applications of the computer. Also of significance is the fact that the Subcommittee initiated the study of nitrogen additions to some of the compositions.

Although all of the work reported in this series has been recorded under various authorships during this 11-year period, the Advisory Subcommittee actually directed and supervised the investigation throughout the entire life of the contract.

STATEMENT OF THE PROBLEM

Welding of columbium-stabilized 18-8 stainless steel (Type 347) has always presented some problems, especially in heavy sections. Prior to the starting of this contract, it was well known that the ferrite level was important to soundness of weld deposits. The greater the ferrite content, the less difficulty one might encounter with fine microfissures or with gross cracking, either in the weld bead or in the craters. It was also well known that ferrite in the columbium-bearing alloys transformed to sigma, resulting in a degree of embrittlement, depending on the amount of ferrite originally present and the conditions of post-welding heat treatment.

There were not many data available to establish the lower limit of ferrite content which would guarantee freedom from cracks and fissures, nor the upper limit which would give acceptable welds when exposed to elevated temperatures. Such information as was available indicated that the spread between the lower and upper limits was small, however, and therefore not commercially feasible.

The amount of ferrite in a given weld has been known for many years to be influenced by the composition not only of the filler metal but also of the base metal, since a mixture of the two occurs during welding. Since a fabricator must deal with base metals widely varying in composition (within the limits of the AISI composition range), and with welding filler metals also varying in composition (within the AWS-ASTM weld metal ranges), it became a metallurgical exercise to predict the approximate ferrite content of each weld for each composition of the base metals and filler metals. While this might be done, it did not present a very satisfactory solution for production welding.

Since the composition of most of the Type 347 base metals produced in heavy thicknesses was balanced on the low side of the elements introducing ferrite and on the high side of the elements eliminating ferrite, in order to facilitate forging and other forming operations, the welding filler metals had to be produced with reverse balance, in order to assure ferrite in the weld metal, especially in root passes where dilution is greatest. Unfortunately, in multipass welding with the same filler metal compositions, the subsequent passes experience less mixing or dilution with the base metal, and, the ferrite therefore builds up, endangering the structure through embrittlement in elevated temperature service.

The ideal solution appeared at that time to be the development somehow of a fully austenitic composition which would be free from embrittlement by the ferrite-to-sigma transformation and also would be free from fissures or crater cracks.

Extensive work had been done during World War II on the influence of individual elements on the crack susceptibility of fully austenitic weldments. The paper entitled "The Effect of Alloying Elements on the Tensile Properties of 25-20 Weld Metal" by H. C. Campbell and R. D. Thomas, Jr. (WELDING JOURNAL 25, Research Suppl., 760-s to 768-s, 1946) indicated that by the control of carbon, silicon, and phosphorus, crack susceptibility could be greatly reduced. Preliminary work done at the laboratories of Arcos Corporation indicated that fully austenitic Type 347 electrodes could be prepared which would meet the required tensile tests under the AWS-ASTM filler metal specifications. Concurrent work on fully austenitic electrodes in England, Germany, and Switzerland, was also known to the subcommittee, and consequently a great deal of hope was placed on this as a possible solution to the filler metal problem for the welding of Type 347.

The original program for evaluating fully austenitic Type 347 welds envisioned two compositions, both having phosphorus, sulfur, and silicon contents as low as practicable, but varying

in carbon. These were to be compared with a conventional ferrite-bearing electrode.

In selecting the conventional Type 347 comparison electrode, it was agreed that this electrode should be designed with a ferrite content approximately midway between the extremes of the ferrite range normally encountered, namely 3 to 12%. It should be recognized in observing the test results obtained with this electrode that some of its properties depend in a known manner on the ferrite content, and consequently the data presented are not necessarily representative of all ferrite-bearing electrodes. The ferrite content of the specific electrode produced and designated as "Composition A" was approximately 7%.

The first of the fully austenitic compositions had the conventional carbon level and was designated "Composition B." This electrode, we recognized at the outset, would be most difficult to produce with tensile properties which would meet existing specifications, because of the fissuring encountered with this type of composition. Nevertheless, it was agreed that an attempt should be made to create such an electrode, particularly in view of earlier work along this line.

The second fully austenitic composition, designated "Composition C", was expected to be much more easily produced, because the higher carbon level of approximately .12% drastically reduces the fissuring tendency of fully austenitic weld metal.

Early project outlines contained only these three electrodes. During reviews of the project, it was felt desirable to expand the scope. The columbium shortage, referred to in the Introduction, made it desirable to incorporate electrodes produced from the more available ferrocolumbium-tantalum alloys, and thus it was planned to duplicate Compositions A and B using the higher tantalum alloys. These electrodes were designated "Composition D" and "Composition E", respectively. At the same time the extra-low-carbon columbium-free variety of stainless electrodes had just been developed and it was felt that a parallel study of this electrode, designated "Composition F", should be made.

METHOD OF EVALUATION

In the early stages, it was agreed that no electrodes would be examined in detail, unless they met certain minimum requirements to show that the composition was feasible. It was readily agreed that the industry specifications for filler metal (ASTM-A298) would be a first minimum requirement with respect to mechanical properties. Experience with fissures and cracks, however, had indicated to us that the specification was inadequate for evaluating small differences and, in view of extensive work with various

circular groove crack sensitivity tests which were being used at the time, it was agreed that all electrodes should be submitted to such tests. A complete description of these tests and the results are shown in the following sections. Suffice it to say here that in the course of testing, Composition B was found to be unsatisfactory and that numerous modifications were prepared in an attempt to attain acceptable electrodes within the agreed composition range. Many of these compositions formed the basis for the statistical survey which is reported in subsequent sections.

One of the modifications conducted at this stage was to increase the manganese content by substantial amounts. This modification was based on evidence from Germany and Switzerland that fully austenitic, high manganese electrodes were being successfully produced for fabricators of gas turbine components. As will be seen subsequently, the increase of manganese had a tremendously favorable influence on the crack sensitivity. As a result we added "Composition H" to the program.

Acceptability of the electrodes was also to be evaluated on the basis of conventional tests required of plate and pipe fabricators. The tests conducted are also reported in subsequent sections. These evaluation tests are mentioned here because they helped to determine the final compositions which were examined in greater detail.

In the course of the evaluation studies, it was recognized that Compositions D and E, containing the columbium-tantalum alloy, showed essentially no difference from Compositions A and B, respectively. Consequently, D and E were eliminated from further detailed investigations. This decision was also based on subsequent work done outside the contract, where the high-temperature properties of the columbium-tantalum alloys were found to be identical with those of the conventional low-tantalum alloys.

Throughout the early period, during which the compositions to be examined were being chosen, it was recognized that it might not be possible to find a single electrode which would be suitable for all types of service. Consequently the compositions which were finally selected were to be evaluated in parallel tests for corrosion resistance, for toughness at very low temperature (-320°F), and for strength at elevated temperatures.

During the course of the elevated temperature testing, which was the final phase of this investigation, a program conducted under the sponsorship of the United States Navy by Babcock & Wilcox Company showed promising results in elevated temperature service for a composition having 16% chromium, 8% nickel, and

2% molybdenum (16-8-2). Therefore, at this stage, certain tests were conducted to evaluate this electrode in comparison with those being evaluated under this program. Also during the evaluation of the high temperature properties it was discovered that high-nitrogen 308L compositions, both partially ferritic and fully austenitic, were promising. These electrodes were therefore incorporated into the high temperature phase of the program.

The weld metals studied were thus the following compositions:

Typical Analyses*

<u>Composition</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>	<u>Mo</u>	<u>N</u>	<u>% Ferrite</u>
A	.07	1.6	.4	19.0	9.0	.8	-	.05	7
B**	.07	1.6	.4	19.0	13.0	.8	-	.05	0
C	.13	1.6	.4	19.0	13.0	.8	-	.05	0
D**	.07	1.6	.4	19.0	9.0	.8***	-	.05	7
E**	.07	1.6	.4	19.0	13.0	.8***	-	.05	0
F	.03	1.2	.4	19.0	10.0	-	-	.05	4
H	.07	5.0	.4	19.0	13.0	.8	-	.05	0
16-8-2	.07	2.0	.2	16.0	8.0	-	2.0	.05	4
308L+N	.03	1.2	.4	20.0	8.0	-	-	.15	4
308L+N+Mn	.03	6.0	.4	18.0	9.0	-	-	.15	0

* Typical sulfur and phosphorus was .02% for all materials.

** Dropped during the preliminary portion of the program.

*** Cb+Ta.

Note: The designation "G" was not used, in order to avoid any chance of confusion with "C" from indistinct markings stamped on test specimens for identification.

SURVEY OF INDUSTRY

As noted in the "History and Credits" section, a joint program to study the Type 347 welding problem had been underway in the late 1940's, conducted by the International Nickel Company and Arcos Corporation, prior to the appointment of the Welding Research Council's subcommittee and the start of Atomic Energy Commission's contract No. AT-(30-1)1233.

One of the first activities recommended by the advisory group (1952) was to survey the experience of 23 American fabricators of stainless steel equipment. They reported extensive cracking in weld metal, which could be divided into four categories: (a) crater cracks, (b) star cracks, (c) microfissures and hot-short cracks, and (d) root cracks.

In studying the incidence of weld metal cracking, the Schaeffler Diagram is frequently referred to by stainless steel fabricators. This diagram is of considerable value since the ferrite content of Type 347 weld metal may be computed on the basis of the chemical composition. (Figure 1)

The detailed results of the industry survey are presented in Tables 1, 2, and 3. The information presented consists of the questionnaire employed, the names and company affiliations of the contributors, and a tabular presentation of the incidence of cracking reported in the survey.

In the light of the circumstances which were uncovered by this survey, the test program was directed towards finding one or more welding electrodes for Type 347 base material that would conform to as many as possible of the following requirements: 1. freedom from weld metal cracks, 2. suitability for applications in corrosion-resisting equipment, 3. freedom from embrittlement when exposed to elevated temperatures, either during heat treatment or in service, 4. suitability for strength applications in high temperature service, 5. suitability for very low temperature service, on the order of -300F.

Enough work had already been done to show that any reasonable program of preheating or postheating would not prevent hot cracks, and that the easiest way to correct them would be to use weld metal with higher ferrite content. This, however, would have some objectionable features--notably embrittlement in service or during certain post welding heat treatments. Another approach involved the careful control of those alloying elements in the electrode which tend to produce hot-cracking and also those which tend to inhibit it. In this regard, fully austenitic welds were also scrutinized.

As described above under "Statement of the Problem", the electrodes studied were Compositions A, B, C, D, E, F, H, 16-8-2, and two types of high-nitrogen Type 308L weld metals: one type deposits partially ferritic weld metal and the other is a high-manganese fully austenitic variety.

EFFECT OF CHEMICAL COMPOSITION

Influence of Composition on Mechanical Properties

The effect of variation of chemical composition on the mechanical properties and crack sensitivity of fully austenitic Type 347 weld deposits was studied extensively. The results of tests on pilot compositions are presented in Tables 4 to 8. These laboratory tests indicate that sound fully austenitic

welds not susceptible to cracking cannot be made by controlling only the silicon content (.26 to .47%), or only the columbium content in the range 0.0-1.06% columbium; however, sound fully austenitic welds free of cracking difficulties can be produced by increasing carbon to 0.12%, or by increasing the manganese content to 5%.

Statistical Analysis of Cracking

Our early studies of the cracking tendencies of fully austenitic Type 347 weld metal are summarized in a report entitled "Statistical Analysis of Effects of Various Elements on the Crack Sensitivity of Fully Austenitic Type 347 Welds," printed in the WELDING JOURNAL, Research Supplement, 1957, 442-s to 448-s. Compositions containing ferrite were excluded from the program because of the well known fact that such weld metals are highly crack resistant. The data and illustrations obtained on the program are presented in Tables 9 to 15 and Figures 2 to 8.

The Arcos segmented circular groove test specimen was employed for this study and welding was done manually with lime-coated electrodes. This admittedly introduces the human factor; nevertheless, a statistically valid relationship between cracking and chemical composition was established.

Chemical analyses of the weld beads were computed from the analyses of electrodes and base metal, taking into account dilution by the latter. The equation with coefficients given by a Univac computer is as follows:

$$\begin{aligned} \text{Percent cracking} = & -133.6 + 6.44/C + 43.1/Mn + 1.8Si + \\ & 384S + 2295P + 9.98Ni - 4.48Cr - 28.8(Cb+Ta) \\ & - 487N \end{aligned}$$

where C, Mn ... represent the percentages by weight of the corresponding elements.

This equation looks odd, for it obviously predicts cracking greater than 100% for a pure 18-chromium 8-nickel alloy. However, it must be remembered that this equation applies only to commercial alloys of the Type 347 variety with normal variations in incidental or added elements; it should not be extrapolated to a theoretical Fe-Cr-Ni alloy. Since the "percent cracking" is measured as the extent of cracking along the circumference of a 2-in. circle, cracks extending from the junctions between the plates add to the total crack length and may result in cracking of more than 100% of the circumference. As a matter of fact, badly cracked specimens have cracks extending into the bead from the junctions between the plates, in addition to circumferential cracking in the center of the weld bead.

When comparing the actual and computed amount of cracking in a large number of these tests, the agreement was close--the distribution of the respective errors being only ± 8 percentage points. This means that the differences between the observed percent cracking and the calculated values had a standard deviation of 8 percentage points. The results may therefore be summarized as follows:

As carbon was increased from 0.062 to 0.104%, the cracking was diminished 42 percentage points. Increasing manganese from 1.31 to 4.13% had the effect of decreasing cracking by 22.4 percentage points.

For every 0.10% increase in silicon content, cracking increased less than 0.2 percentage points.

For every 0.010% increase in sulfur, cracking increased 3.8 percentage points.

For every 0.010 increase in phosphorus, cracking increased 23.0 percentage points.

As indicated by the equation, increasing the nickel has a detrimental effect, while more chromium, columbium, and nitrogen are helpful. In the electrodes and welds studied, however, the range of these elements was small.

Because of the many approximations and assumptions which were introduced, no claim is made by the subcommittee for the numerical accuracy of the mathematical equation. However, the qualitative relationship of the various elements on weld-bead cracking can be the basis for sound conclusions. Two promising fully austenitic modified Type 347 weld metals, one containing 0.12% carbon and the other containing 5% manganese, were accordingly selected for further study at elevated temperatures. More recently, the stress rupture properties of high-nitrogen 308L alloys have been investigated.

QUALIFICATION TESTS

Five Type 347 electrode compositions and a Type 308L composition were subjected to a series of qualification tests to ascertain their commercial usefulness. Three of the electrode compositions yielded completely austenitic weld deposits. Two partially ferritic electrodes, representing the standard Type 347 compositions, were included for comparison. The sixth was a non-columbium Type 308L electrode having a nominal ferrite content.

The tests included bend tests of overlay welds on carbon steel and stainless steel plates, fillet welds in all positions, restrained butt welds, and simulated horizontal fixed position pipe welds. Although all electrodes were found commercially usable, the partially ferritic Type 347 electrodes gave the best overall performance.

Chemical analyses and tensile properties of the electrodes which were selected for testing are presented in Table 16, and the compositions of the base materials are shown in Table 17. Photographs of the test specimens are presented in Figures 9 to 36. Typical microstructures are presented in Figure 37.

The results of the tests for fissures (Tables 18 and 19) indicate that Type 347 austenitic weld deposits, modified by increasing the carbon content to 0.12% (Composition C) or increasing the manganese to 5% (Composition H), show greater ductility than standard partially ferritic Type 347 weld deposits when overlaid on carbon or stainless steels. The high manganese electrode is exceptional in this respect, especially when overlaid on carbon steel. In this case, it shows an average elongation of 38% against 19% for the better of the two partially ferritic deposits. The high manganese, high carbon electrodes show a greater tendency to fissure before failing than do the partially ferritic Type 347 weld deposits. It must be kept in mind that any fissures or fissure nuclei which might exist may react differently under more complex stress systems.

The low carbon electrode, which does not contain columbium, shows satisfactory properties when overlaid on stainless steel, but when overlaid on mild steel its performance is only fair from the standpoint of ductility.

The fully austenitic Type 347 electrode (Composition B) which meets the present chemical specification for Type 347 weld deposits is most prone to form fissures. Tests with this electrode show twice the number of fissures found in either of the other two fully austenitic compositions (Electrodes C and H).

The usability characteristics of all electrodes (Table 20) are found to be commercially acceptable as judged by making fillet weld tests in the horizontal, vertical up, and overhead positions. The low carbon non-columbium bearing electrode (Composition F) is rated superior in the overhead and horizontal positions, but only fair in the vertical position, possibly because of the arc action at the current used. The high manganese electrode (Composition H) is also rated superior in the overhead and horizontal positions but only fair in the vertical position, because the weld metal was more fluid.

Crater cracks were observed in a single crater in each fillet weld position for the fully austenitic electrodes (Composition B and H), indicating that the fully austenitic welds are more prone to crater cracking than the partially ferritic welds (Table 21). Fissures and slight porosity were noted when welding with the low carbon electrode in the vertical position.

Mechanical test specimens cut from the 1-inch thick butt welds (Tables 22 and 23) indicate that the fully austenitic electrode (Composition B) which meets the present composition specifications for Type 347 weld metals will not qualify under present bend and tensile specifications. Both root bends failed to meet the elongation requirements and one side bend failed at a bend angle of 45° , partially because of welding defects in the root of the weld. The tensile bar also failed to meet the 30% elongation requirement. Except for four specimens of a total of 35, all compositions other than Composition B showed 30% or more elongation for tensile bars and face and root bends, and satisfactory guided side bend tests.

Impact test specimens cut from these butt welds and tested in the as-welded condition show a slight superiority for the partially ferritic welds (23 ft. lbs. vs. 20 ft. lbs. average when tested at room temperature, and 14.5 ft. lbs. vs. 11 ft. lbs. average when tested at -300°F).

Bend test coupons cut from the 1-inch thick pipe weld (Tables 24, 25, and 26) indicate that the partially ferritic Type 347 deposits are satisfactory. Except for three specimens out of a total of 24, all specimens of the fully austenitic compositions elongated 30% or more for face and root bends and gave satisfactory side bends. Since there was little difference in the performance of the two partially ferritic deposits in all tests, it is concluded that the substitution of tantalum for a portion of the columbium has no effect on the weldability.

The combined results of all of the tests indicate a superiority in favor of the partially ferritic weld deposits, with the fully austenitic electrodes modified to contain either 0.12% carbon or 5% manganese (Compositions C and H, respectively) running a close second. The effect of exposure to elevated temperature service and the corrosion properties, among other factors, would influence the final selection of an electrode.

The A. O. Smith Corporation and the Pittsburgh Piping and Equipment Company qualification tests which were employed on this program are presented as Tables 27 and 28.

CORROSION RESISTANCE

Nitric Acid and Copper Sulfate-Sulfuric Acid Tests

Small rectangular samples (all-weld-metal) were cut from the middle of welds in 1/2" stainless plate (as sketched in Figure 38) and subjected to two standardized corrosion tests; namely, the Huey test (65% boiling nitric acid) and the acidified copper sulfate test. Parallel work was done on Compositions A, C, F, H, and two other modified Type 347 weld metal compositions. Type 347 base plate was used for the columbium-bearing electrodes and Type 304L plate was used for the 308L electrodes.

The test results are presented in Tables 29 to 31 and Figures 39 to 43. All the weld metals appear to behave as expected; the presence of a small percentage of ferrite did not appear to be objectionable. Acceptable corrosion rates (less than 25 mils per year) were obtained for all of these compositions in the as-welded condition and after heat treatment at 1550F or higher. Probably the most striking observation in these corrosion studies is the fine performance of the columbium-free extra-low-carbon alloy (Composition F). This, too, was not wholly unexpected, although such a superiority had not been previously recognized.

However, one new and unexpected result was obtained; namely, the poor corrosion resistance after exposing all-weld-metal specimens in the as-deposited condition to temperatures in the range of 900 to 1000F for a long time. These alloys were all of a "stabilized" type, it was alarming to discover high corrosion rates, since the conditions described might well be encountered in certain high temperature processing equipment. H. F. Ebling and Merrill A. Scheil (a member of our advisory subcommittee) conducted similar studies on Types 304L, 316L, and 347 base materials and reported the results at the 1958 meeting of the Atomic Energy Commission's Welding Forum. (Published in METAL PROGRESS, July 1959, p. 94, and August 1959, p. 87.) They found similar results, namely, that the corrosion rate in the Huey test depends greatly on the time and temperature of heating in the 700 to 1500F range. For example, very high corrosion rates of 1000 mils or more per year result if these steels are heated 5000 to 10,000 hours at 950 to 1000F. Prior "stabilization" by heating two hours at 1650F does not correct this behavior in Types 304L or 316L, but does have a beneficial effect in Type 347 material.

Time-Temperature Parameters Affecting Corrosion

To investigate this new corrosion phenomenon, studies were concentrated on the 308L material (Composition F) since it exhibited the best behavior in the initial tests. The study consisted

of nitric acid corrosion tests on 18Cr-8Ni welds heat treated in the 800-1500F range for periods up to 20,000 hours.

A graphic presentation of the time-temperature-sensitization phenomenon is shown in Figures 44 to 49. Photomicrographs are presented as Figures 50 and 51. The test data are tabulated in Tables 32 to 34.

Notice the extremely high corrosion rates which result from aging for fairly short periods (100 hours or more) at the lower temperatures (800 to 1000F). It may be generally concluded that as the aging temperature decreases from 1800 towards the 800 to 1000F range, the peak corrosion rate increases; and second, the time required to reach the peak corrosion rate increases with decreasing aging temperature. Long times at low temperatures sensitized welds to an alarming degree--50 to 60 times as much as conventional sensitizing heat treatments of one or two hours at 1200F. The curves of Figure 46, by the way, assume the general form of the TTS diagrams derived by Ebling and Scheil, and indicate the not surprising conclusion that stainless weld metal and base metal of similar types are "sensitized" by similar heat treatments.

In this connection the effect of carbon content was also investigated and, as was expected, the general level of corrosive attack increased with increasing carbon content (Figure 47). Whereas 1000 to 4000 hours at 900F will induce an attack of over 1000 mils per year in Type 308 weld metal with 0.036% carbon, the attack was substantially reduced by lowering the carbon content to 0.026% (and increasing the chromium to 19.7%). It would appear nevertheless that even at 0.026% carbon, trouble may be encountered if the service temperature is 800 to 900F.

The effect of stabilizing heat treatments prior to aging was also investigated for Composition F weld deposits. Figure 46 shows that if the 308L analysis is heated for almost any time at 1200F and higher, the expected corrosion rate will be lower than 25 mils per year. Consequently, stabilizing heat treatments of 8 and 12 hours at 1200F and 8 hours at 1300F were investigated. The samples were subsequently aged at 1000F and subjected to the Huey test. Specimens which were heat treated to 1200F for twelve hours had acceptable corrosion rates for aging periods up to 1000 hours but the other heat treatments were not effective in reducing severe corrosive attack (Figure 48). In fact, no suitable stabilizing heat treatment has yet been determined to avoid the extremely high rates of corrosive attack on Types 308 and 308L weld metal aged in the vicinity of 900F (Figure 49).

EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES

Tensile Tests

The effect of various isothermal heat treatments on the tensile properties of a standard Type 347 weld deposit and five modifications were studied. The heat treatments were conducted on 3/4-inch diameter all-weld-metal bars. The test data are presented in Tables 35 to 40 and Figures 52 to 69. The highest strengths and lowest elongations were obtained after a 100-hour heat treatment at 1300F. Heat treatment at 1950F produced the lowest strengths and highest ductility. One composition having a fully austenitic microstructure showed a severe tendency to fissure after heat treatment. There was not sufficient difference between the values obtained to determine which composition may be the least susceptible to loss of ductility on exposure to elevated temperatures.

It is believed that the reported loss of ductility of the standard partially ferritic compositions may be due to the transformation of ferrite to sigma which was expected from some of the heat treatment conditions.

In the as-welded condition, the only specimens which showed any indication of fissures in the tensile bars were Compositions B and C. After heat treatment all compositions showed some fissuring. This fissuring was most pronounced in the fully austenitic compositions. The largest number of fissures occurred in two heat treating ranges; namely, (1) 1100 and 1300F where the strength level is relatively high and (2) 1700 and 1900F where the elongation exceeded about 38%.

The effect of the 1950F heat treatments was to lower the tensile strength somewhat and the yield strength appreciably. Little difference was seen between holding times of 2, 8, and 24 hours.

The reproduceability of results was excellent. Of the 576 values obtained in the 144 tensile specimens, only nine values taken from eight specimens were not felt to be representative and were disregarded when computing averages for graphic plotting the data. Of these eight specimens, six are believed to have failed prematurely due to fissures.

Notched Bar Impact Properties

Charpy keyhole impact properties of the standard partially ferritic Type 347 weld deposit were compared with four modified Type 347 and one Type 308L weld compositions. The chemical analyses of the materials are presented in Table 41. The joint

design and location of the notch in the impact specimen are illustrated in Figure 70.

Fully austenitic Type 347 weld deposits were found to be less susceptible to embrittlement when exposed to temperatures of 1100F and 1300F than standard partially ferritic compositions. Optimum room temperature impact toughness of all compositions was obtained after heat treatment at temperatures of 1700F and higher (with no subsequent aging at lower temperatures).

Impact tests at -320F indicate that standard partially ferritic Type 347 (Composition A) weld deposits must be heat treated at 1950F to assure a minimum of 15 ft.-lbs. impact strength (Tables 42 and 45). This value cannot be attained by the fully austenitic Type 347 deposits in any of the post-welding heat treatment conditions which were tried (Tables 43, 44, 46).

The fully austenitic weld deposits (Compositions B, C, and H) showed somewhat less tendency to lose impact toughness after heat treatment at 1100 and 1300F than did the partially ferritic weld deposits (Compositions A and D). Their as-welded toughness, however, was somewhat lower (Tables 43, 44, 46).

The optimum room temperature impact toughness of all Type 347 compositions is obtained after heat treatment at 1700F or higher. This is illustrated in Figure 71, 72, and 73.

In Figures 74 to 79 the effect of 8 and 100 hour heat treatments are presented for the individual compositions. Notice in Figure 74 the sharp drop in impact strength for the 7% ferrite 19/9Cb weld metal at 1300F. The Type 308L weld deposit showed by far the highest notch toughness (Table 47 and Figure 79). In no condition of heat treatment employed did the room temperature impact toughness of any of the individual specimens fall below 24.5 ft.-lbs. In only one condition of heat treatment (1100F for 8 hours) did the average impact strength at -320F fall below 15 ft.-lbs., and then only fractionally. The fully austenitic Type 347 composition (B, C, and H) did not meet a value of 15 ft.-lbs. at -320F after any condition of heat treatment (Figures 75, 76, and 78). The difference in carbon content between the fully austenitic compositions (B, C, and H) did not produce a pronounced difference in toughness. The fully austenitic high manganese electrode (Composition H) showed impact values similar to the other fully austenitic compositions. On the basis of a single lot of electrodes it seems that manganese had no effect on the impact toughness.

The substitution of tantalum for a portion of the columbium in the partially ferritic weld deposits apparently did not affect

their impact toughness (Figure 77).

Weld metal microstructures are presented as Figures 80 to 84.

Comparative impact data from various testing laboratories are shown in Table 48.

TESTS AT HIGH TEMPERATURES

The elevated temperature test program is divided into two sections. The first deals principally with the testing of modified Type 347 compositions. The stress rupture properties of high-nitrogen 308L welds are presented in the second section.

Properties of Modified Type 347 Weld Metals

Chemical analyses of the weld metals which were tested are presented in Table 49. Specimen designs for the tensile and stress rupture tests are sketched in Figures 85 and 86.

Tensile tests were conducted at 100° intervals between 1000 and 2000F (Table 50). The relationship of tensile strengths did not change in this temperature interval (Figures 87, 88, and 89). Ductilities of Composition H (austenitic high-manganese 347) and 16-8-2 were well retained up to 2000F; Composition C (austenitic high-carbon 347) was next best.

The reduction of area and elongation values indicate that the high-manganese Type 347, the 16-8-2, or (to a lesser extent) the high-carbon Type 347, would be an improvement over the standard partially ferritic Type 347 electrodes--at least as far as improved tensile ductility at elevated temperatures is concerned.

Stress rupture tests were conducted at 1000, 1200, and 1300F in three conditions of heat treatment (see Table 52) using all-weld-metal specimens. The results are listed in Table 51, and are presented graphically in Figures 90 to 97. Annealing for 1 hour at 1950F followed by air cooling generally improves the rupture ductility of the columbium-bearing welds, particularly at 1200F and 1300F without seriously reducing the stress rupture strength (Table 50, Figures 96 and 97).

These stress rupture tests generally indicate that for temperatures between 1000 and 1300F any of the Type 347 electrodes (Compositions A, C, and H) are suitable for joining Type 347 stainless steels since all are stronger than the base material. Testing of transverse stress rupture specimens which have been aged for 10,000 hours prior to testing gave further evidence that these welds are

stronger than the Type 347 base plate (Table 53 and Figure 98).

The low-carbon 308 weld metal containing 4% ferrite (Composition F) is much weaker than the Type 347 base material in both the as-welded and aged conditions.

Weld metal which is deposited with standard Type 347 electrodes (containing 7% ferrite) is inherently low in tensile ductility between 1500 and 2000F when loaded at standardized strain rates. Additionally, the weld metal strength is considerably above that of Type 347 base material under the same conditions. Thus, in annealing heavy sections it is recommended that the heating rate be rapid between 1100 and 1925F to minimize the chance that the time-dependent, stress rupture type of cracking may occur in the coarse grained heat affected zone in the base material.

In order to get some idea of the conditions which exist in the vicinity of an arc weld made in 1.5-inch stainless steel plate, not preheated, some hot ductility tests were conducted on all-weld-metal specimens at Rensselaer Polytechnic Institute using the method devised there (see "Further Studies of the Hot Ductility of High-Temperature Alloys," by E. F. Nippes, W. F. Savage, and G. Grotke, Welding Research Council Bulletin No. 33, February 1957) wherein test specimens are heated to 2400 or 2450F in a few seconds and immediately cooled to test temperatures. Specimens may be tested either on the heating or cooling cycle. Results are tabulated in Table 54 and are summarized graphically in Figure 99.

The good ductility shown in the Rensselaer tests for the partially ferritic Type 347 and 308L welds (Compositions A and F) confirms the good resistance of these weld metals to hot cracking. The fully austenitic weld deposits, Compositions C and H, behaved rather poorly--that is, they were slow to recover the ductility on cooling from 2400 or 2450F. However, in various qualification tests these electrodes have been found to be practical, usable compositions in production-type welding of stainless.

Other related data and illustrations are presented in Tables 55 to 57 and Figures 100 to 104.

Stress-strain tests were conducted using the materials listed in Table 58. Test data on all-weld-metal and transverse specimens are presented in Table 59. Tests were conducted at room temperature, 1000, 1200, and 1300F.

Properties of High-Nitrogen Type 308L Weld Metals

Chemical analyses and tensile properties of the weld metals

are presented in Tables 60 and 61. The stress rupture specimen designs are presented in Figures 105 and 106. Stress rupture test data obtained at 1000 and 1200F are listed in Tables 62 and 63.

The test results obtained in this program indicate that sound 308L weld metal containing high nitrogen can be obtained with a partially ferritic or a fully austenitic microstructure. The latter composition contains high manganese. On the basis of the all-weld-metal stress rupture properties illustrated graphically in Figures 107, 109, and 110, the high-nitrogen partially ferritic 308L electrode containing 0.2N is the most suitable of the compositions tested for joining Type 347 base material for 1000F service. The other weld metals were somewhat lower in strength than the 347 base material.

All-weld-metal and transverse stress rupture tests in 347 base material at 1200F (Figures 108, 109, 110, and 111) indicate that at this temperature any of the high-nitrogen 308L weld metals are suitable to join Type 347 plate. Annealing at 1950F generally increases stress rupture strength transverse to the weld joint.

For maximum rupture ductility at 1000F the 308L 0.1N weld metal is the first choice. The other welds possessed relatively poor rupture ductility at 1000F.

At 1200F all of the high nitrogen 308L compositions possessed rupture ductility superior to that of the Type 347 base material. However, once again, the outstanding material was the 308L 0.1N weld metal which possessed by far the highest stress rupture ductility in the as-welded condition.

In special corrosion applications where 304L or 347 base materials must be fusion welded with a fully austenitic electrode, the 308L 6Mn electrodes containing 0.1 to 0.2 percent nitrogen offer unique advantages. These electrodes would also be quite useful in applications where a non-magnetic weld is essential when welding Type 304, 304L, or Type 347 base materials.

Typical microstructures of the high-nitrogen 308L weld metals are shown in Figures 112 and 113.

Charpy impact properties at room temperature, -150F, and -320F are presented in Figure 114.

PRACTICAL SIGNIFICANCE OF OVERALL PROGRAM

The results of the years of testing under review have

confirmed the idea that hot-cracking and microfissuring in stainless steel weld metal are clearly an inverse function of ferrite content. It was also confirmed that, at least in columbium-bearing alloys, the ferrite transforms to brittle sigma phase during exposure to elevated temperatures. When ferrite is eliminated, cracking becomes a severe problem unless carbon or manganese is increased substantially. The Composition C alloy, which is fully austenitic by virtue of high (0.12%) carbon, and the Composition H, based on high (5%) manganese, were both proven to be suitable for production welding of austenitic stainless steels and were free from the ferrite-to-sigma transformation.

More recently we have taken advantage of the strengthening effect of nitrogen in Type 308L weld metal. Nitrogen also appeared to be an important cracking inhibitor in Type 347 stainless steel weld metal in our statistical study of cracking. Accordingly, a series of stress rupture tests were conducted to evaluate the elevated temperature strength of the high-nitrogen Type 308L weld deposits.

On the basis of stress rupture tests between 1000 and 1300F the standard Type 347 (containing 7% ferrite), the high-manganese 347 or the high-carbon 347 electrodes are suitable for joining Type 347 base materials. At 1200F the high-nitrogen 308L (partially ferritic) and the high-nitrogen 308L 6Mn (fully austenitic) compositions are suitable for joining Type 347 since their strengths are equivalent to that of the base material. At 1000F the partially ferritic high-nitrogen weld metals essentially match the base metal strength, but the fully austenitic welds are somewhat weaker than Type 347 base material.

Compositions 16-8-2, H, and C, possessed tensile ductility superior to that of the partially ferritic Type 347 weld metal (Composition A) in the 1500 to 2000F range.

Standardized corrosion tests have shown that all three columbium-bearing welds (A, C, and H) possess acceptable corrosion rates in the as-welded and annealed conditions. The 16-8-2 weld metal is not suitable in applications which must resist intergranular corrosion. In general, the Type 308L weld deposit (Composition F) has the best corrosion resistance of the compositions studied.

In applications where notch toughness at very low temperatures is a service criterion for a columbium-bearing weld, the partially ferritic standard Type 347 weld metal would be the best choice. However, the non-columbium Type 308L alloy has the maximum low-temperature toughness. The high-nitrogen 308L weld deposits exhibited good as-welded impact ductility at low temperatures although the degree of toughness was not equivalent to that of

the standard Type 308L alloy (Composition F).

The probable field of application of each of these electrodes seems to be as follows:

Electrode Composition A is representative of present commercial Type 347 electrodes, since its welds will contain 7% ferrite in the as-welded condition. It is the most suitable of the columbium-bearing varieties for fabricating equipment; joints should be free from cracks and fissures even though welded under restraint. Should a columbium-bearing weld metal be required for low-temperature applications (about -300F), Composition A will be suitable if the equipment is heat treated at 1700F or higher.

Electrode Composition C - In applications where a fully austenitic metal is essential and high carbon (0.12%) is not considered objectionable for other reasons, such as highly corrosive service, Composition C might well be considered. The high carbon might prove to be an advantage in certain high-temperature applications, since this weld metal has the highest stress-rupture strength of the materials tested.

Electrode Composition F is a non-columbium extra-low-carbon composition, therefore its properties are difficult to compare with those of the others. One of its chief characteristics is high ductility and toughness even after prolonged exposure to heat. It is especially suitable for applications requiring toughness at ambient or very low (-320F) temperatures. Another feature is its outstanding behavior in the standard corrosion tests. The room-temperature strength of Type 308L weld metal is equal to that of Type 304L plate, but at 1000 to 1300F the weld is weaker.

Electrode Composition H - If a fully austenitic Type 347 weld is desired, this 5% manganese composition will meet the requirements: suitability for production welding, corrosion resistance, and stress-rupture strength at 1000 to 1300F. More crater cracks may be expected than when using partially ferritic compositions. One good feature is its substantially greater tensile ductility in comparison with that of the partially ferritic Type 347 weld metal between 1500 and 2000F.

Electrode Composition 16-8-2 - Only a very limited amount of work was undertaken. In the 1500 to 2000F range of temperature this weld composition exhibited good ductility and relatively low strength as compared with columbium-bearing materials. This is a desirable combination of properties, since high-temperature plastic flow of a 16-8-2 weld in heavy Type 347 plate would tend to prevent excessive stress build-up in the base metal heat-affected-zone.

Electrode Composition 308L with 0.1 to 0.2% Nitrogen - This new welding electrode will deposit weld metal containing approximately 5% ferrite in an austenitic matrix. Laboratory tests have indicated that this metal is sound and free from any tendency towards fissuring. The resistance to hot cracking is excellent, as evaluated on the basis of segmented circular groove cracking tests. Stress rupture tests at 1000 and 1200F indicate that this weld metal (with the nitrogen content on the high side of the range for 1000F service) is suitable for joining Type 347 base material. Although specific data are not available, it is believed that this new welding composition possesses the inherent corrosion resistance and structural stability of Type 308L weld metal. These properties combined with superior rupture ductility auger well for substitution of high-nitrogen 308L for standard Type 347 electrodes in the welding of 347 base materials.

Electrode Composition 308L Containing 0.1 to 0.2% Nitrogen and 6% Manganese - This new welding electrode will deposit weld metal which is fully austenitic. This may be of great utility to industry since over the years there has been a great deal of effort expended to develop a fully austenitic intergranular-corrosion-resistant composition with excellent resistance to hot cracking. In applications where corrosive attack of ferrite could occur and in applications where a non-magnetic weld is essential, this composition offers further advantages. Stress rupture properties at 1000F are below that of Type 347, but at 1200F this weld metal is within the scatterband of Type 347 base material and offers rupture ductility superior to that of base metal.

A tabular summary of properties, covering all of the weld metals and test procedures included in the entire program, is presented as Table 64. In Table 65 are listed all of the published reports which were issued under the AEC contract.

ACKNOWLEDGMENT

The helpful comments and suggestions which were offered by Dr. Hallock C. Campbell during the preparation of this report are gratefully acknowledged.

Table 1

Fabricators & Contributors

1. Westinghouse Electric Corporation, Atomic Power Division, Pittsburgh, Pa., J. Hunter and C. Sheridan.
2. Meetings at Public Service Gas and Electric Company, Newark, N. J.
 - 2a. Public Service Gas and Electric Company, H. Weisburg, H. M. Soldan, H. J. Robar, G. J. Schnabel.
 - 2b. M. W. Kellogg Company, Newark, N. J., R. H. Caughey, W. Bunn, W. Benz.
 - 2c. Westinghouse Electric Corporation, Philadelphia, Pa. N. L. Mochel, J. Pratt.
 - 2d. General Electric Company, Schenectady, N. Y., A. W. Rankin, R. Curran, R. Armstrong, R.D. Shaw.
 - 2e. United Engineers and Constructors, Newark, N. J. L. C. McNutt
3. Foster-Wheeler Corporation, Carteret, N. J., L. Nilsen, K. Walker.
4. Weylin, Davit and Boat Division of Continental Copper and Steel Industries Inc., Perth Amboy, N. J., W. Dolan, J. Dickerson.
5. General Electric Company, West Lynn, Mass., D. Puffer, A. Rosenberg, G. Richardson
6. Pratt & Whitney Aircraft, Division of United Aircraft Corporation, Hartford, Conn., Frank Wallace, R. Dolina, J. Gamache, R. F. Harrigan.
7. Whitlock Manufacturing Company, Hartford, Conn., J. Mortimer.
8. The Pfaudler Company, Elyria, Ohio, C. Yost and S. C. Orr
9. Thompson Products Company, Cleveland, Ohio, R. Sipe
10. Babcock and Wilcox Company, Barberton, Ohio, O. R. Carpenter, N. C. Jessen, R. D. Wylie.
11. I.T.E. Circuit Breaker Company, Philadelphia, Pa., A. Rose
12. Heintz Manufacturing Company, Philadelphia, Pa., W. Mehl
13. American Locomotive Company, Alco Products Division, Dunkirk, N. Y., R. Jesionowski.
14. Nooter Corporation, St. Louis, Mo., O. Kirchner, P. Smith, D. J. Noce, E. Barnes, W. Kleefisch.

Table 1 (Continued)

Fabricators & Contributors Cont'd.

15. Crane Company, Chicago, Ill., E. R. Seabloom, W. Root, R. Mueller, E. Sticha, W. Meinhart.
16. A. O. Smith Corporation, Milwaukee, Wis., M. A. Scheil, J. Chyle, R. Keller, J. Koss, I. Kutuchweif.
17. Allis Chalmers Manufacturing Co., Milwaukee, Wis., A. L. Schaeffler, J. Larson.
18. Struthers-Wells Corporation, Warren, Pa., H. McKillip.
19. Combustion Engineering Superheater-Inc., Chattanooga, Tenn., E. C. Chapman, R. E. Lorentz, Jr.
20. Blaw-Knox Division, Blaw-Knox Company, Pittsburgh, Pa., R. Smith, M. Binder.
21. Pittsburgh Piping and Equipment Company, Pittsburgh, Pa., R. W. Emerson.
22. Elliot Company, Inc., Jeannette, Pa., C. T. Evans, Jr., R. Constantine.

Table 2

Welding of Type 347
Stainless Steels Industry Survey

1. In welding Type 347 stainless steels, have you encountered cracking _____, porosity _____?
2. Grade of filler metal, if used _____.
3. Grade or Grades of base materials involved _____.

What was the prior condition of the base materials?
Wrought _____, Forged _____, Cast _____,
Heat treatment _____.

- 4A. Chemical Analysis if available.

	C	Mn	Si	S	P	Cr	Ni	Mo	Cb	Other
Filler Wire										
Weld Metal										
Base Metal										
Base Metal										

- 4B. From where was the weld metal chemistry sample taken?
Weld pad _____, tensile bar _____, weld joint _____,
other _____.
5. Do you have specifications for welding processes, procedures
joint design that you will make available? If so omit 5A
and 5B.
- 5A. Welding process or processes. Manual _____ Automatic _____.
1. Type of electrode _____, Type of coating _____,
Diameter of electrode _____, Current _____,
Voltage _____, AC or DC. Polarity _____,
Speed of travel _____.
 2. Inert arc _____, tungsten _____, Consumable
electrode _____, size of wire _____,
Current _____, Voltage _____, Polarity _____,
Speed of travel _____.
 3. Submerged arc _____, Type of flux _____,
Size of wire _____, Current _____,
Voltage _____, Speed of travel _____.
 4. Other:

Table 2 (continued)

5B. Weld Joint design and welding technique.

<u>Detail of Weld Joint</u>	Material _____, Thickness _____,
	Free _____, Restrained _____,
	Type _____, Back up _____,
	Preheat _____, Interpass temp. _____,
	No. passes _____, Travel Speed _____,
	Bead Sequence _____,
	Bead Type: String _____, Weave _____,
	Other: _____

Remarks: _____

6. What effects were noted when the items in 5A and 5B were varied? _____
7. Were any precautions taken to keep weld metal dilution to a minimum? _____
8. When were cracks first found? During welding _____, after welding _____, or after stress relieving _____.
9. How were cracks detected? Visual _____, X-Ray _____, zygo _____, dycheck _____, other _____.
10. Where was cracking found? Weld metal _____, base metal _____, both _____. What was the location of the crack with respect to the completed joint? _____
Were crater cracks observed? _____.
- 11A. What was the stress relieving procedure? Temp _____°F. Time _____, Heating Rate _____, Cooling Rate _____, Time in 1000°F to 1400°F range _____. Was the unit stress relieved as a whole or only at the joints? _____
Remarks _____
- 11B. What was the effect of variations of stress relieving time, temperature, heating rates, and cooling rates on the mechanical properties, microstructure, and cracking tendency? _____
12. Was a metallographic examination made of the cracked areas? What were the results of this examination? _____
13. Were you successful in eliminating this cracking? How was this accomplished? _____
14. What do you believe was the cause of the cracking? _____

Table 2 (continued)

15. Was porosity found? _____. Where were you successful in eliminating it? _____. How was this accomplished? _____

What do you believe was the cause for porosity? _____

16. Do you have specifications for welder's qualification tests that you will make available? If so omit 16A.

16A. Type of joint if different from item 5B. _____	Interpass temp. _____
Material _____	X-Rayed _____
Thickness _____	Face bend _____
Back up _____	Root bend _____
Restrained _____	Side bend _____
Free _____	All weld metal .505 tensile bars _____
Preheat _____	_____
Other tests _____	_____

Were tests performed in the as welded and/or stress relieved conditions? _____. What standards were used as a basis for acceptance or rejection? _____

16B. Do you consider these qualification tests and standards satisfactory in all _____ or only some _____ respects? Explain. _____

17. Have you made any other tests on these weld metals or weld joints, such as corrosion, fatigue, thermal shock, stress rupture, impact etc. ?, what were the results? _____

18. Have you examined any service failures involving these materials? If so what were your findings? _____

19. Have you any Company Reports on stainless steel welding that you would care to release? _____

20. Do you know of any published information which might be valuable in this investigation? _____

21. The principle difficulties currently being reported in the Welding of Type 347 materials are as follows:

1. Arc welding of heavy sections.
2. Submerged arc welding of sheets on the order of 1/8" thickness.
3. Inert arc welding in thin sheets

Have you any experience welding Type 18/8 Steels under these conditions? If so please describe. _____

Table 2 (continued)

22. What type of information do you feel is most needed in the welding of stainless steels? _____
-

Table 3

Incidence of Cracking Reported in Survey

Fabri- cator	Crater	Star	Hot Short or Micro	Root	Base Metal	Stress Relief
A	*		*	*		
B	*		*	*		
C	*		*	*		
D	*		*			
E	*		*	*		
F	*	*		*	*	
G	*	*				
H	*		*	*	*	
I	*					
J	*			*		
K	*		*		*	*
L	*		*			
M	*	*	*	*	*	
N	*			*	*	*
O	*		*			*
P	*		*		*	
Q	*		*			
R	*		*		*	
S	*		*			
T	*		*			
U	*		*		*	*
V	*		*	*		
W	*		*		*	*
Percent	100%	13%	78%	43%	39%	22%

Table 4

Results of Tests on Pilot CompositionsChemical Analysis of Weld Deposit

<u>Compo- sition</u>	<u>No.</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>
(A)	7380	19/9Cb	.077	1.53	.48	.013	.012	19.24	9.40	.79
(B)	7381	19/13Cb	.084	1.49	.29	.016	.018	18.79	12.91	.82
(C)	7382	19/13Cb	.121	1.52	.48	.013	.016	18.95	13.09	.82
(D)	7383	19/9CbTa	.085	1.49	.51	.012	.016	19.18	9.27	.75
(E)	7384	19/13CbTa	.090	1.57	.33	.012	.019	18.93	12.87	.92
(F)	7501	19/10LC	.035	0.71	.31	.019	.016	18.77	10.72	--

Mechanical Properties

	<u>No.</u>	<u>Type</u>	<u>YS psi</u>	<u>TS psi</u>	<u>El.₂^m</u>	<u>R.A.</u>	<u>Fissures</u>	<u>Magnetic</u>
(A)	7380	19/9Cb	69,000	97,800	36%	56%	1 v.s.*	Yes
(B)	7381	19/13Cb	60,500	80,500	35%	45%	8 v.s.*	No
(C)	7382	19/13Cb	65,500	86,500	37%	58%	none	No
(D)	7383	19/9CbTa	71,000	96,500	35%	53%	2 v.s.*	Yes
(E)	7384	19/13CbTa	64,000	81,000	29%	38%	2 v.s.*	No
(F)	7501	19/10LC	56,500	79,500	45%	55%	none	Yes

* very small (See footnote in Table 5)

Results of Circular Groove Tests*

<u>No.</u>	<u>Type</u>	<u>Solid</u>			<u>Segmented</u>			
		<u>Bead</u>	<u>Crater</u>	<u>Total</u>	<u>Bead</u>	<u>Crater</u>	<u>Total</u>	
(A)	7380	19/9Cb	none	2.9%	2.9%	none	none	none
(B)	7381	19/13Cb	13.4%	2.4%	15.8%	23.8%	7.0%	30.8%
(C)	7382	19/13Cb	.9%	4.0%	4.9%	.5%	4.7%	5.2%
(D)	7383	19/9CbTa	none	3.8%	3.8%	none	2.9%	2.9%
(E)	7384	19/13CbTa	6.0%	6.0%	12.0%	18.0%	6.0%	24.0%
(F)	7501	19/10LC	none	none	none	none	none	none

* Cracking is indicated, as per cent of circumference in circular groove.

Table 5

Results of Tests on Columbiu SeriesChemical Analysis

<u>No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>
7415	.078	1.37	.17	.013	.020	19.02	13.31	--
7416	.083	1.34	.26	.014	.021	18.81	12.91	.29
7404	.091	1.49	.25	.015	.015	19.03	13.03	.40
7457	.093	1.44	.27	.013	.013	18.99	13.05	.48
7417	.086	1.36	.26	.012	.017	19.39	13.09	.53
7418	.091	1.32	.32	.011	.021	19.39	13.16	.64
7381	.084	1.49	.29	.016	.022	18.79	12.91	.82
7449	.097	1.49	.38	.016	.016	19.50	13.00	1.06

Mechanical Properties

<u>No.</u>	<u>YS psi</u>	<u>TS psi</u>	<u>El.2"</u>	<u>R.A.%</u>	<u>Magnetic</u>	<u>Fissures*</u>
7415	58,000	62,000	23%	35.5	No	m,s
7416	61,000	79,000	32%	39.0	No	m,s
7404	51,500	62,500	7%	28.0	No	l,m,s
7417	48,000	58,500	18%	<5	No	l,m,s
7457	62,000	80,500	28%	43	No	v.s.
7418	57,500	74,000	17%	30.0	No	l,m,s
7381	60,500	80,500	35%	45.0	No	v.s.
7449	61,500	81,000	34%	41.5	No	m,s

- * v.s. - very small (1/32" or less)
s - small (1/32" to 1/16")
m - medium (1/16" to 1/8")
l - large (1/8" and over)

Table 6

Results of Tests in Silicon SeriesChemical Analysis

<u>No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>
7403	.089	1.49	.26	.014	.012	18.91	13.09	.62
7381	.084	1.49	.29	.016	.022	18.79	12.91	.82
7451	.093	1.36	.39	.015	.017	18.99	12.98	.71
7452	.093	1.36	.47	.007	.019	18.78	12.87	.82

Mechanical Properties

<u>No.</u>	<u>YS psi</u>	<u>TS psi</u>	<u>El. 2^m</u>	<u>R.A.%</u>	<u>Magnetic</u>	<u>Fissures*</u>
7403	58,500	77,500	24%	37.5	No	m,s
7381	60,500	80,500	35%	45.0	No	v.s.
7451	62,000	80,000	29%	42.0	No	m,s
7452	60,000	79,500	26%	34	No	m,s

* See Table 5 footnote

Table 7

Results of Tests on Manganese SeriesChemical Analysis

<u>No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>
7381	.084	1.49	.29	.016	.022	18.79	12.91	.82
7455	.093	2.05	.32	.011	.014	18.68	12.80	.77
7406	.091	2.98	.34	.014	.019	18.96	13.02	.72
7454	.092	3.20	.31	.009	.013	18.42	12.54	.89
7453	.095	5.36	.33	.012	.018	18.59	12.35	.82

Mechanical Properties

<u>No.</u>	<u>YS psi</u>	<u>TS psi</u>	<u>El. 2"</u>	<u>R.A. %</u>	<u>Fissures*</u>	<u>Magnetic</u>
7381	60,500	80,500	35%	45.0	8 v.s.	No
7455	63,500	82,000	35%	55	3 v.s.	Slight
7406	63,500	83,000	32%	37	1 v.s.**	V. Slight
7454	62,500	80,000	40%	57.5	1 s	V. Slight
7453	63,000	81,500	39%	58.5	None	V. Slight

Results of Segmented Circular Groove Tests

<u>No.</u>	<u>Bead</u>	<u>Crater</u>	<u>Total</u>
(B) 7381	23.8	7.0	30.8
7455	12.5	6.9	19.4
7454	5.2	5.0	10.2
7453	2.5	None	2.5

* See Table 5 footnote

** Broke at a fissure

Table 8

Results of Tests on Production Electrodes for Qualification TestsChemical Analysis

<u>Compo- sition</u>	<u>No.</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>
(A)	7470	19/9Cb	.080	1.55	.44	.012	.017	19.22	9.31	.71
(B)	7471	19/13Cb	.087	1.49	.33	.013	.017	19.09	13.02	.74
(C)	7472	19/13Cb	.115	1.32	.45	.013	.019	19.09	13.06	.70
(D)	7473	19/9CbTa	.080	1.55	.42	.010	.017	19.22	9.27	.78
(F)	7474	19/10LC	.036	.73	.26	.018	.021	18.92	10.53	--
(H)	7475	19/13MnCb	.095	5.04	.37	.012	.024	18.50	12.99	.91

Mechanical Properties

<u>Compo- sition</u>	<u>No.</u>	<u>YS psi</u>	<u>TS psi</u>	<u>El.2"</u>	<u>R.A.%</u>	<u>Magnetic</u>	<u>Fissures*</u>
(A)	7470-1	68,500	95,000	35%	57.0	Yes	Sound
	7470-2	70,000	97,000	36%	46.5	Yes	Sound
(B)	7471-1	58,500	78,000	29%	39.0	No	2 v.s.**
	7471-2	58,000	78,500	34%	46.0	No	2 v.s.**
(C)	7472-1	63,000	83,500	40%	56.0	No	1 v.s.
	7472-2	64,000	84,500	37%	51.0	No	1 v.s.
(D)	7473-1	79,000	107,500	37%	46.5	Yes	Sound
	7473-2	71,000	97,000	37%	55.5	Yes	Sound
(F)	7474-1	53,000	79,500	50%	64.5	Yes	Sound
	7474-2	54,000	79,500	45%	63.0	Yes	Sound
(H)	7475-1	61,000	80,500	39%	51.0	Slight	Sound
	7475-2	59,000	79,500	39%	59.0	Slight	Sound

* See Table 5 footnote

** Broke at a fissure

Results of Circular Groove Tests**

<u>Compo- sition</u>	<u>No.</u>	<u>Type</u>	<u>Solid</u>			<u>Segmented</u>		
			<u>Bead</u>	<u>Crater</u>	<u>Total</u>	<u>Bead</u>	<u>Crater</u>	<u>Total</u>
(A)	7470	19/9Cb	1.0%	1.2%	2.2%	1.0%	none	1.0%
(B)	7471	19/13Cb	1.6	1.7	3.3	2.2	9.4%	11.6
(B)	7471R*	19/13Cb	---	---	---	29.6	7.4	37.0
(C)	7472	19/13Cb	1.2	4.2	5.4	none	4.1	4.1
(D)	7473	19/9CbTa	1.3	5.7	7.0	none	2.5	2.5
(F)	7474	19/10LC	none	none	none	none	none	none
(H)	7475	19/13MnCb	none	1.6	1.6	none	4.0	4.0
(H)	7475R*	19/13MnCb	---	---	---	3.2	3.8	7.0

* Repeated on circular grooves made from "substitute" plate used for testing pilot electrodes.

** Cracking reported as per cent of circumference.

Table 9

Chemical Analyses of Base Plates

<u>Plate No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb+Ta</u>	<u>N</u>	<u>Mo</u>	<u>Cu</u>	<u>O</u>
4	.059	1.31	.46	.020	.022	18.08	10.94	0.77	.022	.14	.15	.021
8	.080	1.57	.61	.011	.028	17.46	10.98	0.82	.042	.15	.26	.008
12	.058	1.28	.48	.009	.016	18.70	10.82	0.65	.021	.09	.09	.015
13	.048	1.78	.65	.006	.018	18.41	10.57	1.05	.012	.12	.21	.004
14	.053	1.49	.60	.006	.017	18.50	9.45	0.65	.026	.22	.32	.007
15	.045	1.68	.77	.015	.016	18.33	9.96	0.98	.020	.11	.11	.015
17	.075	1.31	.42	.016	.022	17.55	10.53	0.77	.014	.07	.11	.024
19	.059	1.73	.56	.008	.025	19.50	11.11	0.88	.031	.00	.19	.022
20	.078	1.42	.29	.010	.023	17.85	10.06	0.67	.028	.26	.25	.013
21	.096	1.55	.81	.008	.023	17.31	10.75	0.89	.011	.28	.47	.008

Table 10

Nondilution Chemical Analyses of Weld Metals

<u>Electrode</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb+Ta</u>	<u>N</u>	<u>Mo*</u>	<u>Cu*</u>
7381	.084	1.49	.29	.014	.022	18.79	12.91	.87	.039*	.02	.05
7382	.121	1.52	.48	.013	.018	18.95	12.91	.82	.044*	.02	.05
7384	.090	1.57	.33	.012	.019	18.93	12.72	.92	.040*	.02	.05
7453	.095	5.45	.33	.012	.018	18.59	12.35	.82	.040	.20	.05
7454	.092	3.20	.31	.009	.013	18.42	12.54	.89	.038	.20	.05
7455	.093	2.05	.32	.011	.014	18.68	12.80	.75	.042	.20	.05
7471	.087	1.53	.33	.013	.017	19.09	13.33	.72	.039	.02	.05
7472	.116	1.32	.45	.013	.020	19.09	13.21	.69	.044	.02	.05
7475	.096	5.04	.37	.012	.023	18.48	12.99	.94	.037	.02	.05
7513	.058	3.55	.33	.013	.013	19.87	13.15	.90	.081	-	-
7520	.058	4.80	.27	.011	.013	19.66	13.31	.74	.080	-	-
7530	.068	5.02	.26	.017	.011	19.69	13.09	.53	.060	-	-
7534	.071	4.73	.22	.012	.016	19.97	13.31	.80	.077	-	-
7535	.085	4.68	.24	.014	.021	19.78	13.27	.82	.071	-	-
7536	.053	4.62	.28	.013	.018	19.97	13.27	.89	.081	-	-
7537	.059	4.59	.31	.012	.020	19.96	13.30	.54	.078	-	-
7543	.064	4.47	.49	.014	.018	20.11	13.09	.71	.077	-	-
7544	.062	4.41	.64	.009	.018	20.11	13.20	.82	.085	-	-
7554	.113	4.83	.25	.009	.008	19.78	13.03	.62	.084	-	-
8335	.089	1.47	.77	.017	.049	18.72	12.96	.95	-	.02	.05
8476	.081	1.31	.27	.075	.022	18.60	13.32	.49	.057	.02	.05
8743	.076	1.42	.34	.021	.035	18.92	12.85	.88	.039	.02	.05
8749	.078	1.31	.33	.066	.019	18.54	13.02	.52	.049	.02	.05
8753	.081	1.34	.35	.018	.056	18.90	12.86	.71	.041	.02	.05
8754	.082	1.39	.32	.017	.024	18.89	12.82	.74	.041	.02	.05
8756	.072	1.34	.38	.043	.018	18.80	12.83	.61	.053	.02	.05
8844	.078	1.42	.60	.019	.030	18.89	12.91	.86	.045	.02	.05
8845	.081	1.42	.51	.021	.036	18.86	12.76	.83	.045	.02	.05
8846	.080	1.50	.59	.019	.063	18.80	12.76	.94	.062	.02	.05
8847	.080	1.44	.71	.019	.028	18.73	12.87	.90	.039	.02	.05
8848	.079	1.42	.74	.018	.035	18.84	12.98	.81	.039	.02	.05
<u>Core Wire Chemical Analyses</u>											
7381-7475 } 8335-8848 }	.070	1.59	.35	.010	.013	19.60	13.24	-	.019	.02	.05
7513-7554	.039	4.52	.25	.014	.016	21.08	13.24	-	-	-	-

* Estimate, based on core wire analyses.

Table 11

Calculated Weld Bead Chemistry for Welder X

Average weld metal dilution by welder X = 32%

% of element A in weld bead = (0.32)(% of element A in base material + (0.68)(% of element A in nondiluted weld metal)

Example: For test No. 19, % Mn in weld bead = (0.32)(1.31) + (0.68)(3.20) = 2.595

<u>Test No.</u>	<u>Base Plate</u>	<u>Elec-trode</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb+Ta</u>	<u>N</u>
1	21	7471	.0899	1.536	.484	.0114	.0189	18.520	12.504	.771	.0300
2	20	7471	.0841	1.494	.317	.0120	.0189	18.693	12.284	.699	.0355
3	8	7471	.0849	1.543	.420	.0124	.0206	18.568	12.576	.749	.0400
4	12	7471	.0776	1.450	.378	.0117	.0167	18.965	12.527	.694	.0332
5	19	7471	.0781	1.594	.404	.0114	.0196	19.221	12.618	.768	.0364
6	17	7471	.0832	1.459	.359	.0140	.0186	18.597	12.434	.733	.0310
7	4	7471	.0780	1.459	.372	.0152	.0186	18.767	12.565	.733	.0336
8	14	7471	.0761	1.517	.416	.0108	.0170	18.901	12.088	.694	.0348
9	13	7471	.0745	1.610	.432	.0108	.0173	18.872	12.447	.822	.0304
10	4	7381	.0758	1.432	.344	.0156	.0220	18.563	12.280	.835	.0336
11	4	7384	.0801	1.487	.372	.0146	.0200	18.658	12.150	.872	.0342
12	4	7382	.1012	1.453	.474	.0152	.0189	18.672	12.276	.804	.0370
13	8	7472	.1042	1.400	.501	.0124	.0227	18.568	12.491	.732	.0434
14	12	7472	.0970	1.307	.460	.0117	.0187	18.965	12.442	.677	.0366
15	13	7472	.0939	1.467	.514	.0108	.0194	18.872	12.362	.805	.0338
16	14	7472	.0955	1.374	.498	.0108	.0190	18.901	12.003	.677	.0382
17	15	7472	.0929	1.434	.552	.0136	.0187	18.847	12.167	.782	.0363
18	4	7455	.0821	1.813	.365	.0139	.0166	18.488	12.205	.756	.0356
19	4	7454	.0814	2.595	.358	.0125	.0159	18.311	12.028	.852	.0329
20	4	7453	.0835	4.125	.372	.0146	.0193	18.427	11.899	.804	.0342
21	4	7475	.0838	3.846	.399	.0146	.0229	18.352	12.334	.882	.0322
22	8	7513	.0651	2.916	.420	.0124	.0179	19.099	12.454	.874	.0685
23	8	7520	.0650	3.763	.379	.0110	.0176	18.956	12.559	.766	.0678
24	8	7530	.0719	3.916	.372	.0151	.0165	18.976	12.413	.623	.0542
25	8	7534	.0740	3.719	.345	.0117	.0199	19.167	12.563	.806	.0658

Table 11 (Continued)

<u>Test No.</u>	<u>Base Plate</u>	<u>Elec-trode</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb+Ta</u>	<u>N</u>
26	8	7535	.0832	3.685	.358	.0130	.0233	19.038	12.536	.820	.0617
27	8	7536	.0617	3.644	.386	.0124	.0213	19.167	12.536	.868	.0685
28	8	7537	.0658	3.624	.406	.0117	.0227	19.160	12.553	.630	.0665
29	8	7543	.0692	3.542	.528	.0132	.0213	19.262	12.413	.745	.0658
30	8	7544	.0679	3.501	.630	.0093	.0213	19.245	12.488	.820	.0712
31	8	7554	.1025	3.787	.365	.0096	.0145	19.038	12.372	.684	.0706

Table 12

Calculated Weld Bead Chemistry for Welder Z

Average weld metal dilution by welder Z = 24%

% of element A in weld bead = 0.24 (% of element A in base material) + (0.76)(% of element A in nondiluted weld metal)

Example: For test No. 8, % P in weld bead = (0.24)(0.0283) + (0.76)(0.036) = 0.0342

<u>Test No.</u>	<u>Base Plate</u>	<u>Elec-trode</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb+Ta</u>	<u>N</u>
1	8	8756	.0740	1.395	.435	.0353	.0205	18.478	12.385	.660	.0504
2	8	8749	.0786	1.372	.397	.0527	.0212	18.281	12.529	.596	.0469
3	8	8476	.0808	1.372	.352	.0596	.0235	18.326	12.757	.598	.0534
4	8	8754	.0812	1.433	.390	.0155	.0250	18.547	12.377	.759	.0412
5	8	8743	.0770	1.456	.405	.0186	.0334	18.570	12.400	.866	.0397
6	8	8753	.0808	1.395	.412	.0163	.0494	18.554	12.408	.736	.0412
7	8	8844	.0786	1.456	.602	.0170	.0296	18.547	12.446	.850	.0443
8	8	8845	.0805	1.456	.534	.0186	.0342	18.529	12.332	.828	.0440
9	8	8846	.0797	1.517	.595	.0170	.0547	18.478	12.332	.911	.0572
10	8	8847	.0801	1.471	.686	.0170	.0281	18.425	12.415	.881	.0397
11	8	8848	.0789	1.456	.709	.0163	.0334	18.509	12.499	.812	.0397
12	8	8335	.0869	1.494	.732	.0155	.0440	18.418	12.484	.919	.0400

Table 13

Measured Length of Bead Cracks and Actual Percent Cracking

$$\% \text{ Cracking} = \frac{\text{Measured length of bead cracks (excluding crater cracks)}}{\text{Circ. of 2 in. diam. circle} - \text{length of circ. occupied by the crater}} \times 100$$

Example: Test No. 15 for welder X, actual percent cracking = $\frac{0.515}{6.28-0.62} \times 100 = 9.1$

Welder X				Welder Z				
Test No.	Length of Bead Crack, Inches	Length of Crater	Bead Cracking, %	Test No.*	Length of Bead Crack, Inches	Length of Crater	Bead Cracking, %	Avg.
1	0	0.60	0	1-1	2.80	0.62	49.5	54.2
2	0.125	0.60	2.2	1-2	3.60	0.63	63.6	
3	0.560	0.57	9.8	1-3	2.80	0.62	49.5	49.3
4	0.950	0.63	16.8	2-1	2.78	0.63	49.2	
5	1.150	0.56	20.1	2-2	2.80	0.62	49.5	53.9
6	1.760	0.64	31.2	3-1	3.34	0.64	59.2	
7	1.860	0.64	33.0	3-2	2.65	0.63	46.9	49.8
8	1.890	0.61	33.4	3-3	3.14	0.64	55.6	
9	1.950	0.64	34.6	4-1	3.41	0.62	60.3	55.3
10	1.495	0.64	26.5	4-2	2.74	0.63	48.5	
11	1.130	0.63	20.0	4-3	2.30	0.63	40.7	96.9
12	0.035	0.45	0.6	5-1	3.34	0.53	58.1	
13	0	0.57	0	5-2	2.19	0.62	38.7	38.1
14	0.275	0.60	4.8	5-3	3.90	0.64	69.2	
15	0.515	0.62	9.1	6-1	5.47	0.63	96.8	68.6
16	0.590	0.56	10.3	6-2	5.03	0.63	89.0	
17	1.160	0.70	20.8	6-3	5.91	0.65	105.0	101.9
18	0.790	0.60	13.9	7-1	1.39	0.63	24.6	
19	0.330	0.59	5.8	7-2	2.70	0.63	47.8	68.6
20	0.160	0.56	2.8	7-3	2.37	0.63	42.0	
21	0.200	0.72	3.6	8-1	4.24	0.63	75.1	109.1
22	0.460	0.60	8.1	8-2	3.86	0.63	68.4	
23	0.290	0.70	5.2	8-3	3.51	0.63	62.2	101.9
24	0.035	0.45	0.6	9-1	5.45	0.63	96.5	
25	0	0.48	0	9-2	5.66	0.62	100.0	101.9
26	0	0.53	0	9-3	6.17	0.62	109.1	

Table 13 (Continued)

Welder X				Welder Z				
Test No.	Length of Bead Crack, Inches	Length of Crater	Bead Cracking, %	Test No.*	Length of Bead Crack, Inches	Length of Crater	Bead Cracking, %	Avg.
27	0.060	0.82	1.1	10-1	1.62	0.64	28.7	42.2
28	0.230	0.53	4.0	10-2	2.78	0.64	49.4	
29	0.370	0.58	6.5	10-3	2.73	0.63	48.4	
30	0.320	0.46	5.5	11-1	3.80	0.64	67.5	73.8
31	0	0.51	0	11-2	4.61	0.61	81.4	
				11-3	4.10	0.62	72.5	
				12-1	4.85	0.64	86.0	82.4
				12-2	4.18	0.63	74.0	
				12-3	4.94	0.63	87.3	

* Numbers after dashes indicate the number of repeat tests.

Table 14

Calculated Percent Cracking in Comparison with the Actual Measured Values

$$\% \text{ Cracking} = -133.6 + \frac{6.144}{C} + \frac{43.1}{Mn} + 1.8 Si + 384 S + 2295 P + 9.98 Ni - 4.48 Cr - 28.8 (Cb + Ta) - 487 N$$

	<u>Test No.</u>	<u>Calculated % Cracking</u>	<u>Actual % Cracking</u>	<u>Difference</u>
Welder X	1	20.2	0	+20.2
	2	22.4	2.2	+20.2
	3	24.8	9.8	+15.0
	4	26.9	16.8	+10.1
	5	26.7	20.1	+6.6
	6	27.1	31.2	-4.1
	7	32.1	33.0	-0.9
	8	22.8	33.4	-9.6
	9	25.9	34.6	-8.7
	10	38.1	26.5	+11.6
	11	24.3	20.0	+4.3
	12	7.9	0.6	+7.3
	13	16.3	0	+16.3
	14	16.4	4.8	+11.6
	15	13.3	9.1	+4.2
	16	24.2	10.3	+13.9
	17	13.8	20.8	-7.0
	18	12.9	13.9	-1.0
	19	2.2	5.8	-3.6
	20	0.3	2.8	-2.5
	21	13.4	3.6	+9.8
	22	7.4	8.1	-0.7
	23	7.6	5.2	+2.4
	24	6.2	0.6	+5.6
	25	0.5	0	+0.5
	26	1.2	0	+1.2
	27	18.2	1.1	+17.1
	28	23.5	4.0	+19.5
	29	11.6	6.5	+5.1
	30	7.9	5.5	+2.4
	31	0	0	0
Welder Z	1	43.4	54.2	-10.8
	2	53.0	49.3	+3.7
	3	57.4	53.9	+3.5
	4	39.0	49.8	-10.8
	5	61.0	55.3	+5.7
	6	97.3	96.9	+0.4
	7	49.0	38.1	+10.9
	8	57.9	68.6	-10.7
	9	95.5	101.9	-6.4
	10	45.4	42.2	+3.2
	11	60.4	73.8	-13.4
	12	74.4	82.4	-8.0

Table 15

Cracking Effect of the Elements

<u>Element</u>	<u>Effect of Increasing Amount on Cracking</u>	<u>Slope Factor</u>	<u>Range of Variation, %</u>	<u>Calculated % Cracking Variation</u>
<u>Elements Which Were Unintentionally Varied</u>				
Cr	Decreases	4.48 Cr	18.28-19.26	4.4
Ni	Increases	9.98 Ni	11.89-12.75	8.6
Cb + Ta	Decreases	28.8 (Cb + Ta)	0.60-0.92	9.2
N	Decreases	487 N	0.030-0.071	20.0
<u>Elements Which Were Intentionally Varied</u>				
C	Decreases	6.44/C	0.062-0.104	42.0
Mn	Decreases	43.1/Mn	1.31-4.13	22.4
Si	Increases	1.8 Si	0.32-0.73	0.7
S	Increases	384 S	0.009-0.060	19.6
P	Increases	2295 S	0.014-0.055	94.1

TABLE 16

Chemical Analysis and Tensile Properties of
Electrodes Selected for Test⁽¹⁾

Composition and Designations of Electrodes*

<u>Composition</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>Ferrite % Calc.+</u>
A**	19/9Cb	.080	1.55	.017	.012	.44	9.31	19.22	.71	7%
B	19/13Cb	.087	1.49	.017	.013	.33	13.02	19.09	.74	None
C	19/13Cb	.115	1.32	.019	.013	.45	13.06	19.09	.70	None
D***	19/9CbTa	.080	1.55	.017	.010	.42	9.27	19.22	.78	7%
F	19/10LC	.036	.73	.021	.018	.26	10.53	18.92	--	4%
H	19/13MnCb	.095	5.04	.024	.012	.37	12.99	18.50	.91	None

* Chemical analyses from non-dilution weld pads made in accordance with ASTM-AWS specifications.

** Standard Type 347 Composition.

*** Standard Type 347 Cb+Ta Composition.

+ Calculated from chemical composition according to Schaeffler diagram.

Duplicate All-Weld-Metal .505 Tensile Properties

<u>Composition</u>	<u>Type</u>	<u>YS, psi*</u>	<u>TS, psi</u>	<u>El. in 2" %</u>	<u>R.A.</u>	<u>Fissures**</u>
A	19/9Cb	68,500	95,000	35.0	57.0	None
		70,000	97,000	36.0	46.5	None
B	19/13Cb	58,500	78,000	29.0	39.0	2 v.s.
		58,000	78,500	34.0	46.0	2 v.s.
C	19/13Cb	63,000	83,500	40.0	56.0	1 v.s.
		64,000	84,500	37.0	51.0	1 v.s.
D	19/9CbTa	79,000	107,500	37.0	46.5	None
		71,000	97,000	37.0	55.5	None
F	19/10LC	53,000	79,500	50.0	54.5	None
		54,000	79,500	45.0	63.0	None
H	19/13MnCb	61,000	80,500	39.0	51.0	None
		59,000	79,500	39.0	59.0	None

* Yield Strength measured at .5% extension under load.

** v.s. - very small, less than 1/64 inch.

s. - 1/64" to 1/32".

m. - 1/32" to 1/16".

l. - 1/16" and over.

(1) A study of the chemical analysis, mechanical properties, microstructures, and crack sensitivity of welds deposited with these electrodes will be found in the bibliography.

TABLE 17

Compositions of Base Materials*

<u>MATERIALS FOR FISSURE TESTS</u>										
<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	
347	1/2"	.06	1.39	.026	.010	.66	10.51	19.40	.77	
304L	1/2"	.024	1.55	.026	.016	.38	9.50	17.76	--	
<u>MATERIAL FOR FILLET WELD TESTS</u>										
<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	
347	1/4"	.07	1.84	.030	.014	.70	11.00	18.56	.85	
<u>MATERIALS FOR BUTT WELD TESTS</u>										
<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>Cu</u>
347	1"	.07	1.60	.030	.021	.62	10.74	17.92	.84	.26
304L	1"	.026	.66	.019	.012	.65	8.43	19.01		
<u>MATERIAL FOR PIPE WELD TESTS</u>										
<u>Type</u>	<u>Size</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>Ta</u>
347	8-5/8" O.D. x 1" Wall	.059	1.37	.024	.013	.46	10.39	17.55	.54	.06

* Mill Reports

TABLE 18

Fissures Revealed by Etching and Bending

Fissure Test Specimens

<u>Composition</u>	<u>Base Plate</u>	<u>Arcos Fissures**</u>		<u>Crane Fissures**</u>		<u>A.O. Smith Fissures**</u>		<u>Number of Laboratories Reporting Defects</u>		<u>Total</u>
		<u>Etching</u>	<u>Bending</u>	<u>Etching</u>	<u>Bending</u>	<u>Etching</u>	<u>Bending</u>	<u>Etching</u>	<u>Bending</u>	
A	Carbon Steel Type 347	No	No	No	No	No	No	0	0	0
		No	No	No	1s,3vs	No	No	0	1	$\frac{1}{1}$
B	Carbon Steel Type 347	Yes	12m,11s	No	1m,5vs	No	No	1	2	3
		Yes	3m,4s,12vs	No	3m,6s,10vs	Yes	10vs	2	3	$\frac{5}{8}$
C	Carbon Steel Type 347	No	1m,1s,1vs	No	6vs	No	No	0	2	2
		No	1s,2vs	No	1s,2vs	No	No	0	2	$\frac{2}{4}$
D	Carbon Steel Type 347	No	No	No	No	No	No	0	0	0
		No	No	No	No	No	No	0	0	$\frac{0}{0}$
H	Carbon Steel Type 347	No	No	No	1vs	Yes	No	1	1	2
		No	No	No	No	Yes	No	1	0	$\frac{1}{3}$
F	Carbon Steel Type 304-L	No	No	No	1-1,10m,21s	No	No	0	1	1
		No	No	No	Many vs	No	No	0	1	$\frac{1}{2}$
	<u>Welding Conditions</u>		<u>Arcos</u> 128-132 Amps 26-28 Volts		<u>Crane</u> 115-120 Amps 23-28 Volts		<u>A.O. Smith</u> 125-130 Amps 24-25 Volts			

** See note at bottom of Table 16.

TABLE 19

Elongation of Fissure Test Specimens
Before Fissuring or Cracking

Composition	Base Plate	Arcos			Crane			A.O. Smith					
		Bend Angle	Elongation %			Bend Angle	Elongation %			Bend Angle	Elongation %		
			1/2"	1"	2"		1/2"	1"	2"		1/2"	1"	2"
A	Carbon Steel Type 347	70°	19	16	12	101°	20	19	17	20°	10	7	5
		173°	36	36	31	202°	50	48	41	180°	30	28	27
B	Carbon Steel Type 347	74°	24	22	18	183°	46	40	33	55°	22	19	13
		175°	37	38	33	175°	36	34	31	180°	30	27	26
C	Carbon Steel Type 347	80°	23	23	18	184°	30	29	28	45°	18	17	13
		187°	39	38	36	203°	52	48	39	180°	34	28	25
D	Carbon Steel Type 347	68°	24	19	14	111°	30	27	21	30°	8	8	7
		173°	37	35	31	205°	50	46	39	180°	32	30	27
F	Carbon Steel Type 304-L	149°	17	19	23	86°	18	18	13	40°	18	13	9
		169°	35	33	30	205°*	46*	45*	38*	180°	32	27	25
H	Carbon Steel Type 347	171°	35	38	30	186°	40	35	33	180°	40	36	32
		173°	42	43	32	200°	56	50	39	180°	34	30	26

* Fissures observed on pre-bending to 60° - 80°
Elongation measured after bending to 205°

Rating Based on Elongation in 1/2 inch

	Arcos		Crane		A.O. Smith	
	Base Plate		Base Plate		Base Plate	
	Carbon Steel	Stainless	Carbon Steel	Stainless	Carbon Steel	Stainless
1	H	H	B	H	H	H
2	B	C	H	C	B	C
3	D	B	C	A	C	D
4	C	D	D	D	F	F
5	A	A	A	B	A	A
6	F	F	F	F**	D	B

** F Rating assumed, see (*)

< Indicates equal elongation in 1/2"

TABLE 20

Performance Characteristics of the Various Electrodes

<u>Electrode Composition</u>	<u>Position and Current</u>		
	<u>Horizontal-110 amps</u>	<u>Vertical-115 amps</u>	<u>Overhead-125 amps</u>
A	Satisfactory	Satisfactory	Satisfactory
B	Satisfactory	Satisfactory	Satisfactory
C	Satisfactory	Satisfactory	Satisfactory
D	Satisfactory	Satisfactory	Satisfactory
F	Satisfactory	Fair, some tendency to pinch out.	Satisfactory
H	Satisfactory	Fair, metal more fluid	Satisfactory

TABLE 21

Location of Fissures in Fillet Welds

<u>Composition</u>	<u>Welding Position</u>	<u>Remarks</u>
A	Horizontal	No fissures
B	Horizontal	Fissures at No. 1 crater in single-pass weld
C	Horizontal	No fissures
D	Horizontal	No fissures
F	Horizontal	No fissures
H	Horizontal	Fissures at No. 2 crater in single-pass weld
A	Vertical	No fissures
B	Vertical	Fissures at No. 1 crater in single-pass weld
C	Vertical	No fissures
D	Vertical	No fissures
F	Vertical	Fissures at 1" from finish end in first pass of 3-pass weld. Also fissures and slight porosity at 1" from start end in same weld.
H	Vertical	Fissures at No. 1 crater in single-pass weld
A	Overhead	No fissures
B	Overhead	Fissures at No. 4 crater in second pass of 3-pass weld
C	Overhead	No fissures
D	Overhead	No fissures
F	Overhead	No fissures
H	Overhead	Fissures at No. 2 crater in first pass of 3-pass weld

TABLE 22

Defects noted by Dy-Chek Inspection of Butt Welds

<u>Electrode Composition</u>	<u>Type of Defect</u>			
	<u>Fusion Line</u>	<u>Slag</u>	<u>Porosity</u>	<u>Other</u>
A	Intermittent Medium	Two Very Small	None	None
B	Intermittent Medium	Two Small	Three Very Small	None
C	Intermittent Light	Two Small	One Small Void	None
D	Intermittent Very Light	None	None	None
F	Continuous	One Large	None	Light line outside fusion line on base metal side.
H	Intermittent	None	None	Two short (1/8"-3/16") indications 2-3" from finish end.

TABLE 23

Test Results of Butt Weld Specimens

Hardness Survey

Electrode Composition	Spec. No.	V.P.N. - 30 K.G. Loading					
		Unaffected** Base Metal	Heat Affected B.M.		Fusion Zone		Weld Metal
			1	2	B.M.	Weld	
A	1	184	210	222	226	239	232
	2	176	211	214	214	220	222
B	1	176	200	210	210	202	215
	2	178	199	209	207	199	208
C	1	168	209	213	213	214	223
	2	171	208	208	208	208	218
D	1	174	212	218	217	229	234
	2	170	215	222	227	234	248
F	1	158	209	211	217	216	204
	2	165	198	202	200	194	201
H	1	167	202	213	212	205	213
	2	165	203	217	209	198	202

Tensile Properties - All Weld Metal .505" Specimens

Electrode Composition	TS, psi	YS, psi*	Elong. %-2in.	Red Area %	Remarks
A	97,500	76,000	34.0	47.0	Irreg. Break. One small defect noted before test (Zyglo)
B	82,000	65,000	28.0	33.0	Irreg. break in area of two pinhole defects found before test (Zyglo)
C	85,900	67,300	32.0	38.0	Irreg. break. Irreg. pattern of cracks opened up. 1/8" crack noted before test (Zyglo)
D	100,000	80,100	30.0	50.0	Full cup. Zyglo O.K.
F	80,300	59,500	37.0	48.0	Irreg. break. Zyglo O.K.
H	84,700	69,000	33.0	30.5	Irreg. break 6 v.s. & 1 m. fissures after test. One small crack noted before test (Zyglo).

* Yield strength determined by 0.2% offset method and a crosshead speed of .05 ipm up to yield point.

** Type 347 base metal was used with electrodes A,B,C,D & H.
Type 304L base metal was used with electrode F.

(Cont'd)

TABLE 23 (continued)

Results of Free Face Bend Specimens

<u>Base Metal</u>	<u>Electrode Composition</u>	<u>Spec. No.</u>	<u>Bend Degrees</u>	<u>Elong. % - 1 in.</u>	<u>Fissures*</u>	<u>Remarks</u>
Type 347	A	1	180	45.5(1)	1vs	1-1/16" tear in base metal H.A.Z.
		2	180	27.5	None	
Type 347	B	1	143	36.5(2)	5vs,1s	Trans. tear across all but 3/16" of weld.
		2	153	42.0(2)	3vs,6s,6m	Trans. tear across entire weld. Fissures in small area.
Type 347	C	1	127	24.5	None	1/4 in. edge tear
		2	158	57.5(1) (2)	2s,1m	Trans. tear across entire weld. Also 3/16 in. edge tear.
Type 347	D	1	180	32.0	None	-----
		2	180	30.0	1vs	-----
Type 304L	F	1	180	36.0	1vs	1 small fissure found in Base Metal H.A.Z.
		2	180	44.0	1vs	-----
Type 347	H	1	166	41.0(2)	2vs	Trans. tear 3/4 across weld. 1-1/8 in. & 1-3/32 in openings.
		2	168	44.5(2)	3s,1m,1-1	1/2 in. tear crack in weld runs intermittent to edge.

Results of Free Root Bend Specimens

<u>Base Metal</u>	<u>Electrode Composition</u>	<u>Spec. No.</u>	<u>Bend Degrees</u>	<u>Elong. % - 1/2 in.</u>	<u>Elong. % - 1 in.</u>	<u>Fissures*</u>	<u>Remarks</u>
Type 347	A	1	180	32.0	34.0	7vs,1m	-----
		2	180	30.0	32.0	6vs	-----
Type 347	B	1	71	6.0	8.0	3vs,1s	7/32", 15/32" and several small openings near fusion line
		2	73	4.0	9.0	2s	3/16" & 7/32" openings just inside fusion line.
Type 347	C	1	167	38.0	40.0	6vs,2-1	7/64" opening near line of fusion
		2	180	40.0	37.0	4vs	5/32" V-shaped opening at fusion line
Type 347	D	1	180	30.0	31.0	2vs,1s	-----
		2	180	32.0	33.0	1vs	-----
Type 304L	F	1	180	40.0	37.0	4vs,1s	5/32" opening due to slag
		2	180	38.0	38.0	2s**	1-3/32" & 1-1/64" cold shut or incomplete fusion
Type 347	H	1	152	40.0	39.0	4vs,1-1	Severe edge tear originating at fusion line. Started at 125°.
		2	106	18.0	18.0	None	1/64", 3/64" and 9/32" openings just inside fusion line.

* See note at end of table.

** Base Metal H.A.Z.

(Cont'd)

TABLE 23 (continued)

Base Metal	Electrode Composition	Results of Guided Side Bend Tests		Results of Impact Tests Charpy Keyhole - Ft. lbs.			
		Bend Degrees	Fissures*	Room Temp.		-300°F	
				Av.		Av.	
Type 347	A	180°	None	20.5	21	11.5	12
		180°	None	19.5		11.5	
				23.0		12.5	
Type 347	B	45°(3)	2vs,3s,1-1	18.0	19	12.5	12
		180°	2vs	20.0		10.0	
				20.0		12.5	
Type 347	C	180°	3vs,3s,1-1	19.0	20	9.5	10
		180°	2vs	20.0		10.5	
				20.5		10.5	
Type 347	D	180°	2vs	25.5	25	20.0	17
		180°	None	24.5		15.0	
				25.0		15.5	
Type 304L	F	180°	None	26.5	28	16.5	22
		180°	None	28.0		26.0	
				30.0		23.5	
Type 347	H	180°	2vs,2s	18.0	20	10.5	10
		180°	None	20.5		10.0	
				21.0		10.5	

- (1) Wrong jig used in pre-bending
 (2) Approximate due to tear
 (3) Failure at 45 - 90°
 Evidence of hot-tear voids.

* vs - under 1/64"
 s - 1/64" - 1/32"
 m - 1/32" - 1/16"
 l - 1/16" & over

TABLE 24

Pipe Weld Test Specimens

Elec- trode	Flaws in Side Bend Specimens	% Elongation of Free Bend Specimens		Transverse Tensile Specimens		Average Rockwell B Hardness of Weld		Average % Ferrite ⁺	
		Root	Face	Strength, psi	Location of Failure	Root	Face	Root	Face
A	1. None	36N	45	89,500	Base Metal	98.9	90.9	4.7	5.8
	2. None	38N	45N	91,300	Base Metal				
	3. None			89,750	Base Metal				
	4. None								
B	1. None	38N	34	86,500	Base Metal	97.8	83.8	0	0
	2. Eight Small	42	37	88,950	Weld & Base				
	3. None			86,600	Weld				
	4. Two Small								
C	1. Three Small, Edge Tears	22	30	93,600	Base Metal	96	86.8	0	0
	2. One Small	37.5N	33	87,950	HA Zone				
	3. None			87,250	HA Zone				
	4. None								
D	1. None	36N	39N	76,000*	Base Metal	99.1	92.9	4.3	6.8
	2. None	33N	40	78,450*	Base Metal				
	3. One Small			78,500*					
	4. None								
H	1. None					96.1	84.9	0	0
	2. Two 3/16" Tears	33	37	87,200	Base Metal				
	3. One Small	37N	37	85,700	Base Metal				
	4. One Small			85,500	Weld & Base				

N - No defects evident after completion of bead.

* - Values questioned because hardness measurements show no evidence of a difference in strength of the individual forged rings used.

+ - By Magnegage.

TABLE 25

Rockwell B. Hardness of Weld Deposits Made in Pipe Welds

<u>Composition</u>	<u>Specimen No.</u>	<u>Surface Bead</u>	<u>Root Bead</u>	<u>Avg. of 8 Readings</u>
A	12	90.5	99.0	96.1
A	13	90.0	99.5	97.9
A	14	93.2	98.0	98.0
A	15	90.0	99.0	96.4
B	12	82.0	99.0	93.3
B	13	83.0	101.0	92.8
B	14	84.5	97.0	93.6
B	15	83.5	94.0	91.7
C	12	86.0	89.0	94.4
C	13	86.5	96.0	94.7
C	14	90.5	95.0	91.8
C	15	84.0	98.0	93.4
D	12	95.2	99.0	97.4
D	13	92.0	99.5	97.8
D	14	97.0	98.0	98.2
D	15	87.5	100.0	96.6
H	12	84.0	98.0	94.6
H	13	90.0	97.5	94.3
H	14	84.5	95.0	92.9
H	15	81.0	94.0	92.5

Base Metal Hardness Rockwell B.

<u>High</u>	<u>Low</u>	<u>Avg. of 240 Readings</u>
89	82	85.8

TABLE 26

Ferrite Determinations in Pipe Welds*

<u>Test</u>	<u>Specimen No.</u>	<u>Percent Ferrite in Weld Deposit</u>		
		<u>Surface Bead</u>	<u>Root Bead</u>	<u>Avg. of 6 Readings</u>
A	12	6.4	4.4	5.6
A	13	5.2	3.8	4.5
A	14	5.0	4.8	5.3
A	15	6.4	5.8	6.27
(B) - All specimens non-magnetic				
(C) - All specimens non-magnetic				
D	12	7.8	5.0	6.7
D	13	6.0	3.6	5.3
D	14	7.0	4.8	5.8
D	15	6.4	3.6	6.1
(H) - All specimens non-magnetic				

* By Magnegage

Table 27

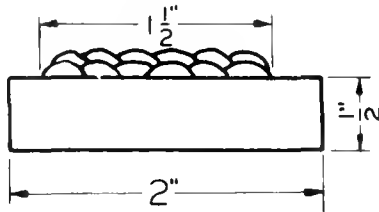
A. O. Smith Qualification Test for Welding of 18-8 Cb
Stainless Steel, Atomic Energy Commission Project

For evaluation of the performance and usability of the special 18-8 stabilized electrodes which were produced by the Arcos Corporation, the A. O. Smith Corporation proposed the following types of tests.

- A. Deposit weld for fissures
- B. Fillet weld test for position welding
- C. Butt weld test, restricted joint

A. Test for Fissures

Prepare a deposit weld six beads wide, two layers high, and eight (8") long on a 1/2" thick A-285 carbon steel base plate with each electrode (all electrodes to be 5/32" diameter), as shown in Sketch 1. The ends of the base plate shall be held down by means of "C" clamps to minimize bowing.



Note: Plate material used for this project was 3" wide. Width of weld bead was maintained at 1-1/2".

Sketch 1

The carbon steel base plate shall be sandblasted prior to deposit of weld metal.

The interpass temperature shall not exceed 190°F.

One electrode shall be used for each bead deposited. A new electrode shall be used for each succeeding bead.

The surface of the weld deposit shall be ground and polished in order to obtain a smooth surface for proper examination and bend testing. (A disc grinder is recommended in order to obtain

Table 27 Cont'd

an even surface). The polished surface of the weld deposit shall be etched with a saturated solution of HCl and FeCl₂, and the surface examined for fissures. A low power* magnifying glass may be used to detect the presence of fissures.

The bend specimen shall be machined to a 1-1/2" width (the width of the weld deposit) along the length of the weld, and gage lines shall be lightly scribed at 1/4" intervals for a distance of 1" on each side of the center across the weld. In this way the elongation can be measured in 1/2", 1", and 2" gage lengths.

Bending to be carried until the ends have been compressed to about 170° or until the occurrence of tears or fissures is first observed.

Evaluation to be based on angle of bending and weld appearance.

The weld deposit shall be tested in the longitudinal direction as a free bend, with the weld in tension.

This test shall be duplicated on 1/2" thick Type 347 plates for columbium bearing electrodes A, B, C, D, and H, and on 1/2" thick Type 308L plate for the low carbon electrode F.

B. Fillet Weld Test

In order to evaluate the welding performance of each electrode for all-position welding, fillet welds shall be prepared in the horizontal, vertical-up, and overhead positions.

The material used for making the fillet welds shall be 1/4" x 2" x 12", Type 347 material.

The horizontal plate surface shall be flat and the edge of the vertical plate, which is to be welded, shall be machined to a square finish so that intimate contact may be obtained with the horizontal plate surface.

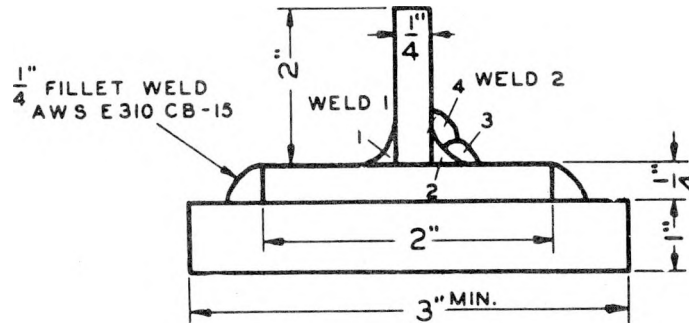
A tack weld shall be made at each end of the test plate to hold the vertical member in position.

The 1/4" thick horizontal plate shall be restrained by fillet welding the outer 12" long edges to a 1" thick low carbon steel backing plate.

A single bead fillet weld shall be made on one side of the specimen and a triple bead fillet weld shall be made on the opposite side, as shown in Sketch 2. The maximum interpass temperature of 190°F shall be maintained.

* For this research project a 20X binocular microscope was employed. For the inspection of welded fabrication, a 10X or under magnifying glass is recommended.

Table 27 Cont'd

Sketch 2

Each electrode shall be rated on its fillet welding performance, such as slag coverage, wash-up, and cracks.

Each crater shall be accurately marked and a macro specimen shall be prepared through each crater from the start, middle, and end portions of each weld and shall be examined for penetration and cracks. The craters need not be removed unless visible cracks were detected.

C. Butt Welds (Restrained)

Since the performance of each electrode for all-position welding will be determined in the fillet weld test, it is recommended that the butt weld test be made in the downhand position.

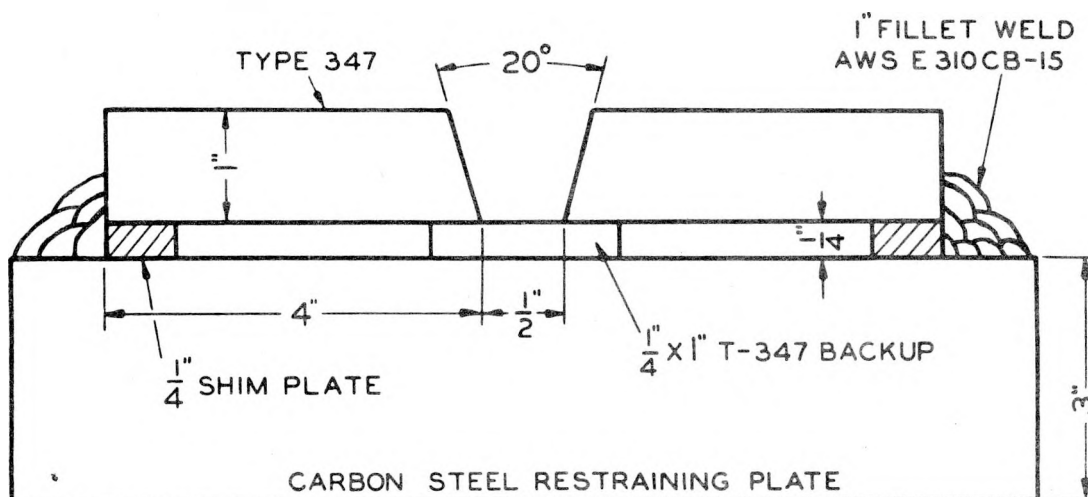
The material for this test will consist of plates 1" x 4" x 20" Type 304 stainless steel, which will result in a welded test plate 1" x 8" x 20". In the case of composition F, Type 304L plate material will be used. The 1" thick test plate shall be restrained by fillet welding the outer 20" long edges to a 3" thick low carbon steel backing plate. The groove design is shown in Sketch 3.

Double beading and triple beading technique shall be used for the butt welds (weaving shall be tentatively limited to twice the diameter of the electrode, coating included).

A maximum interpass temperature of 190°F shall be maintained.

Table 27

Cont'd

Sketch 3

Do not remove the weld craters unless crater cracks are visually detected.

Remove a macro specimen from each end of the test plate with the chill intact. The backup strip shall be removed by machining, care being taken not to machine into the parent stock or weld. The root surface shall then be ground and polished flush with the parent metal. The polished root surface shall be etched with acid-ferric chloride solution, and "Zyglo" inspected.

Ultra-sonic inspection shall be made on the cross-section of the 8" plate edge through the length of the weld.

Radiographic examination of the weld is required.

The following specimens shall be prepared from each test plate:

- 1) One .505" "All-weld" tensile specimen for detection of internal fissures and obtaining the mechanical properties.

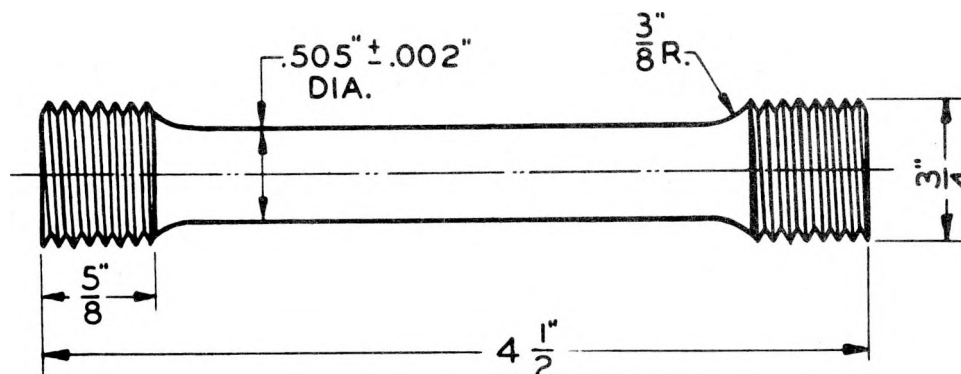
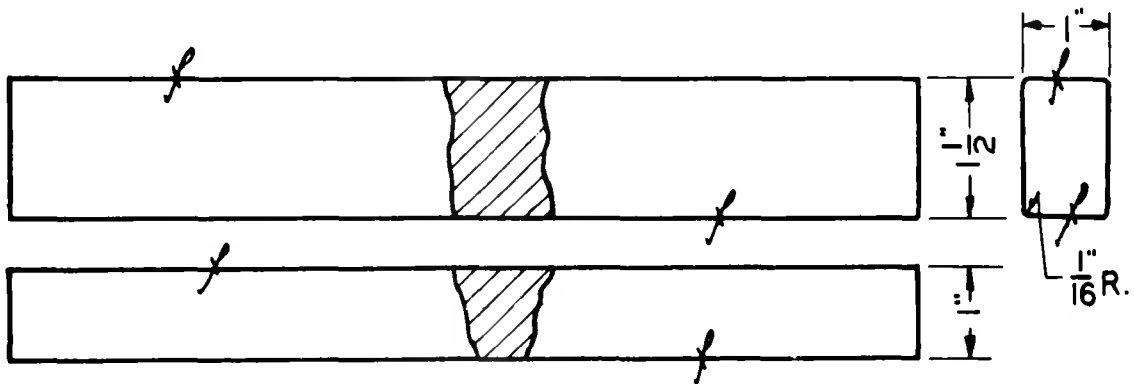
Sketch 4

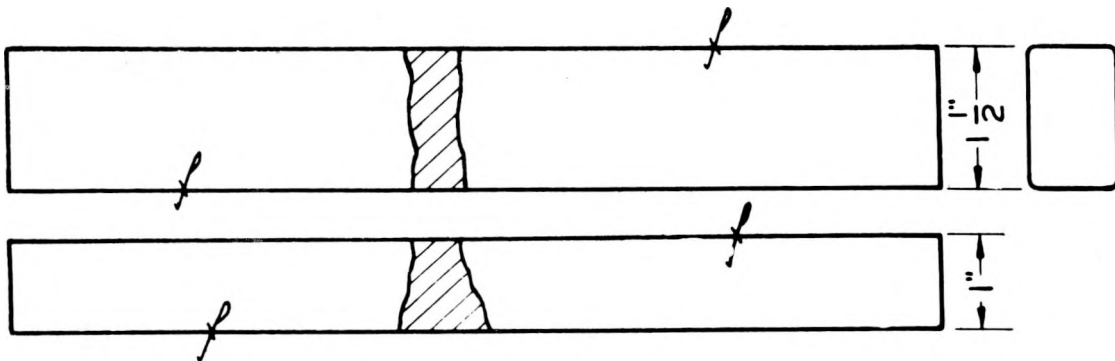
Table 27 Cont'd

2) Two face bend specimens (Tested as free bends)

Sketch 5

Machine light cut on each side (clean up only)

3) Two root bend specimens (As free bend test)

Sketch 6

Machine light cut on each side (clean up only)

4) Two side bend specimens (Guided bend test, 1/2" wide plunger)

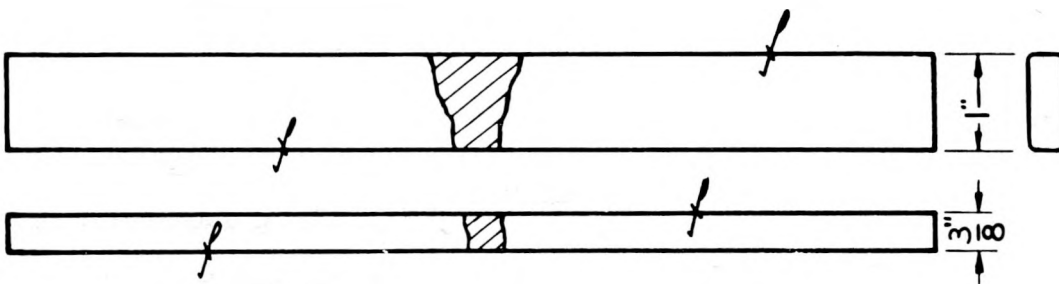
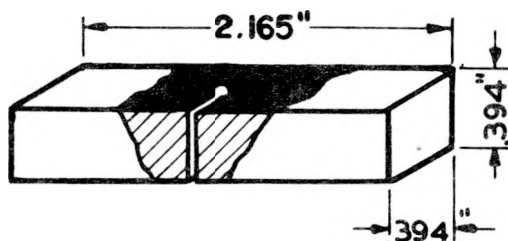
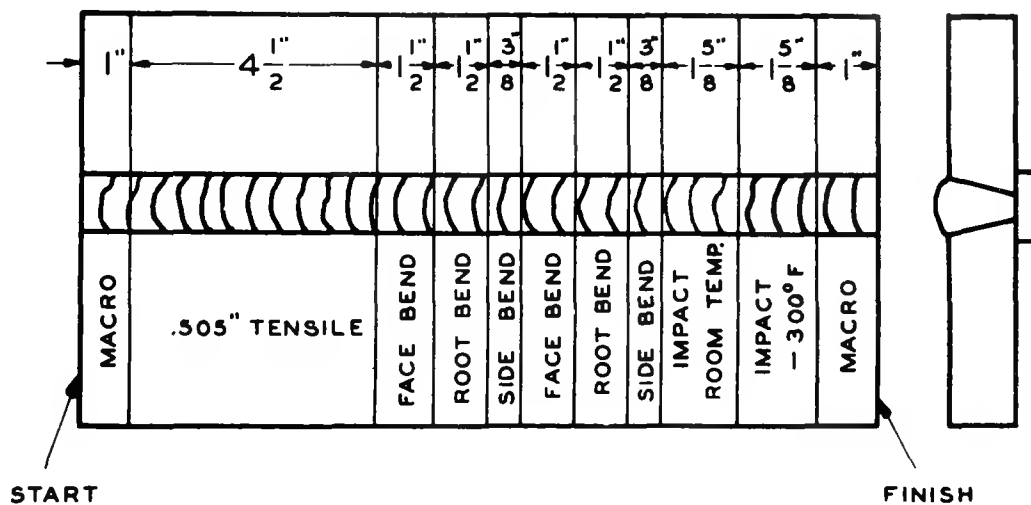
Sketch 7

Table 27 Cont'd

- 5) Three Charpy keyhole impact specimens shall be tested at room temperature and at -300°F . The hole shall be drilled normal to the weld surface, as shown in Sketch 8.

Sketch 8

- 6) Macro specimen for hardness survey from each end of the test plate, with the back-up chill intact. Sketch 9 shows location of specimens.

Sketch 9

Welding Research Laboratory

Approved by: J. J. Chyle

Prepared by: J. P. Koss

JK;hl

Table 28

Pipe Qualification Tests for Welding of Type 347 steels for Atomic Energy Project as recommended by R. Emerson of the Pittsburgh Piping and Equipment Company.

Test to be made in Forged and Bored Pipe 8-5/8" O.D. X 1" wall.

I. Welding Technique

1. Groove Design (see Drawing #1)
2. Position - horizontal fixed
3. Preheat - none
4. Interpass temperature 190°F max.
5. Weave limited to two electrode diameters including coating
6. Crater treatment - grind visible crater defects

II. Non-Destructive Tests

1. Zyglo after 1st pass
2. Zyglo and radiograph finished weld after grinding weld surface (back-up not removed)
3. Zyglo all test specimens prior to testing (bends, etc.)

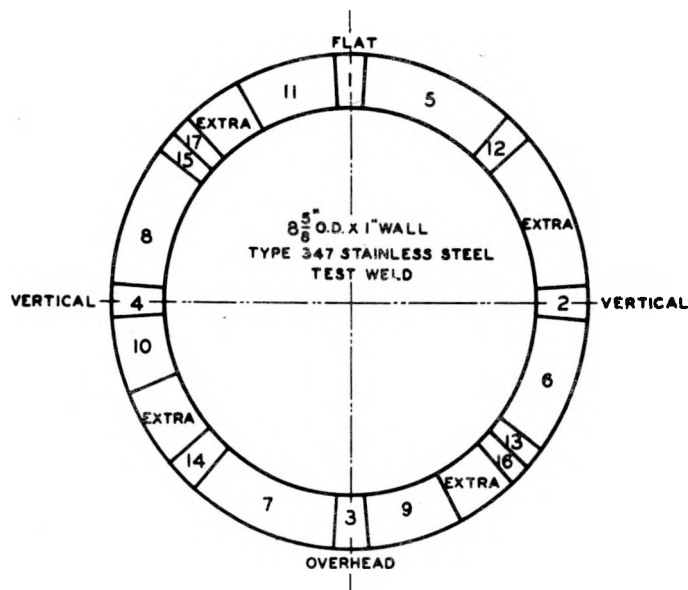
III. Destructive Tests

<u>Type Test</u>	<u>Position of Specimen During Welding*</u>	<u>No. Spec.</u>
Side Bend (guided)	2-vertical, 1-flat, 1-overhead	4
Face Bend (free)	1-flat, 1-vertical	2
Root Bend (free)	1-vertical, 1-overhead	2
Reduced Section Transverse Tensile Test	1-flat, 1-vertical, 1-overhead	3
Macro Sections	Quadrants I, II, III, & IV	4
Micro	To be taken from macro after photographing	

*Exact locations from which specimens were taken are shown in Drawing #2.

Magne gauge readings and a hardness survey shall be made on the macrospecimens.

Table 28 Cont'd



- 1 TO 4 - SIDE BENDS - CUT $\frac{1}{2}$ " TO FINISH $\frac{3}{8}$ "
- 5 AND 8 - FACE BEND - { CUT $\frac{5}{8}$ " TO FINISH $1\frac{1}{2}$ "
- 6 AND 7 - ROOT BEND - {
- 9 TO 11 - REDUCED SECTION TENSILES - CUT $1\frac{1}{2}$ " NO FINISH
- 12 TO 15 - MACRO - SECTION - CUT $\frac{3}{8}$ " TO FINISH $\frac{1}{4}$ "
- 16 AND 17 - MICROSTRUCTURE - CUT $\frac{1}{4}$ " NO FINISH

**TYPE NUMBER AND LOCATION OF SPECIMENS
CUT FROM EXPERIMENTAL TEST WELDS**

Drawing 2

Table 29A

Composition and Designations of Experimental Electrodes*

<u>Composition</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>N₂</u>	<u>Ferrite % Calc.+</u>
A**	19/9Cb	.080	1.55	.017	.012	.44	9.31	19.22	.71	.044	7%
B	19/13Cb	.087	1.49	.017	.013	.33	13.02	19.09	.74	.039	None
C	19/13Cb	.115	1.32	.019	.013	.45	13.06	19.09	.70	.044	None
D	19/9CbTa	.080	1.55	.017	.010	.42	9.27	19.22	.78	.039	7%
F	19/10LC	.036	.73	.021	.018	.26	10.53	18.92	--	.044	4%
H	19/13MnCb	.095	5.04	.024	.012	.37	12.99	18.50	.91	.037	None

* Chemical analysis from non-dilution weld pads made in accordance with AWS-ASTM specifications.
 + Calculated from chemical analysis according to the Schaeffler diagram.
 ** Standard Type 347 composition, recently reclassified by the American Iron and Steel Institute as Type 348.

Table 29B

Composition of Base Metals*

<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>
347	1/2"	.06	1.39	.026	.010	.66	10.51	19.40	.77
304L	1/2"	.024	1.55	.026	.016	.38	9.50	17.76	--

* Mill analysis reports.

Table 30

Boiling 65% Nitric Acid Corrosion Data-
Mils Per Year

(Average of Five 48 Hr. Periods)

Heat Treatment	Code	Composition					
		Partially Ferritic		Fully Austenitic			Low Carbon
		A	D	B	C	H	F
As-Welded	AW	12	10	9	14	12	7
8 hr. 1100F WQ	18	30	24	199(1)	448(1)	262(1)	21
100 hr. 1100F WQ	10	27	28	466(1)	631(1)	661(1)	12
8 hr. 1300F WQ	38	19	14	22	26	19	10
100 hr. 1300F WQ	30	17	13	17	21	19	9
8 hr. 1550F WQ	58	8	8	9	11	12	8
100 hr. 1550F WQ	50	7	7	8	9	10	7
8 hr. 1700F WQ	78	6	6	6	7	10	6
100 hr. 1700F WQ	70	6	6	5	7	8	6
2 hr. 1950F WQ	92	6	7	7	8	12	6
2 hr. 1950F WQ } + 1 hr. 1250F WQ }	92S	12	11	10	18(2)	13	17(1)
1 hr. 1250F WQ	S	27	21	120(1)	254(1)	54(1)	15

The predominant type of corrosion was general in nature unless otherwise noted.

(1) Intergranular attack.

(2) General + intergranular attack.

Table 31

Evidence of Intergranular Attack Revealed by Bending Corrosion
Samples After Boiling 500 Hours in 10% Copper Sulfate - 10% Sulfuric Acid
Solution

Heat-Treatment	Composition					
	Partially Ferritic		Fully Austenitic			Low Carbon
	A	D	B	C	H	F
As-welded	no	no	slight**	slight+	slight+	no
8 hr. 1100°F.WQ	no	no	severe	severe	severe	slight**
100 hr. 1100°F.WQ	no	no	severe	severe	severe	no***
8 hr. 1300°F.WQ	no	no	slight**	severe+	slight**	no
100 hr. 1300°F.WQ	no	no	no**	severe+	slight**	no
8 hr. 1550°F.WQ	no	no	no	no	no	no
100 hr. 1550°F.WQ	no	no	no	no	no	no
8 hr. 1700°F.WQ	no	no	no	no	no	no
100 hr. 1700°F.WQ	no	no	no	no	no	no
2 hr. 1950°F.WQ	no	no	no	no	no	no
2 hr. 1950°F.WQ)	no	no	slight+	slight	slight**	slight*
+1 hr. 1250°F.WQ)						
1 hr. 1250°F.WQ	no	no	slight+	slight+	slight+	no***

* Metallographic examination showed intergranular penetrations of less than one grain in depth.

** Showed one slight intergranular penetration in metallographic examination.

*** Metallographic examination showed no intergranular penetrations.

+ Intergranular attack was not observed when examining the corresponding nitric acid test specimens under a binocular microscope.

Table 32

Chemical Analyses of Weld Metals, Type 308 at Four Carbon Levels

<u>Electrode Diameter, Inches</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>N</u>	<u>Calculated % Ferrite</u>
1/4	.026	1.20	.44	.013	.021	19.70	10.88	.070	5
5/32	.036	.68	.33	.011	.016	18.51	10.63	.048	3
5/32	.047	.73	.33	.015	.015	18.77	10.84	.050	2
5/32	.067	.62	.35	.016	.006	19.45	10.50	.040	4

Table 33

Boiling Nitric-acid Corrosion Data for 18Cr-8Ni Weld
Metal Aged in the As-welded Condition - Penetration in
Mils Per Year (Average of Five 48-Hour Periods)

<u>Hours at</u> <u>Temperature*</u>	<u>Percent Carbon</u>			
	<u>0.026</u>	<u>0.036</u>	<u>0.047</u>	<u>0.067</u>
800°F aging				
1	-	11	-	-
2	-	10	-	-
8	-	10	-	-
100	-	11	-	-
1000	-	48	-	-
850°F aging				
8	-	8	-	-
100	-	28	-	-
1000	-	350	-	-
2500	-	1040	-	-
5000	-	1520	-	-
10000	-	1340	-	-
20000	-	805	-	-
900°F aging				
1	6	11	22	84
2	7	11	50	160
8	6	10	94	226
100	13	108	484	642
500	38	777	-	-
1000	41	1043	-	-
2000	29	1302	-	-
10000	262	435	-	-
1000°F aging				
1	6	26	49	-
2	6	106	101	-
8	20	264	290	-
30	383	-	-	-
100	136	540	435	-
300	16	-	-	-
1000	12	22	-	-
1050°F aging				
1	6	19	101	235
2	7	104	278	373
8	43	288	306	543
100	17	25	156	272
1000	-	16	-	-

Table 33 (Continued)

Hours at Temperature*	Percent Carbon			
	<u>0.026</u>	<u>0.036</u>	<u>0.047</u>	<u>0.067</u>
1100°F aging				
.1	-	12	-	-
.5	-	34	-	-
1	12	31	116	-
2	11	72	206	-
3	14	-	-	-
8	23	24	61	-
100	11	12	38	-
1200°F aging				
.1	-	17	-	-
.2	-	16	-	-
.5	-	17	-	-
1	11	18	18	48
2	10	19	24	41
8	10	16	16	36
100	8	16	16	20
1000	-	12	-	-
1300°F aging				
.1	-	13	-	-
.2	-	12	-	-
.5	-	13	-	-
1	-	13	-	-
2	-	12	-	-
8	-	11	-	-
100	-	11	-	-
1550°F aging				
8	-	8**	-	-
100	-	7**	-	-
1700°F aging				
8	-	6**	-	-
100	-	6**	-	-
1950°F aging				
2	-	6**	-	-

* Water quenched after aging.

** Data from U.S. AEC Report NYO-3499 (see Bibliography).

Table 34

The Effect of Stabilizing Heat Treatments on the Boiling Nitric-acid Corrosion Resistance of 0.036% Carbon 18-8 Weld metal--Penetration in Mils Per Year(Average of Five 48-hr. Periods)

Condition Before Aging	Hours at Temperature ^a									
	<u>0</u>	<u>1</u>	<u>2</u>	<u>8</u>	<u>100</u>	<u>1000</u>	<u>2500</u>	<u>5000</u>	<u>10,000</u>	<u>20,000</u>
As-Welded ^c	7 ^b	-	-	-	-	-	-	-	-	-
850F aging										
As-Welded				8	28	349	1040	1520	1340	805
1300F 12-hr.,AC	-	-	-	12	58	400	316	269	60	56
1200F 15-hr.,AC	-	-	-	14	65	338	328	205	54	58
1100F 24-hr.,AC	-	-	-	48	196	295	156	435	168	80
900F aging ^c										
As-Welded	-	11	11	10	108	1043	-	-	435	-
1200F 12-hr.,AC	-	20	17	25	58	80	-	-	75	-
1000F aging ^c										
As-Welded ^c	-	26	106	264	540	22	-	-	-	-
1200F 8-hr.,AC	-	-	29	36	24	91	-	-	-	-
1200F 12-hr.,AC	-	-	14	16	14	16	-	-	-	-
1300F 8-hr.,AC	-	-	17	22	16	44	-	-	-	-

a Water quenched from the aging temperature.

b Data from U.S. AEC Report NYO-3499(see Bibliography).

c These data also appear in Table 33.

TABLE 35

Effect of Heat Treatments on the Mechanical Properties
of Composition "A" Weld Metal

Elec- trode No.	C	Mn	P	S	Si	Ni	Cr	Cb	% Ferrite Calc.	
7470	.080	1.55	.017	.012	.44	9.31	19.22	.71	7	
Code No.	Condition		YS psi**	TS psi	El. in 2" %	R.A. %	Fissures *			
A1	AW		68,500	95,000	35.0	57.0	-	-	-	-
A2			70,000	97,000	36.0	46.5	-	-	-	-
A181	1100°F 8 hrs.		68,500	98,500	32.0	41.0	-	-	-	-
A182			67,500	98,500	37.0	52.0	-	-	-	-
A101	1100°F 100 hrs.		68,500	99,500	35.0	48.5	-	-	-	-
A102			69,000	99,500	32.0	43.0	-	-	-	1
A381	1300°F 8 hrs.		68,000	100,000	33.0	50.5	-	-	-	1
A382			65,000	97,000	36.0	44.0	-	-	-	-
A301	1300°F 100 hrs.		65,000	104,000	31.0	46.5	-	-	-	-
A302			65,500	102,500	29.0	43.0	-	-	-	-
A581	1550°F 8 hrs.		64,000	98,000	36.0	53.0	-	-	-	-
A582			61,500	96,500	35.0	49.0	-	-	-	-
A501	1550°F 100 hrs.		56,500	94,500	37.0	52.5	-	-	1	-
A502			56,500	94,000	36.0	53.5	-	-	-	-
A781	1700°F 8 hrs.		53,000	92,500	38.0	54.5	-	-	-	1
A782			73,000+	93,000	37.0	52.5	-	-	-	-
A701	1700°F 100 hrs.		56,000	87,500	42.0	54.5	-	-	-	-
A702			46,500	88,500	42.0	53.5	-	-	-	-
A921	1950°F 2 hrs.		44,000	85,500	42.0	55.0	-	-	-	-
A922			43,500	85,000	42.0	52.5	-	-	-	-
A981	1950°F 8 hrs.		42,500	84,000	44.0	53.5	-	-	-	-
A982			42,500	84,000	48.0	56.0	-	-	-	-
A941	1950°F 24 hrs.		41,000	84,000	48.0	54.5	-	-	1	4
A942			41,000	83,000	51.0	55.5	-	-	-	1

+ Disregarded in computing averages for graphs.

* l - large (1/8" and over)
 m - medium (1/16" to 1/8")
 s - small (1/32" to 1/16")
 v.s. - very small (1/32" or less)

** Yield strength measured at .5% extension under load.

TABLE 36

Effect of Heat Treatments on the Mechanical Properties
of Composition "B" Weld Metal

<u>Elec- trode No.</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>% Ferrite Calc.</u>
7471	.087	1.49	.017	.013	.33	13.02	19.09	.74	None
<u>Code No.</u>	<u>Condition</u>	<u>YS psi**</u>	<u>TS psi</u>	<u>El. in 2" %</u>	<u>R.A.%</u>	<u>Fissures *</u>			
B1	AW	58,500	78,000	29.0	39.0	-	-	-	2
B2		58,000	78,500	34.0	46.0	-	-	-	2
B181	1100°F 8 hrs.	59,000	82,500	32.0	29.0	-	-	2	6
B182		60,000	78,000	13.0+	29.5	-	-	6	5
B101	1100°F 100 hrs.	64,000	85,500	30.0	29.5	-	1	-	2
B102		58,000	82,500	38.0	45.5	-	-	1	2
B381	1300°F 8 hrs.	60,500	84,000	23.0	23.0	-	-	2	6
B382		62,500	85,000	19.0	31.0	-	-	2	14
B301	1300°F 100 hrs.	61,000	87,000	25.0	31.0	-	-	-	4
B302		60,000	86,000	25.0	24.5	-	-	1	11
B581	1550°F 8 hrs.	53,500	83,000	29.0	27.0	-	1	1	9
B582		55,000	85,000	28.0	21.0	-	-	1	7
B501	1550°F 100 hrs.	48,500	80,000	28.0	27.0	-	-	-	1
B502		49,000	81,000	29.0	28.5	-	-	4	4
B781	1700°F 8 hrs.	46,000	78,000	23.0	30.5	-	-	3	6
B782		47,000	80,500	37.0	44.0	-	1	1	11
B701	1700°F 100 hrs.	42,500	77,000	32.0	35.5	-	-	1	5
B702		41,500	76,500	27.0	28.0	-	-	-	5
B921	1950°F 2 hrs.	38,500	74,500	42.0	45.0	-	-	-	6
B922		39,000	74,500	43.0	47.5	-	-	1	6
B981	1950°F 8 hrs.	37,500	73,500	38.0	32.5	-	-	-	10
B982		37,000	73,000	36.0	37.5	-	-	-	-
B941	1950°F 24 hrs.	38,500	72,500	45.0	48.0	-	-	-	5
B942		32,500	75,500	55.0	53.5	-	-	-	3

+ * ** See footnote Table 35

TABLE 37

Effect of Heat Treatments on the Mechanical Properties
of Composition "C" Weld Metal

Elec- trode No.	C	Mn	P	S	Si	Ni	Cr	Cb	% Ferrite Calc.
7472	.115	1.32	.019	.013	.45	13.06	19.09	.70	None
Code No.	Condition	YS psi**	TS psi	El. in 2' %	R.A. %	Fissures *			
						l	m	s	v.s.
C1	AW	63,000	83,500	40.0	56.0	-	-	-	1
C2		64,000	84,500	37.0	51.0	-	-	-	1
C181	1100°F 8 hrs.	63,000	86,000	40.0	45.0	-	-	3	6
C182		62,500	85,500	29.0	29.0	-	-	-	3
C101	1100°F 100 hrs.	63,500	87,000	38.0	43.5	-	-	-	6
C102		65,000	87,500	33.0	32.0	-	-	-	4
C381	1300°F 8 hrs.	64,500	88,000	31.0	39.5	-	-	-	3
C382		65,000	89,500	31.0	39.0	-	-	-	4
C301	1300°F 100 hrs.	62,500	89,500	24.0	28.0	-	-	-	4
C302		63,500	90,000	28.0	40.0	-	-	1	4
C581	1550°F 8 hrs.	58,000	86,000	23.0+	29.0	-	-	1	4
C582		59,500	86,500	32.0	36.6	-	-	2	12
C501	1550°F 100 hrs.	52,500	83,500	31.0	32.0	-	-	-	6
C502		52,500	84,500	33.0	37.5	-	-	-	7
C781	1700°F 8 hrs.	49,500	82,500	36.0	45.0	-	1	1	2
C782		49,000	82,500	35.0	39.0	-	-	-	5
C701	1700°F 100 hrs.	44,000	80,000	38.0	46.5	-	-	-	1
C702		44,000	80,500	36.0	43.5	-	-	-	2
C921	1950°F 2 hrs.	40,000	77,000	38.0	36.5	-	-	2	4
C922		39,500	77,000	45.0	46.0	-	-	-	5
C981	1950°F 8 hrs.	40,500	76,000	44.0	46.0	-	-	-	3
C982		39,000	76,500	44.0	40.5	-	-	1	4
C941	1950°F 24 hrs.	37,000	76,000	45.0	49.0	-	-	-	1
C942		37,500	75,000	46.0	47.5	-	-	-	3

+ * ** See footnote Table 35

TABLE 38

Effect of Heat Treatments on the Mechanical Properties
of Composition "D" Weld Metal

Elec- trode No.	C	Mn	P	S	Si	Ni	Cr	Cb+Ta	% Ferrite Calc.	
7473	.080	1.55	.017	.010	.42	9.27	19.22	.78	7	
Code No.	Condition	YS psi**	TS psi	El. in		R.A. %	Fissures *			
				2"	%		l	m	s	v.s.
D1	AW	79,000	107,500	37.0	46.5	-	-	-	-	
D2		71,000	97,000	37.0	55.5	-	-	-	-	
D181	1100°F 8 hrs.	70,000	100,000	34.0	45.0	-	-	-	5	
D182		70,000	100,000	34.0	49.0	-	-	-	3	
D101	1100°F 100 hrs.	74,000	101,500	33.0	48.0	-	-	-	1	
D102		70,000	101,000	34.0	47.0	-	-	-	1	
D381	1300°F 8 hrs.	70,000	99,000	34.0	48.5	-	-	-	3	
D382		68,000	100,000	31.0	46.5	-	-	-	2	
D301	1300°F 100 hrs.	66,000	105,500	27.0	36.5	-	-	-	2	
D302		66,000	105,000	29.0	37.5	-	-	-	1	
D581	1550°F 8 hrs.	62,000	99,000	35.0	52.5	-	-	-	-	
D582		60,500	97,500	35.0	49.0	-	-	-	1	
D501	1550°F 100 hrs.	53,000	94,000	39.0	55.0	-	-	-	1	
D502		55,000	94,000	39.0	56.0	-	-	-	1	
D781	1700°F 9 hrs.	52,500	93,000	37.0	55.5	-	-	-	2	
D782		52,500	91,500	39.0	59.0	-	-	-	1	
D701	1700°F 100 hrs.	47,500	87,500	41.0	53.0	-	-	-	2	
D702		47,000	87,500	40.0	57.5	-	-	-	1	
D921	1950°F 2 hrs.	43,500	87,000	47.0	55.0	-	-	-	2	
D922		43,500	86,500	44.0	54.0	-	-	-	-	
D941	1950°F 8 hrs.	41,000	84,500	46.0	52.5	-	-	-	3	
D942		41,500	85,000	45.5	54.0	-	-	-	2	
D981	1950°F 24 hrs.	43,000	86,000	42.0	44.0	-	-	-	1	
D982		42,000	86,500	47.0	55.5	-	-	-	2	

* ** See footnote Table 35

Table 39

Effect of Heat Treatments on the Mechanical Properties
of Composition "H" Weld Metal

<u>Elec- trode No.</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>% Ferrite Calc.</u>
7475	.095	5.04	.024	.012	.37	12.99	18.50	.91	None
<u>Code No.</u>	<u>Condition</u>	<u>YS psi**</u>	<u>TS psi</u>	<u>El. in 2" %</u>	<u>R.A.%</u>	<u>Fissures *</u>			
						<u>l</u>	<u>m</u>	<u>s</u>	<u>v.s.</u>
H1	AW	61,000	80,500	39.0	51.0	-	-	-	-
H2		59,000	79,500	39.0	59.0	-	-	-	-
H181	1100°F 8 hrs.	60,500	83,500	35.0	41.0	-	-	-	3
H182		60,000	83,000	34.0	32.0	-	1	1	6
H101	1100°F 100 hrs.	63,000	86,000	33.0	28.5+	-	1	2	2
H102		63,500	85,500	37.0	43.5	-	-	-	3
H381	1300°F 8 hrs.	62,500	85,500	37.0	47.0	-	-	-	4
H382		62,500	85,000	28.0	31.0	-	-	1	2
H301	1300°F 100 hrs.	59,000	85,000	34.0	39.0	-	-	-	4
H302		61,000	85,500	28.0	36.0	-	-	-	8
H581	1550°F 8 hrs.	55,000	83,000	36.0	42.5	-	-	1	2
H582		54,500	84,000	26.0	29.0	-	-	1	4
H501	1550°F 100 hrs.	45,000	80,500	29.0	29.0	-	-	2	3
H502		45,500	79,500	30.0	27.0	-	-	1	4
H781	1700°F 8 hrs.	44,000	77,500	38.0	47.0	-	-	-	2
H782		44,000	78,000	39.0	50.5	-	1	-	6
H701	1700°F 100 hrs.	40,000	76,000	40.0	45.5	-	-	-	1
H702		49,000	61,500+	39.0	37.5	-	-	1	4
H921	1950°F 2 hrs.	39,000	75,000	44.0	47.0	-	-	-	-
H922		38,000	74,000	45.0	50.5	-	-	-	2
H981	1950°F 8 hrs.	37,000	73,500	45.0	43.5	-	-	1	2
H982		37,500	74,500	47.0	49.5	-	-	2	3
H941	1950°F 24 hrs.	34,500	72,000	46.0	49.0	-	-	1	2
H942		36,500	73,000	48.0	49.5	-	-	-	3

+ * ** See footnote Table 35

TABLE 10

Effect of Heat Treatments on the Mechanical Properties
of Composition "F" Weld Metal

<u>Elec- trode No.</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>% Ferrite Calc.</u>
7474	.036	.73	.021	.018	.26	10.53	18.92	--	4
<u>Code No.</u>	<u>Condition</u>	<u>YS psi**</u>	<u>TS psi</u>	<u>El. in 2" %</u>	<u>R.A.%</u>	<u>Fissures *</u>			
F1	AW	53,000	79,500	50.0	54.5	-	-	-	-
F2		54,000	79,500	45.0	63.0	-	-	-	-
F181	1100°F 8 hrs.	46,000	81,500	47.0	43.0	-	-	-	-
F182		47,000	80,000	40.0	48.0	-	-	-	1
F101	1100°F 100 hrs.	44,500	78,500	41.0	48.5	-	-	-	-
F102		43,500	78,500	50.0	52.5	-	-	-	-
F381	1300°F 8 hrs.	49,500	79,000	48.0	52.5	-	-	-	1
F382		40,000	79,000	46.0	46.5	-	-	-	1
F301	1300°F 100 hrs.	38,000	80,000	48.0	54.0	-	-	-	-
F302		54,000	81,500	49.0	50.0	-	-	-	2
F581	1550°F 8 hrs.	48,500	80,500	50.0	54.5	-	-	-	-
F582		37,500	79,000	48.0	56.0	-	-	-	1
F501	1550°F 100 hrs.	37,000	76,500	52.0	57.0	-	-	-	2
F502		36,500	77,500	48.0	44.5	-	-	-	-
F781	1700°F 8 hrs.	37,000	76,500	52.0	51.0	-	-	-	-
F782		37,500	78,000	51.0	48.5	-	-	-	-
F701	1700°F 100 hrs.	36,500	74,500	53.0	50.5	-	-	-	-
F702		36,000	75,000	53.0	56.5	-	-	-	1
F921	1950°F 2 hrs.	34,000	76,000	55.0	47.5	-	-	-	-
F922		34,000	74,500	37.0+	41.0	1	-	2	3
F981	1950°F 8 hrs.	33,000	75,500	56.0	52.0	-	-	-	-
F982		34,000	75,500	57.0	52.5	-	-	1	1
F941	1950°F 24 hrs.	35,000	71,000	31.0+	28.0+	-	-	1	8
F942		32,500	75,500	57.0	51.0	-	-	-	1

+ * ** See footnote Table 35

TABLE 41A

Composition and Designations of Experimental Electrodes*

<u>Composition</u>	<u>Type</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>	<u>Ferrite % (Calc)+</u>
A**	19/9Cb	.080	1.55	.017	.012	.44	9.31	19.22	.71	7%
B	19/13Cb	.087	1.49	.017	.013	.33	13.02	19.09	.74	None
C	19/13Cb	.115	1.32	.019	.013	.45	13.06	19.09	.70	None
D	19/9CbTa	.080	1.55	.017	.010	.42	9.27	19.22	.78	7%
F	19/10LC	.036	.73	.021	.018	.26	10.53	18.92	--	4%
H	19/13MnCb	.095	5.04	.024	.012	.37	12.99	18.50	.91	None

* Chemical analyses from weld pads made in accordance with ASTM-AWS specifications

+ Calculated from chemical analysis according to the Schaeffler diagram

** Standard Type 347 composition

TABLE 41B

Composition of Base Metals*

<u>Type</u>	<u>Thickness</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb+Ta</u>
347	1/2"	.06	1.39	.026	.010	.66	10.51	19.40	.77
304L	1/2"	.024	1.55	.026	.016	.38	9.50	17.76	--

* Mill Reports

TABLE 42

Effect of Various Heat Treatments on the Notched Bar Impact
Strength of Composition A Weld Deposit

		Composition							
	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>% Ferrite Calc.</u>
	.08	1.55	.017	.012	.44	9.31	19.22	.71	7
		Charpy Keyhole Impact Values							
Code	Condition	Tested at Room Temperature			Tested at -320°F				
		Dev.+	Ft.-Lbs.	Ave.	Dev.+	Ft.-Lbs.	Ave.		
A-AW	As Welded	2	22		1	9.5			
		2	20.5		2	10			
		3	20.5	21	*	*	9.7		
A-18	1100°F 8 hrs. W.Q.	1	24		3	12.5			
		0	21.5		3	15			
		4	22.5	22.7	3	16.5	14.7		
A-10	1100°F 100 hrs. W.Q.	0	20		3	14.5			
		1	20.5		3	12.5			
		2	20	20.2	2	15	14		
A-38	1300°F 8 hrs. W.Q.	1	18		2	7			
		2	17		0	9			
		2	18.5	17.8	0	9	8.3		
A-30	1300°F 100 hrs. W.Q.	3	8.5		0	5.5			
		1	9.5		0	3			
		*	*	9	0	4	4.2		
A-58	1550°F 8 hrs. W.Q.	3	25		*	*			
		3	20		*	*			
		0	28.5	24.5	*	*			
A-50	1550°F 100 hrs. W.Q.	2	24		1	19.5			
		3	24		0	18			
		2	24.5	24.2	1	20.5	19.3		
A-78	1700°F 8 hrs. W.Q.	0	28		0	14			
		5	26		0	22.5			
		4	29	27.7	2	17.5	18		
A-70	1700°F 100 hrs. W.Q.	0	24		2	24			
		0	28.5		2	16			
		2	30	27.5	*	*	20		
A-92	1950°F 2 hrs. W.Q.	1	28.5		3	21			
		2	31.5		2	24.5			
		1	24.5	28.2	2	28	24.5		
A-98	1950°F 8 hrs. W.Q.	4	33.5		0	19.5			
		2	32		0	21.5			
		4	26.5	30.7	*	*	20.5		
A-94	1950°F 24 hrs. W.Q.	3	32		*	*			
		*	*		*	*			
		*	*	32	*	*			

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.

* No samples available.

TABLE 43

Effect of Various Heat Treatments on the Notched Bar Impact
Strength of Composition B Weld Deposits

		Composition						% Ferrite Calc.
C	Mn	P	S	Si	Ni	Cr	Cb	
.087	1.49	.017	.013	.33	13.02	19.09	.74	None
		Charpy Keyhole Impact Values						
Code	Condition	Tested at Room Temperature			Tested at -320°F			
		Dev.+	Ft.-Lbs.	Ave.	Dev.+	Ft.-Lbs.	Ave.	
B-AW	As Welded	2	21.5		1	8		
		3	33		1	9.5		
		3	20.5	25	2	16	11.2	
B-18	1100°F 8 hrs. W.Q.	1	23		3	16		
		4	22.5		3	18		
		2	17	20.8	2	9	14.3	
B-10	1100°F 100 hrs. W.Q.	1	22		0	8		
		1	20		1	9.5		
		4	17	19.7	0	7	8.2	
B-38	1300°F 8 hrs. W.Q.	1	17		0	9		
		1	19		3	14.5		
		2	18	18	3	14.5	12.7	
B-30	1300°F 100 hrs. W.Q.	2	12.5		2	14		
		3	17.5		2	12		
		2	14	14.7	3	12.5	12.8	
B-58	1550°F 8 hrs. W.Q.	3	14		1	**		
		0	18		1	11		
		0	19	17	1	7.5	9.2	
B-50	1550°F 100 hrs. W.Q.	0	**		2	9.5		
		2	23.5		2	10		
		3	17	20.2	3	15***	9.7	
B-78	1700°F 8 hrs. W.Q.	0	29		2	11.5		
		3	22		2	14		
		3	23	24.7	2	14.5	13.3	
B-70	1700°F 100 hrs. W.Q.	3	22		0	13.5		
		1	22		0	12.5		
		2	25	23	*	*	13	
B-92	1950°F 2 hrs. W.Q.	2	23		3	17.5		
		2	18.5		0	11.5		
		1	21.5	21	0	10.5	13.2	
B-98	1950°F 8 hrs. W.Q.	0	28		3	20.5		
		1	27		0	12.5		
		3	24.5	26.5	3	18	17	
B-94	1950°F 24 hrs. W.Q.	2	29		*	*		
		0	25		*	*		
		*	*	27	*	*		

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.

* No samples available.

** No reading.

*** Poor notch.

Table 44

Effect of Various Heat Treatments on the Notched Bar Impact
Strength of Composition C Weld Deposits

Composition								
C	Mn	P	S	Si	Ni	Cr	Cb	% Ferrite Calc.
.115	1.32	.019	.013	.45	13.06	19.09	.70	None
Charpy Keyhole Impact Values								
Code	Condition	Tested at Room Temperature			Tested at -320°F			
		Dev.+	Ft.-Lbs.	Ave.	Dev.+	Ft.-Lbs.	Ave.	
C-AW	As Welded	4	21		2	10		
		2	18		2	7		
		1	20.5	19.8	0	9	8.7	
C-18	1100°F 8 hrs. W.Q.	2	22		1	**		
		1	21		0	6.5		
		2	19	20.7	0	9	7.7	
C-10	1100°F 100 hrs. W.Q.	2	17		0	7		
		3	19		1	7		
		4	19.5	18.5	1	8	7.3	
C-38	1300°F 8 hrs. W.Q.	1	24.5		3	12.5		
		3	16		2	11.5		
		1	21	20.5	0	7	10.3	
C-30	1300°F 100 hrs. W.Q.	2	14.5		1	6		
		2	13.5		1	4.5		
		4	13.5	13.8	1	5.5	5.3	
C-58	1550°F 8 hrs. W.Q.	2	17.5		2	12		
		3	16		3	14		
		2	16	16.5	2	9	11.7	
C-50	1550°F 100 hrs. W.Q.	3	18		1	9		
		0	20.5		1	7		
		2	18.5	19	1	7	7.7	
C-78	1700°F 8 hrs. W.Q.	1	19.5		2	15		
		2	21		2	15		
		2	20	20.2	2	16.5	15.5	
C-70	1700°F 100 hrs. W.Q.	5	26		1	10		
		0	23		2	15		
		0	26.5	25.2	2	10	11.7	
C-92	1950°F 2 hrs. W.Q.	1	18		2	9.5		
		1	22		2	15		
		2	19.5	19.8	2	15.5	13.3	
C-98	1950°F 8 hrs. W.Q.	4	31		2	15.5		
		2	30.5		2	15.5		
		2	29	30.2	0	11	14	
C-94	1950°F 24 hrs. W.Q.	2	28		*	*		
		4	30		*	*		
		1	25.5	27.8	*	*		

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.

* No samples available.

** No reading.

TABLE 45

Effect of Various Heat Treatments on the Notched Bar Impact
Strength of Composition D Weld Deposits

		Composition								
		C	Mn	P	S	Si	Ni	Cr	Cb+Ta	% Ferrite Calc.
		.080	1.55	.017	.010	.42	9.27	19.22	.78	7
		Charpy Keyhole Impact Values								
Code	Condition	Tested at Room Temperature			Tested at -320°F					
		Dev.+	Ft.-lbs.	Ave.	Dev.+	Ft.-lbs.	Ave.			
D-AW	As Welded	1	24		2	11				
		8	27		2	11				
		6	25	25.3	2	16.5	12.8			
D-18	1100°F 8 hrs. W.Q.	2	21		0	9				
		2	20		0	9.5				
		3	23.5	21.5	1	9.5	9.3			
D-10	1100°F 100 hrs. W.Q.	1	21		2	11				
		6	19.5		2	12.5				
		5	19.5	20	2	11	11.5			
D-38	1300°F 8 hrs. W.Q.	4	13.5		1	6.5				
		2	12.5		0	5				
		2	14.5	13.5	0	5	5.5			
D-30	1300°F 100 hrs. W.Q.	1	12		3	9				
		1	15.5		3	9				
		1	7	11.5	*	*	9			
D-58	1550°F 8 hrs. W.Q.	3	25		0	16.5				
		1	32		1	20				
		5	30.5	29.2	0	17	17.8			
D-50	1550°F 100 hrs. W.Q.	3	26.5		0	14.5				
		3	24.5		2	15				
		3	29.5	26.8	0	16.5	15.3			
D-78	1700°F 8 hrs. W.Q.	3	28		0	14.5				
		4	32		2	14.5				
		4	27.5	29.2	0	18	15.7			
D-70	1700°F 100 hrs. W.Q.	2	30.5		2	23				
		2	28.5		0	22.5				
		*	*	29.5	*	*	22.7			
D-92	1950°F 2 hrs. W.Q.	2	33.5		2	23.5				
		0	32.5		2	27.5				
		4	29	31.7	*	*	25.5			
D-98	1950°F 8 hrs. W.Q.	2	30		3	26				
		2	32		2	17.5				
		1	34	32	0	20	21.2			
D-94	1950°F 24 hrs. W.Q.	0	33.5		*	*				
		1	34.5		*	*				
		*	*	34	*	*				

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.
* No samples available.

TABLE 46

Effect of Various Heat Treatments on the Notched Bar Impact
Strength of Composition H Weld Deposits

		<u>Composition</u>							<u>% Ferrite Calc.</u>	
	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>		
	.095	5.04	.024	.012	.37	12.99	18.50	.91	None	
		<u>Charpy Keyhole Impact Values</u>								
<u>Code</u>	<u>Condition</u>	<u>Tested at Room Temperature</u>			<u>Tested at -320°F</u>					
		<u>Dev.+</u>	<u>Ft.-Lbs.</u>	<u>Ave.</u>	<u>Dev.+</u>	<u>Ft.-Lbs.</u>	<u>Ave.</u>			
H-AW	As Welded	3	22		0	6.5				
		2	18		1	7.5				
		4	20	20	2	9			7.7	
H-18	1100°F 8 hrs. W.Q.	4	20.5		3	14				
		2	20.5		3	14.5				
		4	16.5	19.2	3	15			14.5	
H-10	1100°F 100 hrs. W.Q.	3	19		2	12.5				
		1	19.5		2	13				
		2	21.5	20	*	*			12.7	
H-38	1300°F 8 hrs. W.Q.	1	19		2	14				
		4	17		2	9.5				
		0	16	17.3	2	8			10.5	
H-30	1300°F 100 hrs. W.Q.	3	12		2	11.5				
		1	16.5		2	13.5				
		1	14	14.1	*	*			12.5	
H-58	1550°F 8 hrs. W.Q.	4	21		1	11.5				
		4	18		1	7				
		4	20.5	19.8	0	9.5			9.3	
H-50	1550°F 100 hrs. W.Q.	2	23		0	14.5				
		3	20.5		0	10				
		2	24	22.5	0	9			11.2	
H-78	1700°F 8 hrs. W.Q.	5	25		2	11				
		0	23.5		2	16.5				
		0	23.5	24	2	12.5			13.3	
H-70	1700°F 100 hrs. W.Q.	3	19		2	19.5				
		0	20.5		2	15.5				
		2	20	19.8	2	17.5			17.5	
H-92	1950°F 2 hrs. W.Q.	6	32		0	14				
		6	22.5		1	10				
		2	27	27.2	0	9.5			11.2	
H-98	1950°F 8 hrs. W.Q.	4	27.5		1	13.5				
		5	26.5		1	11.5				
		6	26	26.7	3	16			13.7	
H-94	1950°F 24 hrs. W.Q.	2	28		*	*				
		2	21.5		*	*				
		*	*	24.7	*	*				

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.

* No samples available.

TABLE 47

Effect of Various Heat Treatments on the Notched Bar Impact Strength
of Composition F Weld Deposits

		<u>Composition</u>						
<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Cb</u>	<u>% Ferrite Calc.</u>
.036	.73	.021	.018	.26	10.53	18.92	--	4
		<u>Charpy Keyhole Impact Values</u>						
<u>Code</u>	<u>Condition</u>	<u>Tested at Room Temperature</u>			<u>Tested at -320°F</u>			
		<u>Dev.+</u>	<u>Ft.-Lbs.</u>	<u>Ave.</u>	<u>Dev.+</u>	<u>Ft.-Lbs.</u>	<u>Ave.</u>	
F-AW	As Welded	2	24.5		3	28.5		
		1	26		3	24.5		
		1	25	25.2	3	28.5	27.2	
F-18	1100°F 8 hrs. W.Q.	1	25		1	13		
		3	29		1	14		
		3	25.5	26.5	1	17	14.7	
F-10	1100°F 100 hrs. W.Q.	5	32.5		0	14.5		
		2	26.5		3	22.5		
		1	36	31.7	3	13	16.7	
F-38	1300°F 8 hrs. W.Q.	2	34		1	17		
		3	28.5		2	20.5		
		3	34	32.2	0	17	18.2	
F-30	1300°F 100 hrs. W.Q.	4	32		2	24		
		5	35.5		0	14.5		
		2	33	33.5	0	20	19.5	
F-58	1550°F 8 hrs. W.Q.	2	38		2	27.5		
		3	31.5		2	29.5		
		3	31.5	33.7	1	23.5	26.8	
F-50	1550°F 100 hrs. W.Q.	2	35		1	26		
		0	35.5		0	26		
		3	31.5	34	1	22.5	24.8	
F-78	1700°F 8 hrs. W.Q.	1	37		2	27.5		
		2	39.5		0	25.5		
		3	40	38.8	1	21	24.7	
F-70	1700°F 100 hrs. W.Q.	2	44		3	34		
		6	42.5		3	41.5		
		*	*	43.3	0	26.5	34.0	
F-92	1950°F 2 hrs. W.Q.	0	36		2	19		
		6	34.5		1	29.5		
		4	31.5	34	1	29.5	26	
F-98	1950°F 8 hrs. W.Q.	0	39.5		2	35		
		2	36		2	28		
		4	35	36.8	2	31.5	31.5	

+ Deviation in 1/64 in. from standard ASTM distance from notch to end of specimen.

* No samples available.

TABLE 48

Comparison of INCO Data with Impact Values Obtained at Arcos and Crane

<u>Electrode Composition</u>	<u>Charpy Keyhole Impact Strength - Ft.-Lbs.</u>						
	<u>Average Values, As-welded</u>					<u>Average Values</u>	
	<u>Room Temperature</u>			<u>-320°F</u>		<u>-300°F</u>	
	<u>INCO</u>	<u>CRANE</u>	<u>ARCOS</u>	<u>INCO</u>	<u>CRANE</u>	<u>INCO</u>	<u>ARCOS</u>
A (Partially ferritic)	21	21	26	10	12	9	10
B (Fully austenitic)	25	19	24	11	12	15	16
C (Fully austenitic)	20	20	20	9	10	14	15
D (Partially ferritic)	25	25	--	13	17	12	--
F (Type 308L)	25	28	--	27	22	34	--
H (Fully austenitic)	20	20	20	8	10	14	15

Table 49

Chemical Analyses

Undiluted Weld Metals
All Electrodes Were 5/32" Diameter

<u>Comp.</u>	<u>Sample No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>	<u>Mo</u>	<u>N</u>	<u>Calc. Ferrite</u>	<u>Severn Ferrite</u>
A	7470	.080	1.55	.44	.012	.017	19.22	9.31	.71	-	.044	7%	9-10%
C	7472	.115	1.32	.45	.013	.019	19.09	13.06	.70	-	.044	-	-
C	10604	.110	1.30	.39	.009	.017	18.82	12.83	.65	-	.046	-	-
C	10795	.111	1.33	.43	.016	.013	19.00	12.85	.74	-	.044	-	-
F	9616	.036	.68	.33	.011	.016	18.51	10.63	-	-	.053	3%	3-5%
F	10467	.033	.68	.36	.012	.017	18.58	10.58	-	-	.043	3%	3-5%
H	9716	.088	4.94	.39	.014	.016	18.24	12.44	1.00	-	.074	-	-
H	10897	.077	5.00	.42	.009	.013	18.46	12.40	1.02	-	.032	-	-
16-8-2	9904	.067	1.92	.20	.005	.021	15.84	7.83	-	1.92	.046	4%	1-3%

Plate Materials (Mill Analyses)

<u>Type</u>	<u>Supplier</u>	<u>Heat No.</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>	<u>N</u>
304L*	G. O. Carlson	65170-1A	.022	1.00	.57	.018	.025	18.50	9.21	-	.028
347*	G. O. Carlson	46767-2B	.054	1.77	.71	.025	.027	18.37	11.45	.85	.010

* Used for transverse stress rupture tests.

Table 49 (Continued)

<u>Sample Numbers of Electrodes Which Were Used in Specific Tests</u>				
<u>Comp.</u>	<u>Elevated Temperature Tensile</u>	<u>All-Weld-Metal Stress Rupture</u>	<u>Transverse Stress Rupture</u>	<u>R.P.I. Hot Ductility</u>
A	7470	7470	7470	7470
C	7472	7472 except for C53 (10604) and C54, C55, C56, C57 (10795)	7472	7472
F	9616	9616 except for F51, F53 (10467)	9616	9616
H	9716	9716 except for H58, H59 (10897)	9716	9716
16-8-2	9904	-	-	-

Table 50
Elevated Temperature Tensile Test Data
 (All-weld-metal specimens tested in the as-welded condition)

<u>Comp. & No.</u>	<u>Temp., F</u>	<u>U.T.S., Ksi</u>		<u>El. %, 2"</u>		<u>% R.A.</u>		<u>% Ferrite After Testing*</u>
			<u>Avg.</u>		<u>Avg.</u>		<u>Avg.</u>	
A-1,A-2	1000	68.1,65.1	66.6	24,23	24	47,49	48	9-10
C-1,C-2	1000	63.5,63.0	63.2	28,33	30	49,50	49	-
F-1,F-2	1000	51.8,51.5	51.6	30,28	29	48,54	51	3-5
H-1,H-2	1000	58.5,57.1	57.8	29,29	29	42,48	45	-
16-8-2,W-7	1000	63.1	63.1	28	28	50	50	1-3
A-3,A-4	1100	60.1,61.0	60.6	21,21	21	46,45	46	7-9
C-3,C-4	1100	59.0,60.0	59.5	26,26	26	43,46	44	-
F-3,F-4	1100	44.5,44.5	44.5	28,31	29	54,55	54	1-3
H-1R,H-3,H-4	1100	52.8,55.7,56.0	54.8	28,25,27	27	50,32,47	43	-
16-8-2,W-8	1100	58.0	58.0	29	29	53	53	1-3
A-5,A-6	1200	55.0,55.0	55.0	20,21	20	42,42	42	5-7
C-5,C-6	1200	56.0,56.0	56.0	26,27	26	45,47	46	-
F-5,F-6	1200	39.3,38.5	38.9	28,38	33	50,52	51	1-3
H-5,H-6	1200	51.8,53.1	52.4	26,28	27	50,47	48	-
16-8-2,W-9	1200	49.6	49.6	31	31	54	54	1-3
A-7,A-8	1300	49.2,48.0	48.6	26,23	24	39,32	36	3-5
C-7,C-8	1300	49.0,47.5	48.2	27,29	28	38,44	41	-
F-7,F-8	1300	32.0,31.8	31.9	32,29	30	40,47	43	1-3
H-2R,H-7,H-8	1300	45.0,46.1,46.5	45.9	22,32,28	27	39,42,46	42	-
16-8-2,W-10	1300	39.5	39.5	48	48	61	61	1-3
A-9,A-10	1400	43.2,40.7	42.0	15,11	13	20,18	19	5-7
C-9,C-10	1400	40.5,41.4	41.0	30,31	30	46,45	45	-
F-9,F-10	1400	23.2,23.5	23.4	23,27	25	49,23	36	0-1
H-9,H-10	1400	39.0,38.9	39.0	34,34	34	40,52	46	-
16-8-2,W-11	1400	31.9	31.9	58	58	61	61	1-3

Table 50 (Continued)

Comp. & No.	Temp., F	U.T.S., Ksi		El. %, 2"		% R.A.		% Ferrite After Testing*
			Avg.		Avg.		Avg.	
A-11,A-12	1500	34.5,34.5	34.5	9,8	8	15,16	15	5-7
C-11,C-12	1500	35.0,35.8	35.4	27,23	25	39,42	41	-
F-11,F-12	1500	18.0,19.0	18.5	15,15	15	23,20	21	0-1
H-11,H-12	1500	36.5,33.8	35.2	38,33	36	48,49	49	-
16-8-2,W-1	1500	25.0	25.0	53	53	55	55	1-3
A-13,A-14	1600	27.4,27.8	27.6	3,3	3	5,6	6	5-7
C-13,C-14	1600	29.1,30.2	29.6	7,14	10	22,35	28	-
F-13,F-14	1600	13.5,15.0	14.2	8,6	7	12,11	12	0-1
H-13,H-14	1600	26.9,27.0	27.0	21,22	22	40,41	40	-
16-8-2,W-2	1600	19.9	19.9	44	44	47	47	0-1
A-15,A-16	1700	24.3,23.7	24.0	2,3	2	4,6	5	5-7
C-15,C-16	1700	26.2,26.1	26.2	5,9	7	17,22	20	-
F-15,F-16	1700	11.2,12.2	11.7	8,10	9	11,10	11	0-1
H-15,H-16	1700	22.1,23.0,23.7	22.9	12,12,15	13	32,28,30	31	-
16-8-2,W-3	1700	15.9	15.9	27	27	24	24	0-1
A-17,A-18	1800	20.1,20.3	20.2	4,0	2	6,4	5	3-5
C-17,C-18	1800	21.0,20.5	20.8	8,6	7	18,17	17	-
F-17,F-18	1800	9.5,9.7	9.6	7,8	8	12,10	11	0-1
H-17,H-18	1800	15.9,17.2,17.2	16.8	16,20,13	16	21,30,30	27	-
16-8-2,W-4	1800	11.1	11.1	21	21	22	22	0-1
A-19,A-20	1900	16.4,13.6	15.0	5,2	4	1,3	2	1-3
C-19,C-20	1900	15.6,16.0	15.8	5,12	8	14,18	16	-
F-19,F-20	1900	7.5,8.3	7.9	10,10	10	9,13	11	0-1
H-19,H-20	1900	12.8,12.7	12.8	16,15	16	26,27	27	-
16-8-2,W-6	1900	6.9	6.9	19	19	16	16	1-3
A-33,A-34	2000	10.8,10.3	10.6	10,12	11	16,15	16	1-3
C-31,C-32	2000	8.5,14.0	11.2	10,10	10	25,21	23	-
F-31,F-32	2000	4.2,6.0	5.1	14,18	16	18,18	18	0-1
H-35,H-36	2000	9.4,9.0	9.2	20,18	19	38,36	37	-
16-8-2,W-5	2000	5.9,	5.9	21	21	19	19	1-3

*Ferrite by Severn Indicator. Before testing: Comp. A, 9-10%; Comp. F, 3-5%; 16-8-2, 1-3%.
Compositions C and H were non-magnetic before and after testing.

Table 51 (Part 1)
All-Weld-Metal Stress Rupture Data at 1000F

Comp. & Code	Heat Treat	Stress, Ksi	Hrs. to Rupture	% El. in 2"	% Red. of Area	Percent Ferrite*	
						Before Testing	After Testing
A37	AW	65	22.0	25	34	9-10	7-9
A24	AW	62	148	18	24	9-10	7-9
A25	AW	60	221	15	19	9-10	7-9
A28	AW	58	544	8	16	9-10	7-9
A32	AW	56	593	8	14	9-10	7-9
A51	ST	55	80.3	20	34	1-3	0-1
A52	ST	50	1182	11	17	1-3	0-1
A45	ET	62	62.4	20	29	7-9	5-7
A46	ET	57	422	8	15	7-9	5-7
C36	AW	65	109	23	28	-	-
C21A	AW	61	434	11	24	-	-
C27	AW	59	571	12	23	-	-
C33	AW	58	839	11	20	-	-
C42	ST	58	6.6	32	48	-	-
C39	ST	54	419	25	32	-	-
C46	ET	62	224	19	24	-	-
C45	ET	53	2108	18	18	-	-
F21	AW	42	29.3	34	53	3-5	3-5
F24	AW	38	145	28	39	3-5	3-5
F23	AW	35	402	33	24	3-5	3-5
F25	AW	34	593	26	39	3-5	1-3
F26	AW	32.5	1068	26	37	3-5	1-3
F52	ST	40	41.3	22	23	0-1	0-1
F51	ST	35	181	16	22	0-1	0-1
F45	ET	38	174	35	43	3-5	1-3
F46	ET	33	739	20	40	3-5	1-3
H55	AW	58.5	121	19	26	-	-
H37	AW	58	510	15	18	-	-
H33	AW	57	607	14	19	-	-
H34	AW	56	997	18	20	-	-
H53	ST	50.5	632	25	32	-	-
H6R	ST	50	1141	21	26	-	-
H46	ET	58	610	10	17	-	-
H45	ET	56	1012	13	19	-	-
H57	ST	51	709	28	32	-	-

AW = As-Welded

ET = Embrittlement treatment, 1000 hours at 1050F, air cooled

ST = Solution treatment, 1950F, 1-hour, air cooled

* Ferrite by Severn Indicator.

Compositions C and H were non-magnetic in all conditions.

Table 51 (Part 2)
All-Weld-Metal Stress Rupture Data at 1200F

Comp. & Code	Heat Treat	Stress Ksi	Hrs. to Rupture	% El. in 2"	% Red. of Area	Percent Ferrite*	
						Before Testing	After Testing
A35	AW	40	7.5	7	16	9-10	3-5
A38	AW	34	126	0.8	6	9-10	1-3
A36	AW	31.5	185	1	6	9-10	1-3
A22	AW	30	263	0.5	4	9-10	1-3
A30	AW	25	773	0.8	2	9-10	1-3
A40	ST	40	10.9	18	36	1-3	0-1
A39	ST	30	246	8	16	1-3	0-1
A48	ET2	38	27.3	6	13	1-3	0-1
A47	ET2	30	229	3	7	1-3	0-1
C22	AW	45	30.0	8	15	-	-
C54	AW	42	50.5	5	24	-	-
C35	AW	40	110	6	20	-	-
C37	AW	38	286	6	19	-	-
C55	AW	35	426	4	18	-	-
C56	AW	34	878	6	16	-	-
C57	AW	33	1153	4	17	-	-
C40	ST	38	7.6	34	48	-	-
C43	ST	27	425	30	46	-	-
C47	ET2	38	204	16	35	-	-
C48	ET2	34.5	1415	5	14	-	-
F29	AW	25	21.8	54	45	3-5	0-1
F35	AW	22	58.7	31	42	3-5	1-3
F34	AW	20	179	36	34	3-5	0-1
F37	AW	17	680	24	40	3-5	0-1
F39	ST	21	17.7	13	27	0-1	0-1
F41	ST	15	433	16	15	0-1	0-1
F48R	ET2	16	546	23	39	1-3	0-1
F47	ET2	20	94.0	20	32	1-3	1-3
H58	AW	45	37.1	13	38	-	-
H59	AW	43	35.2	16	42	-	-
H25	AW	40	134	8	34	-	-
H27	AW	37	503	4	14	-	-
H22	AW	35	748	4	13	-	-
H26	AW	34	1023	5	12	-	-
H53A	ST	37	21.9	18	35	-	-
H41	ST	35	52.7	19	38	-	-
H43	ST	30	236	22	34	-	-
H47	ET2	39	45.0	21	39	-	-
H48	ET2	34	916	1	4	-	-

AW - As-Welded

ET2 - Embrittlement treatment, 1000 hours at 1200F, air cooled.

ST - Solution treatment, 1950F, 1-hr., air cooled

* - Ferrite by Severn Indicator.

Compositions C and H were non-magnetic in all conditions.

Table 51 (Part 3)

All-Weld-Metal Stress Rupture Data at 1300F

Comp. & Code	Heat Treat	Stress Ksi	Hrs. to Rupture	% El. in 2"	% Red. of Area	Percent Ferrite*	
						Before Testing	After Testing
A55	AW	30	18.0	2	5	9-10	1-3
A26	AW	25	54.8	2	4	9-10	1-3
A23	AW	20	294	0.7	2	9-10	1-3
A29	AW	18	583	0.5	2	9-10	1-3
A31	AW	17	609	0.0	0	9-10	1-3
A43	ST	30	7.0	15	28	1-3	0-1
A44	ST	18	433	14	12	1-3	0-1
A49	ET3	20	219	0.0	0.2	1-3	0-1
A50	ET3	17	592	1	2	1-3	0-1
C24	AW	35	28.7	4	17	-	-
C25	AW	32	155	3	15	-	-
C26	AW	31	154	4	12	-	-
C34	AW	29	580	2	16	-	-
C41	ST	30	2.0	42	57	-	-
C53	ST	22	54.3	36	58	-	-
C44	ST	18	1260	21	35	-	-
C49	ET3	30	278	10	36	-	-
C50	ET3	28.5	928	6	28	-	-
F28	AW	17	19.5	18	28	3-5	0-1
F33	AW	14	130	10	20	3-5	0-1
F36	AW	12.5	260	10	18	3-5	0-1
F38	AW	11	764	2	10	3-5	0-1
F40	ST	15	18.8	9	21	0-1	0-1
F53	ST	10	479	18	24	0-1	0-1
F49	ET3	14	32.8	5	17	0-1	0-1
F50	ET3	10	405	3	8	0-1	0-1
H28	AW	35	18.5	15	24	-	-
H38	AW	33	25.5	9	34	-	-
H24	AW	30	168	2	12	-	-
H23	AW	25	460	2	0.7	-	-
H29	AW	24	500	1	4	-	-
H31	AW	22	805	2	7	-	-
H56	AW	21	795	1	7	-	-
H32	AW	20	981	4	7	-	-
H52	ST	24	120	2	18	-	-
H54	ST	15	2064	2	2	-	-
H50	ET3	28	33.3	18	36	-	-
H49	ET3	20	858	2	8	-	-

AW - As-Welded

ET3 - Embrittlement treatment, 1000 hours at 1350F, air cooled

ST - Solution treatment, 1950F, 1-hr., air cooled

* Ferrite by Severn Indicator.

Compositions C and H were non-magnetic in all conditions.

Table 52

<u>Type of Heat Treatments</u>		
<u>Heat treatment</u>	<u>Stress-rupture test temperature, ° F</u>	<u>Object of heat treatment</u>
1050° F for 1000 hr. AC	1000	Aged at service temperatures before testing to determine the effect of aging on stress-rupture properties.
1200° F for 1000 hr. AC	1200	
1350° F for 1000 hr. AC	1300	
1950° F for 1 hr. AC	1000	Annealed before testing to determine the effect of annealing heat treatment on stress-rupture properties.
1950° F for 1 hr. AC	1200	
1950° F for 1 hr. AC	1300	

Table 53

Transverse Stress Rupture Data

Comp. & Code	Heat Treat	Test Temp., F	Stress, Ksi	Hrs. to Rupture	% El. in Weld	% El. in 2"	% Red. of Area	Location of Failure	Percent Ferrite* in Weld	
									Before Testing	After Testing
A7T	AW	1000	60	**	0	22	58	BM	9-10	9-10
A2T	AW	1000	50.5	612	3	13	17	BM***	9-10	7-9
A11T	ET4	1000	50	87.9	1	18	46	BM	3-5	3-5
A10T	ET4	1000	43	597	0	11	27	BM	3-5	3-5
C2T	AW	1000	54	21.6	3	24	60	BM	-	-
C7T	AW	1000	49	1312	0	6	16	LF	-	-
C10T	ET4	1000	48	182	1	16	21	BM	-	-
C11T	ET4	1000	42	668	1	9	26	BM	-	-
F7T	AW	1000	36	515	22	14	29	Weld	3-5	3-5
F11T	ET4	1000	30	1289	12	6	14	Weld	3-5	1-3
H2T	AW	1000	54	20.2	3	24	59	BM	-	-
H7T	AW	1000	52	258	5	15	25	BM***	-	-
H10T	ET4	1000	50	91.2	3	22	49	BM	-	-
H11T	ET4	1000	43	582	0	14	31	BM	-	-
A1T	AW	1200	26	160	0	4	14	BM	9-10	1-3
A5T	AW	1200	22	406	15	3	12	BM	9-10	0-1
A13T	ET5	1200	20	469	0	6	18	BM	0-1	0-1
A14T	ET5	1200	18	893	0	7	18	BM	0-1	0-1
C1T	AW	1200	24.4	274	3	2	12	BM	-	-
C5T	AW	1200	22	438	0	2	12	BM	-	-
C13T	ET5	1200	20	346	0	6	21	BM	-	-
C14T	ET5	1200	18.5	608	0	7	17	BM	-	-
F1T	AW	1200	20	127	23	17	28	Weld	3-5	1-3
F13T	ET5	1200	12	656	3	2	4	Weld	0-1	0-1
H1T	AW	1200	24.4	224	3	3	11	BM	-	-
H5T	AW	1200	22	471	0	2	13	BM	-	-
H14T	ET5	1200	21	401	1	8	20	BM	-	-
H13T	ET5	1200	18	945	0	4	16	BM	-	-

Table 53 (Continued)

Comp. & Code	Heat Treat.	Test Temp., F	Stress Ksi	Hrs. to Rupture	% El. in Weld	% El. in 2"	% Red. of Area	Location of Failure	Percent Ferrite* in Weld	
									Before Testing	After Testing
A4T	AW	1300	18	125	2	2	13	BM	9-10	1-3
A8T	AW	1300	15.5	342	2	4	14	BM	9-10	0-1
A16T	ET6	1300	13.5	206	0	28	43	BM	0-1	0-1
A17T	ET6	1300	10.5	565	6	17	27	BM	0-1	0-1
C4T	AW	1300	18	163	0	5	14	BM	-	-
C8T	AW	1300	16	308	2	2	14	BM	-	-
C16T	ET6	1300	13.5	219	0	32	44	BM	-	-
C17T	ET6	1300	10.5	781	9	14	23	BM	-	-
F4T	AW	1300	13	181	17	11	4	Weld	3-5	1-3
F16T	ET6	1300	9.5	138	4	0.5	2	Weld	0-1	0-1
H4T	AW	1300	18	176	1	4	14	BM	-	-
H8T	AW	1300	13	875	0	3	4	LF	-	-
H16T	ET6	1300	13.5	191	0	22	43	BM	-	-
H17T	ET6	1300	10.5	928	0	22	39	BM	-	-

ET4 - Embrittlement treatment, 10,000 Hours at 1050F, A.C.

ET5 - Embrittlement treatment, 10,000 Hours at 1200F, A.C.

ET6 - Embrittlement treatment, 10,000 Hours at 1350F, A.C.

AW - As-Welded.

BM - Type 347 Base Material.

LF - Line of Fusion.

* Ferrite by Severn Indicator. Compositions C and H were none-magnetic in all

** Failed during loading. conditions.

*** Failure was initiated at the line of fusion.

Table 54

RPI Hot-ductility Data

All-weld-metal specimens tested in the as-welded condition

<u>Compo- sition</u>	<u>Ultimate Tensile Strength, ksi</u>		<u>Reduction of Area, %</u>		<u>Total Strain, Inches</u>		<u>% Ferrite in Heated Portion After Testing*</u>			
		<u>Avg.</u>		<u>Avg.</u>		<u>Avg.</u>			<u>Avg.</u>	
<u>Tests Conducted on Heating</u>										
<u>1800F</u>										
A	20.8, 24.4	22.6	46.2, 47.7	47.0	0.075, 0.078	0.077	5-7, 5-7		6	
C	22.4, 20.8	21.6	64.1, 56.3	60.2	0.136, 0.125	0.131	-	-	-	
F	14.7, 14.3	14.5	61.3, 55.8	58.6	0.107, 0.112	0.110	0-1, 0-1		.5	
H	21.0, 22.4	21.7	72.1, 65.3	68.7	0.131, 0.111	0.121	-	-	-	
<u>2000F</u>										
A	15.1, 16.3	15.7	43.6, 40.3	42.0	0.081, 0.084	0.083	3-5, 3-5		4	
C	13.8, 14.3	14.1	61.1, 67.3	64.2	0.119, 0.122	0.121	-	-	-	
F	9.0, 8.6	8.8	57.9, 53.6	55.8	0.127, 0.153	0.140	0-1, 0-1		.5	
H	13.7, 13.3	13.5	68.9, 61.9	65.4	0.145, 0.155	0.150	-	-	-	
<u>2200F</u>										
A	9.8, 8.6	9.2	58.8, 54.3	56.6	0.103, 0.124	0.114	3-5, 3-5		4	
C	6.6, 7.4	7.0	59.7, 50.1	54.9	0.080, 0.092	0.086	-	-	-	
F	5.5, 5.1	5.3	50.1, 62.3	56.2	0.122, 0.166	0.144	0-1, 0-1		.5	
H	7.5, 7.1	7.3	44.8, 49.3	47.1	0.073, 0.091	0.082	-	-	-	
<u>2300F</u>										
A	9.8, -	9.8	54.7, 59.2	57.0	0.111, 0.124	0.118	3-5, 3-5		4	
C	-	-	22.1, 32.0	27.1	0.039, 0.036	0.038	-	-	-	
F	-	-	52.5, 69.1	60.8	-	-	0-1, 0-1		.5	
H	-	-	9.8, 13.2	11.5	-	-	-	-	-	

Table 54 (Continued)

<u>Compo- sition</u>	<u>Ultimate Tensile Strength, ksi</u>			<u>Reduction of Area, %</u>			<u>Total Strain, Inches</u>		<u>% Ferrite in Heated Portion After Testing*</u>		
			<u>Avg.</u>			<u>Avg.</u>		<u>Avg.</u>			<u>Avg.</u>
<u>Tests Conducted on Heating (Continued)</u>											
<u>2400F</u>											
A	3.5,	4.5	4.0	5.2,	6.7	6.0	0, 0	0	5-7,	7-9	7
C	-	-	-	3.1,	2.9	3.0	0, 0	0	-	-	-
F	4.1,	-	4.1	60.0,	53.4	56.7	0.141, -	0.141	0-1,	0-1	.5
H	-	-	-	0.0,	2.9	1.5	- -	-	-	-	-
<u>2450F</u>											
A	-	-	-	4.6,	4.8	4.7	0, 0	0	7-9,	7-9	8
C	-	-	-	1.2,	0.3	0.8	0, 0	0	-	-	-
F	4.5,	-	4.5	29.5,	37.6	33.6	0.054, -	0.054	0-1,	0-1	.5
H	-	-	-	1.2,	0.0	0.6	- -	-	-	-	-
<u>Tests Conducted on Cooling from 2400F</u>											
<u>2300F</u>											
A	5.5,	5.1, 6.1	5.6	65.5,	39.7, 62.7	56.0	.144, .051, .120	0.105	3-5,	3-5, 5-7	5
C	-	5.5, 3.1	4.3	8.8,	4.6	6.7	0, 0	0	-	-	-
F	-	5.1, 5.1	5.1	75.7,	56.8	66.3	0.184, 0.176	0.180	0-1,	0-1	.5
H	-	3.1, 3.1	3.1	2.3,	1.6	2.0	0, 0	0	-	-	-
<u>2200F</u>											
A	12.2,	13.2	12.7	69.6,	65.4	67.5	0.164, 0.161	0.163	1-3,	1-3	2
C	12.7,	12.3	12.5	20.4,	26.6	23.5	0.039, 0.081	0.060	-	-	-
F	11.4,	9.2	10.3	63.3,	60.3	61.8	0.142, 0.186	0.164	0-1,	0-1	.5
H	11.6,	12.2	11.9	11.3,	7.4	9.3	- -	-	-	-	-

Table 54 (Continued)

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Compo- sition	Ultimate Tensile Strength, ksi		Reduction of Area, %			Total Strain, Inches			% Ferrite in Heated Portion After Testing*	
	Avg.		Avg.			Avg.			Avg.	

Tests Conducted on Cooling from 2400F (Continued)2000F

A	17.1, 16.5	16.8	51.3, 50.8	51.1	0.095, 0.106	0.101	3-5, 3-5	4
C	15.7, -	15.7	46.1, 44.1	45.1	0.084, 0.069	0.077	-	-
F	9.4, 9.8	9.6	57.6, 45.6	51.6	0.138, 0.135	0.137	0-1, 0-1	.5
H	16.7, 9.4	13.1	39.8, 40.2	40.0	0.055, 0.063	0.059	-	-

1800F

A	23.4, 23.4	23.4	46.6, 47.1	46.9	0.087, 0.113	0.100	3-5, 3-5	4
C	22.0, 21.6	21.8	56.3, 53.3	54.8	0.100, 0.120	0.110	-	-
F	22.0, 21.6	21.8	44.4, 51.5	48.0	0.106, 0.108	0.107	0-1, 0-1	.5
H	18.3, 18.3	18.3	46.5, 44.4	45.5	0.060, 0.052	0.056	-	-

Tests Conducted on Cooling from 2450F2300F

A	5.5, 4.5	5.0	13.6, 16.3	15.0	-	-	7-9, 5-7	7
C	-	-	2.9, 2.9, 3.3	3.0	-	-	-	-
F	-	-	-	-	-	-	-	-
H	-	-	1.4, 1.6	1.5	-	-	-	-

2200F

A	11.6, -	11.6	39.2, -	39.2	0.064, -	0.064	5-7, -	6
C	10.6, -	10.6	12.9, -	12.9	0.021, -	0.021	-	-
F	9.6, -	9.6	-	-	0.172, -	0.172	-	-
H	11.4, -	11.4	10.1, -	10.1	0.010, -	0.010	-	-

* Ferrite by Severn indicator. Before testing: Composition A, 9-10%; Composition F, 3-5%; Compositions C and H were nonmagnetic before and after testing.

Table 55

Comparative Tensile Properties at 1800° F*

	<u>Composition A</u>		<u>Composition C</u>		<u>Composition F</u>		<u>Composition H</u>	
	<u>HTT**</u>	<u>RPI</u>	<u>HTT</u>	<u>RPI</u>	<u>HTT</u>	<u>RPI</u>	<u>HTT</u>	<u>RPI</u>
Ultimate tensile strength,ksi	20.2	22.6	20.8	21.6	9.6	14.5	16.8	21.7
Reduction of area,%	5	47.0	17	60.2	11	58.6	27	68.7

* These data appear in Tables 50 and 54.

** HTT = Conventional high-temperature tensile test.

RPI = RPI hot-ductility test, "on heating" data.

Table 56

Some Basic Differences Between HTT and RPI Tests

	<u>HTT</u>	<u>RPI</u>
Time required to reach test temperature	60-90 min.	Few seconds
Soaking time at test temperature	1/2 hour	None
Type of heating	Furnace (radiant)	Electrical resistance
Specimen size at reduced section	.505-in. diam.	.250-in. diam.
Rate of strain (free running crosshead or platen speed in inches per inch of gage length per minute)	.04	Approximately 600

Table 57

Strength and Ductility as
Affected by Speed of Testing

Composition A Tested in the As-Welded Condition at 1800F

Code	Free Running Crosshead Speed In./In. of Gage Length/Min.	Ult. Ten. Str., ksi	% El. in 2"	% R.A.	% Ferrite After Testing*
A70	.020	17.3	3	6	3-5
A17**	.040	20.1	4	6	3-5
A18**	.040	20.3	0	4	3-5
A60	.044	20.0	6	11	3-5
A61	.228	20.1	7	12	3-5
A67	.65	22.4	12	20	3-5
A62	.76	20.2	7	16	3-5
A71	1.02	21.9	19	24	3-5
A63	1.22	20.4	15	17	3-5
A68	1.36	22.5	20	22	3-5
A65	1.47	24.5	16	26	3-5
A66	1.47	22.5	18	23	3-5
A69	1.56	24.7	24	29	3-5
A64	1.56	-	17	29	3-5

*Ferrite by Severn Indicator; 9-10% before testing.
**The data for these tests also appear in Table 50.

Table 58

Chemical Analysis of Materials Used in Stress-Strain Tests

<u>Material</u>	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>	<u>Mo</u>	<u>N</u>
					Undiluted weld metals					
Composition A	.067	1.35	.48	.011	.017	19.56	9.47	.77	-	.036
Composition C	.109	1.39	.51	.011	.019	19.11	12.96	.67	-	.049
Composition F	.033	0.65	.32	.010	.018	18.81	10.73	-	-	.050
Composition H	.078	4.85	.45	.014	.018	18.76	10.91	.90	-	.058
Composition W	.063	1.81	.20	.005	.021	15.88	7.83	-	1.92	.036
Composition X	.032	1.23	.38	.021	.010	19.05	8.02	-	-	.146
Composition Y	.035	5.96	.43	.015	.011	18.35	10.15	-	-	.142
					Base materials					
Type 347	.054	1.77	.71	.025	.027	18.37	11.45	.85	-	.010
Type 304L	.027	1.21	.48	.017	.019	18.00	9.65	-	-	.024

Table 59

Stress-Strain Tensile Test Data
(All tests were conducted in the as-welded condition.)

Longitudinal all-weld-metal

Code	Proportional	YS, ksi	TS, ksi	YS/TS	% El. in 2"	Modulus, "E", ksi x 10 ⁻³
	Limit, ksi					
Room Temperature						
A	36.8	68.4	95.8	.71	30	22.5
A	33.3	70.0	95.1	.72	31	22.5
C	31.2	65.3	85.3	.76	31	18.5
C	34.1	64.1	84.7	.76	25	18.4
F	30.2	53.1	77.6	.70	36	19.7
F	35.9	52.6	75.5	.70	36	19.4
H	35.6	58.6	80.8	.72	30	17.6
H	39.2	61.6	82.6	.75	24	18.7
W	33.8	65.4	93.1	.70	41	22.0
W	37.7	64.0	91.8	.70	38	21.5
X	44.2	65.5	93.6	.70	42	22.5
Y	44.2	61.0	83.2	.73	32	19.6
1000F						
A	28.8	50.3	63.9	.79	15	17.0
A	32.0	49.3	62.7	.79	14	15.2
C	32.0	43.5	59.5	.73	19	12.8
C	30.0	44.1	57.0	.77	15	14.3
F	28.8	37.2	47.7	.78	23	14.5
F	25.6	37.2	47.6	.78	25	14.8
H	31.2	46.7	56.4	.83	22	18.0
W	26.9	44.0	61.0	.72	24	15.8
W	30.2	45.4	62.1	.73	19	16.4

Table 59(Continued)

<u>Code</u>	<u>Proportional Limit, ksi</u>	<u>YS, ksi</u>	<u>TS, ksi</u>	<u>YS/TS</u>	<u>% El. in 2"</u>	<u>Modulus, "E", ksi x 10⁻³</u>	<u>Location of Fracture</u>
1200F							
A	21.4	42.3	53.7	.79	-	16.3	-
A	21.8	42.3	50.0	.85	14	16.4	-
C	24.3	39.3	50.0	.79	17	14.3	-
C	19.8	39.6	52.2	.76	20	12.8	-
F	19.2	31.3	36.9	.85	16	14.0	-
F	19.2	30.1	37.2	.81	15	13.2	-
H	20.2	39.2	49.2	.80	20	15.8	-
H	18.8	36.8	47.2	.78	21	13.4	-
W	25.1	37.0	50.5	.73	20	12.9	-
W	21.9	34.8	47.4	.74	24	16.3	-
1300F							
A	15.5	39.8	48.7	.82	16	14.4	-
A	24.0	39.3	46.2	.86	18	15.1	-
C	22.2	38.4	45.8	.84	22	12.7	-
C	23.6	40.0	46.4	.86	17	13.6	-
F	13.0	24.1	30.6	.79	34	12.3	-
F	13.0	24.4	30.6	.80	27	12.5	-
H	24.1	36.9	43.5	.85	20	11.4	-
H	24.8	37.0	42.8	.86	27	11.8	-
W	18.6	29.4	39.7	.74	30	15.7	-
W	18.4	31.7	40.2	.79	27	13.5	-

Table 59(Continued)

Transverse to weld joint*

Code	Proportional Limit, ksi	YS, ksi	TS, ksi	YS/TS	% El. in 2"	Modulus, "E," ksi x 10 ⁻³	Location of Fracture
Room Temperature							
A	19.6	48.8	86.1	.57	28	26.6	base plate
A	18.7	47.7	86.5	.55	29	26.6	base plate
C	19.1	46.1	86.6	.53	36	23.9	base plate
C	21.5	48.6	86.0	.56	33	23.3	base plate
F	19.4	42.3	79.3	.53	34	25.3	weld
F	18.7	41.4	81.7	.51	41	25.1	weld
H	21.6	48.2	84.2	.57	24	22.2	weld
H	15.7	49.1	84.1	.58	28	23.8	weld
W	25.2	52.0	87.9	.59	28	26.1	base plate
W	22.3	52.2	87.8	.59	30	24.8	base plate
X	29.1	49.3	89.6	.55	30	26.4	base plate
X	27.5	50.2	89.0	.56	26	25.0	base plate
Y	20.4	49.3	86.8	.57	30	24.8	weld
Y	22.0	47.2	85.6	.55	32	25.8	weld
1000F							
A	19.8	33.9	-	-	-	17.4	base plate
A	22.2	39.1	54.3	.72	-	19.8	base plate
C	23.3	39.5	59.2	.67	13	17.7	base plate
C	18.9	32.2	52.9	.61	-	16.5	base plate
F	9.5	24.5	50.2	.49	26	15.0	base plate
F	14.7	24.7	48.8	.51	22	12.2	weld
H	19.8	35.8	49.6	.72	9	14.7	base plate
H	20.6	35.2	53.6	.66	12	13.1	base plate
W	22.7	33.9	52.8	.64	-	16.0	base plate
W	20.8	37.4	54.0	.69	-	12.3	base plate

Table 59(Continued)

Code	Proportional Limit, ksi	YS, ksi	1200F		% El. in 2"	Modulus, "E," ksi x 10 ⁻³	Location of Fracture
			TS, ksi	YS/TS			
A	16.7	31.8	46.7	.68	-	15.3	base plate
A	19.2	32.9	48.2	.68	-	20.4	base plate
C	20.5	28.6	46.8	.61	-	20.5	base plate
C	21.6	31.0	47.2	.66	-	23.8	base plate
F	9.9	22.2	39.2	.57	16	15.8	weld
F	12.6	23.7	40.0	.59	17	17.4	base plate
H	18.8	30.7	46.8	.66	14	20.6	base plate
H	18.0	29.5	46.2	.64	-	19.0	base plate
W	16.7	33.2	47.2	.70	16	19.4	base plate
W	19.7	31.8	46.4	.68	14	16.8	base plate
1300F							
A	12.8	28.8	41.7	.69	18	16.3	base plate
A	14.6	28.6	41.4	.69	-	17.1	base plate
C	10.3	28.4	42.0	.68	13	19.9	base plate
C	18.7	28.6	41.9	.68	14	30.6	base plate
F	9.8	21.1	31.7	.67	18	16.8	weld
F	14.1	22.0	33.5	.66	18	24.9	weld
H	17.6	29.5	43.0	.68	-	14.4	base plate
H	14.4	29.7	41.8	.71	-	18.4	base plate
W	13.3	28.0	41.0	.68	-	19.1	base plate
W	15.4	30.0	42.6	.70	-	16.4	base plate

Key: Code A - Composition A
 Code C - Composition C
 Code F - Composition F
 Code H - Composition H
 Code W - Composition 16-8-2
 Code X - 308L - 0.15N with 3-5% ferrite.
 Code Y - 308L - 0.14N-6Mn; fully austenitic.

*Type 317 base plate for all weld joints except for Composition F for which
 Type 304L base material was employed.

Table 60

Chemical Analyses

Undiluted Modified Type 308L Weld Metals
(5/32-Inch Diameter Electrodes Welded in Accordance with AWS-ASTM A298-55T)

<u>Composition</u>	<u>Sample No.</u>	%								
		<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>N</u>	<u>Ferrite*</u>
.1N	11889	.032	1.23	.38	.015	.013	19.05	8.02	.15	3-5
.2N	11954	.030	1.22	.45	.017	.013	20.50	7.98	.20	3-5
.1N 6Mn	11953	.035	5.96	.43	.013	.012	18.35	10.15	.14	<1
.2N 6Mn	11888	.033	6.44	.39	.012	.013	18.28	8.70	.20	<1

* Severn Indicator

Plate Material (Mill Analysis)

<u>Type</u>	<u>Heat No.</u>	%								
		<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Cr</u>	<u>Ni</u>	<u>Cb</u>	<u>N</u>
347	46767-2B	.054	1.77	.71	.025	.027	18.37	11.45	.85	.010

Table 61

Tensile Properties (Room Temperature)All-Weld-Metal Modified Type 308L Specimens Tested in the As-Welded Condition

<u>Composition</u>	<u>Yield Strength, psi</u>	<u>Ultimate Tensile Strength, psi</u>	<u>% Elongation in 2"</u>	<u>% Reduction of Area</u>
.1N	67,900	95,100	43	61
.2N	74,400	100,100	38	64
.1N 6Mn	58,600	81,700	42	62
.2N 6Mn	67,500	91,500	38	61

Table 62

Modified Type 308L All-Weld-Metal Stress Rupture DataTests at 1000F

<u>Composition</u>	<u>Code</u>	<u>Heat Treatment</u>	<u>Stress, Ksi</u>	<u>Hours to Rupture</u>	<u>Elongation % in 2"</u>	<u>Reduction Of Area, %</u>
0.1N	S25	AW	52	50.0	35	46
	S26	AW	50	93.3	27	29
	S27	AW	44	514	20	26
	S49	AW	41	1696	14	22
	S28	ST	56	9.7	34	47
	S29	ST	52	40.2	34	50
	S30	ST	50	100	28	39
	S63	ST	41	525	16	27
	S89	ST	39	1302	12	19
	S74	ST	35	4001	11	16
0.2N	S31	AW	56	28.4	28	35
	S32	AW	52	103	23	34
	S33	AW	50	205	18	20
	S54	AW	45	670	14	25
	S75	AW	44	844	11	22
	S78	ST	45	218	16	18
	S77	ST	42	494	12	24
	S76	ST	40	1002	12	21
0.1N 6Mn	S39	AW	50	12.0	34	44
	S38	AW	42	159	16	36
	S57	AW	39	324	14	28
	S81	AW	37	825	10	30
	S82	AW	34	2514	10	29
	S40	ST	46	73.9	20	23
	S42	ST	44	97.4	16	28
	S41	ST	42	132	14	31
	S83	ST	39	160	20	20
	S67	ST	35	341	17	24
S84	ST	31	1653	13	26	
0.2N 6Mn	S43	AW	48	61.4	14	30
	S45	AW	46	89.8	13	29
	S44	AW	44	149	8	23
	S60	AW	41	263	11	22
	S58	AW	37	1138	5	26
	S48	ST	48	66.5	14	22
	S46	ST	46	96.0	12	26
	S47	ST	44	135	10	25
	S70	ST	34	306	12	23
	S87	ST	32	946	12	18
S88	ST	28	2923*	-	-	

Table 62 (Continued)

<u>Tests at 1200F</u>						
<u>Composition</u>	<u>Code</u>	<u>Heat Treatment</u>	<u>Stress, Ksi</u>	<u>Hours to Rupture</u>	<u>Elongation % in 2"</u>	<u>Reduction of Area, %</u>
0.1N	S3	AW	28.5	205	30	37
	S2	AW	27	313	28	31
	S50	AW	23	821	18	22
	S51	AW	21.5	1405	17	20
	S6	ST	28.5	89.2	29	33
	S5	ST	27	198	22	26
	S4	ST	26	367	20	27
	S62	ST	22	1047	16	24
0.2N	S7	AW	30	97.7	10	21
	S8	AW	27	186	8	19
	S9	AW	23	463	6	11
	S79	AW	22	462	5	7
	S80	AW	21	466	4	9
	S53	AW	20	746	4	7
	S12	ST	32	50.3	26	32
	S11	ST	30	172	21	29
	S10	ST	27	365	18	28
S65	ST	23	1220	17	19	
0.1N 6Mn	S13	AW	30	15.8	20	34
	S14	AW	27	51.0	15	33
	S56	AW	20	580	11	24
	S85	AW	18	1152	13	18
	S18	ST	27	45.2	30	39
	S17	ST	23	254	28	36
	S68	ST	18	1312	10	15
0.2N 6Mn	S19	AW	30	78.2	8	28
	S20	AW	27	166	7	17
	S21	AW	24	327	6	19
	S59	AW	20	823	7	15
	S24	ST	29	66.9	18	28
	S22	ST	27	110	12	22
	S23	ST	24	360	10	22
S71	ST	20	786	18	22	

AW = As-Welded

ST = Solution Treated at 1950F for 1 Hour, Air Cooled.

* Test stopped, no failure.

Table 63

Transverse Modified Type 308L Stress-Rupture Data at 1200F
(Type 347 Base Material)

Weld Composition	Code	Heat Treatment	Stress Ksi	Hours to Rupture	Elongation, %		Reduction of Area, %	Location of Failure
					In Weld	In 2"		
0.1N	1N2	AW	25	238	2	3	14	BM
	1N1	AW	23	352	1	1	12	BM
	1N3	AW	22	454	0	1	11	BM
	1N5	ST	27	170	8	8	12	LF
	1N4	ST	25	329	7	6	12	LF
	1N6	ST	23	479	4	3	6	LF
0.2N	2N1	AW	25	200	1	4	12	BM
	2N2	AW	23	335	1	2	10	BM
	2N3	AW	22	408	0	2	13	BM
	2N5	ST	27	170	8	5	12	LF
	2N4	ST	25	305	3	4	6	LF
	2N6	ST	23	545	1	3	4	LF
0.1N 6Mn	1NM1	AW	25	197	0	4	14	BM
	1NM2	AW	23	282	1	2	14	BM
	1NM3	AW	22	331	0	2	13	BM
	1NM5	ST	27	118	6	6	14	LF
	1NM4	ST	25	243	-	4	10	-
	1NM6	ST	23	378	3	4	6	LF
0.2N 6Mn	2NM1	AW	25	175	0	2	14	BM
	2NM2	AW	23	334	4	2	6	Weld
	2NM3	AW	22	329	5	4	6	Weld
	2NM6	ST	27	112	8	7	7	Weld
	2NM4	ST	25	365	3	6	13	LF
	2NM5	ST	23	356	10	7	11	LF

AW = As-Welded

ST = Solution Treated, 1950F 1-Hour, Air Cooled.

BM = Type 347 Base Material

LF = Line of Fusion

Table 64

Summary of Weld Metal Properties

<u>Electrode</u>	<u>Commercial Usability</u>	<u>Hot Cracking Resistance</u>	<u>Intergranular Corrosion Resistance¹</u>	<u>Tensile Ductility at 1800F²</u>	<u>RPI Hot Ductility</u>
Composition A Standard 347, 7% Ferrite	G	G	G	P	G
Composition B 13% Ni 347, 0% Ferrite	G	P	G	ND	ND
Composition C .11% C 347, 0% Ferrite	G	G	G	P	P
Composition D Standard 347 Cb+Ta, 7% Ferrite	G	G	G	ND	ND
Composition F Standard 308L, 7% Ferrite	G	G	G	P	G
Composition H 6% Mn 347, 0% Ferrite	G	G	G	G	P
Composition 16-8-2 16Cr-8Ni-2Mo, 4% Ferrite	G	G	P	G	G
Type 308L with .12% N, 5% Ferrite	ND	G	ND	ND	ND
Type 308L with .12% N & 6% Mn, 0% Ferrite	ND	G	ND	ND	ND

Code G = Good
P = Poor
ND = No Data

1. Huey test, as-welded.
G < 25 mpy, P > 25 mpy.

2. G > 15% El.
P < 15% El.

Table 64 (Continued)

<u>Electrode</u>	<u>Stress Rupture Strength</u>			<u>Stress Rupture Ductility</u>			<u>Keyhole Notch Toughness</u>	
	<u>As-Welded Condition (1000 Hours)³</u>			<u>As-Welded Condition (100 Hours)⁴</u>			<u>at -320F⁵</u>	
	<u>1000F</u>	<u>1200F</u>	<u>1300F</u>	<u>1000F</u>	<u>1200F</u>	<u>1300F</u>	<u>As-Welded</u>	<u>Annealed</u>
Composition A Standard 347, 7% Ferrite	G	G	G	P	P	P	P	G
Composition B 13% Ni 347, 0% Ferrite	ND	ND	ND	ND	ND	ND	P	P
Composition C .11% C 347, 0% Ferrite	G	G	G	P	P	P	P	P
Composition D Standard 347 Cb+Ta, 7% Ferrite	ND	ND	ND	ND	ND	ND	P	G
Composition F Standard 308L, 7% Ferrite	P	P	P	G	G	G	G	G
Composition H 6% Mn 347, 0% Ferrite	G	G	G	P	G	P	P	P
Composition 16-8-2 16Cr-8Ni-2Mo, 4% Ferrite	ND	G	ND	ND	G	ND	ND	ND
Type 308L with .12% N, 5% Ferrite	P	G	ND	G	G	ND	G	G
Type 308L with .12% N & 6% Mn, 0% Ferrite	P	G	ND	P	G	ND	G	G

Code G = Good
P = Poor
ND = No Data

3. $G \geq 347$ Base Plate
 $P < 347$ Base Plate

4. $G > 347$ Base Plate
 $P < 347$ Base Plate

5. $G > 15$ ft. lbs.
 $P < 15$ ft. lbs.

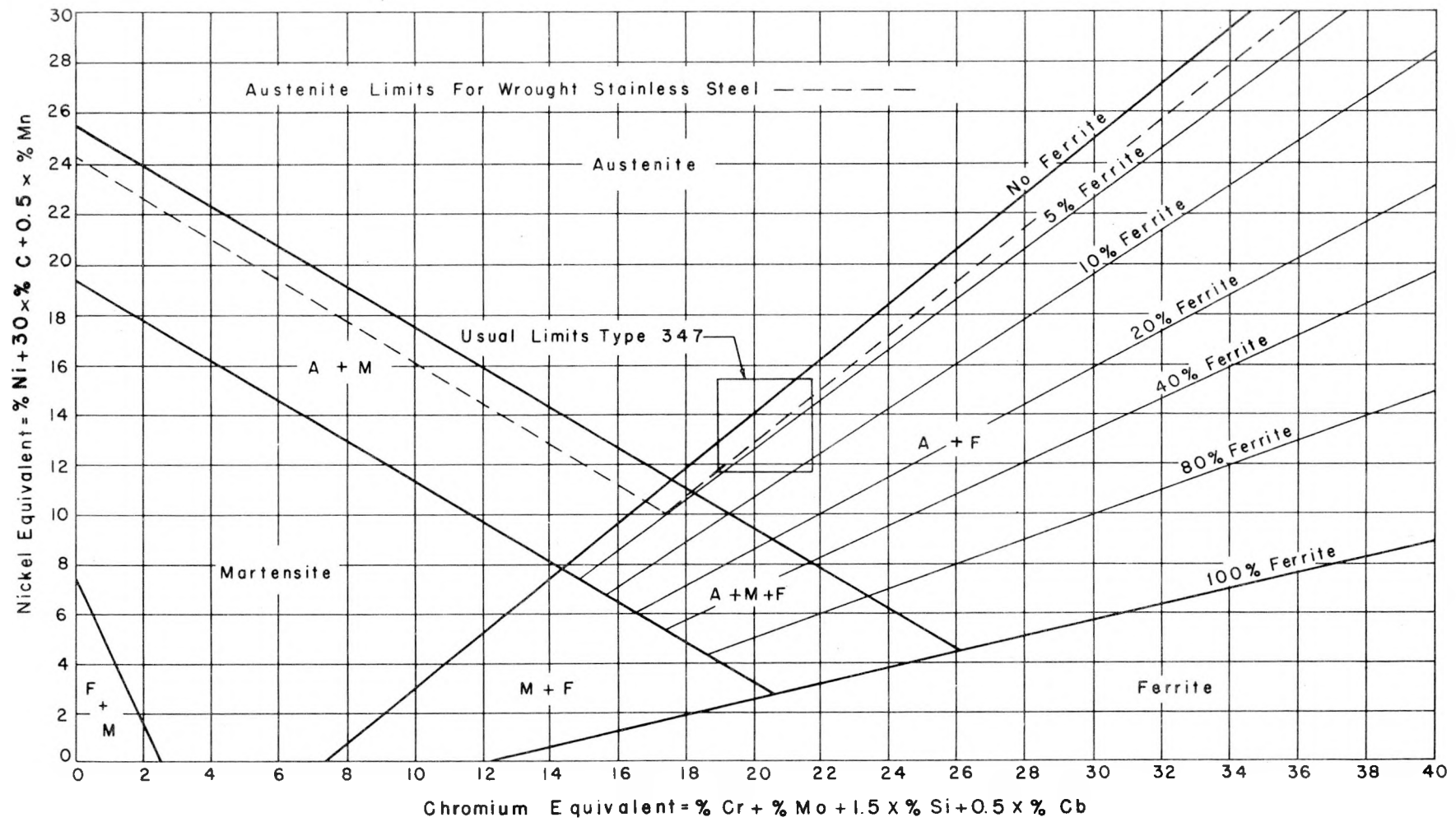
Table 65

Reports Issued Under the Contract

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2. Poole, Lorin K., "The Incidence of Cracking in Welding Type 347 Steels," The WELDING JOURNAL 32 (8), Research Suppl., 403-s to 412-s (1953).
3. Poole, Lorin K., "Technical Report No. 1 on the Effect of Composition and Microstructure on the Mechanical Properties and Crack Sensitivity of Type 347 Weld Metals," U.S. AEC NYO-3495 (August 28, 1952).
4. Poole, Lorin K., "The Effect of Various Heat Treatments on the Tensile Properties of Modified Type 347 Weld Deposits," U.S. AEC NYO-3496 (May 12, 1953).
5. Poole, L. K., "Weld Qualification Tests on Modified Type 347 Welding Electrodes," U.S. AEC NYO-3497 (November 7, 1954).
6. Poole, Lorin K., "The Effect of Various Heat Treatments on the Notched Bar Impact Properties of Modified Type 347 Weld Deposits," U.S. AEC NYO-3498 (November 8, 1954).
7. Poole, Lorin K., and Thomas, R. David, Jr., "Mechanical Properties of Modified Type 347 Weld Metals," The WELDING JOURNAL 34 (12), Research Suppl., 583-s to 595-s (1955).
8. Poole, Lorin K., "The Results of Nitric Acid and Copper Sulfate-Sulfuric Acid Tests on Modified Type 347 Weld Deposits," U.S. AEC NYO-3499 (July 28, 1955).
9. Hoerl, Arthur, and Moore, Thomas J., "Statistical Analysis of Effects of Various Elements on the Crack Sensitivity of Fully Austenitic Type 347 Welds," U.S. AEC NYO-3500 (October 29, 1956).
10. Hoerl, Arthur, and Moore, Thomas J., "Statistical Analysis of Effects of Various Elements on the Crack Sensitivity of Fully Austenitic Type 347 Welds," The WELDING JOURNAL 36 (10), Research Suppl., 442-s to 448-s (1957).
11. Moore, Thomas J., "Elevated-Temperature Properties of Modified Type 347 Weld Metals," The WELDING JOURNAL 38 (12), Research Suppl., 457-s to 474-s (1959).
12. Moore, Thomas J., "Time-Temperature Parameters Affecting Corrosion of 18Cr-8Ni Weld Metals," The WELDING JOURNAL 39 (5), Research Suppl., 199-s to 204-s (1960).
13. Moore, Thomas J., "Stress Rupture Properties of High-Nitrogen 308L Weld Metals," to be published in the WELDING JOURNAL.

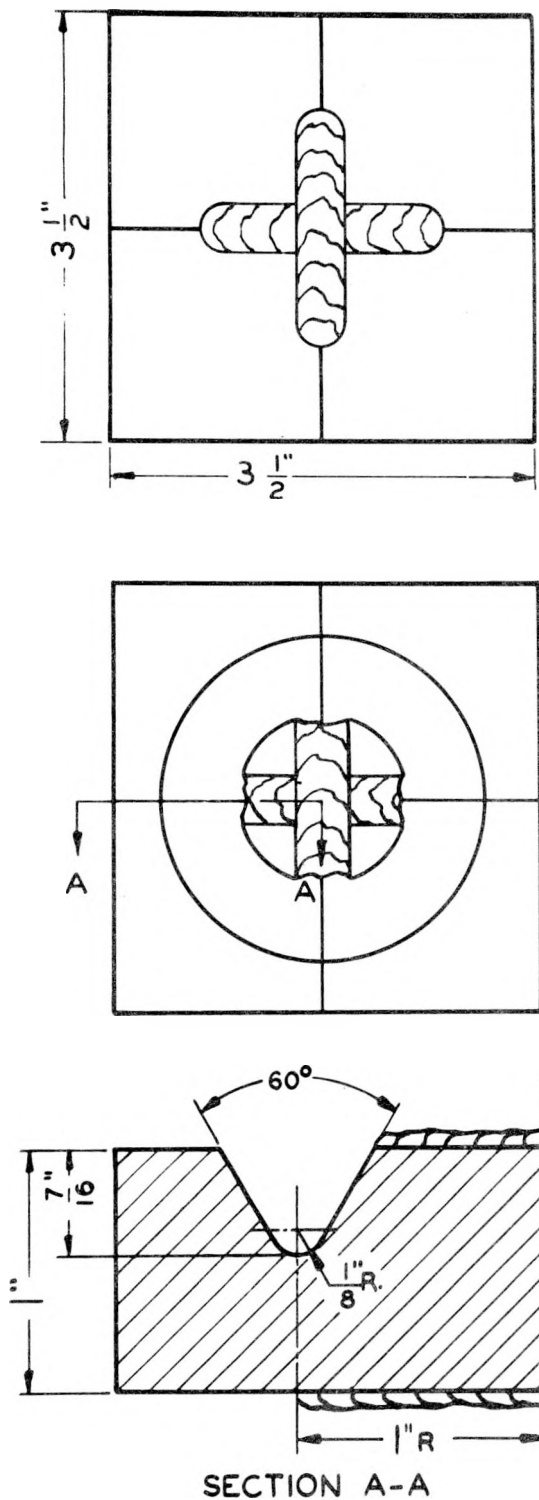
Constitution Diagram For Stainless Steel Weld Metal

By Anton L. Schaeffler



Austenite Limits Of Wrought Stainless Steel Superimposed On The Constitution Diagram For Stainless Steel Weld Metal. Usual Limits For Type 347 Are Indicated By The Rectangle.

Figure 1



NOTES:

1. FOUR BLOCKS ARE CAREFULLY SURFACE GROUND ON THEIR MATING EDGES, CLAMPED TOGETHER AND TACK WELDED WITH BEADS APPROXIMATELY 2" LONG ON BOTH TOP AND BOTTOM SURFACES AS SHOWN.
2. ASSEMBLY IS THEN PLACED IN THE LATHE FOR MACHINING THE GROOVE.

Figure 2. Design of segmented circular-groove test specimen.

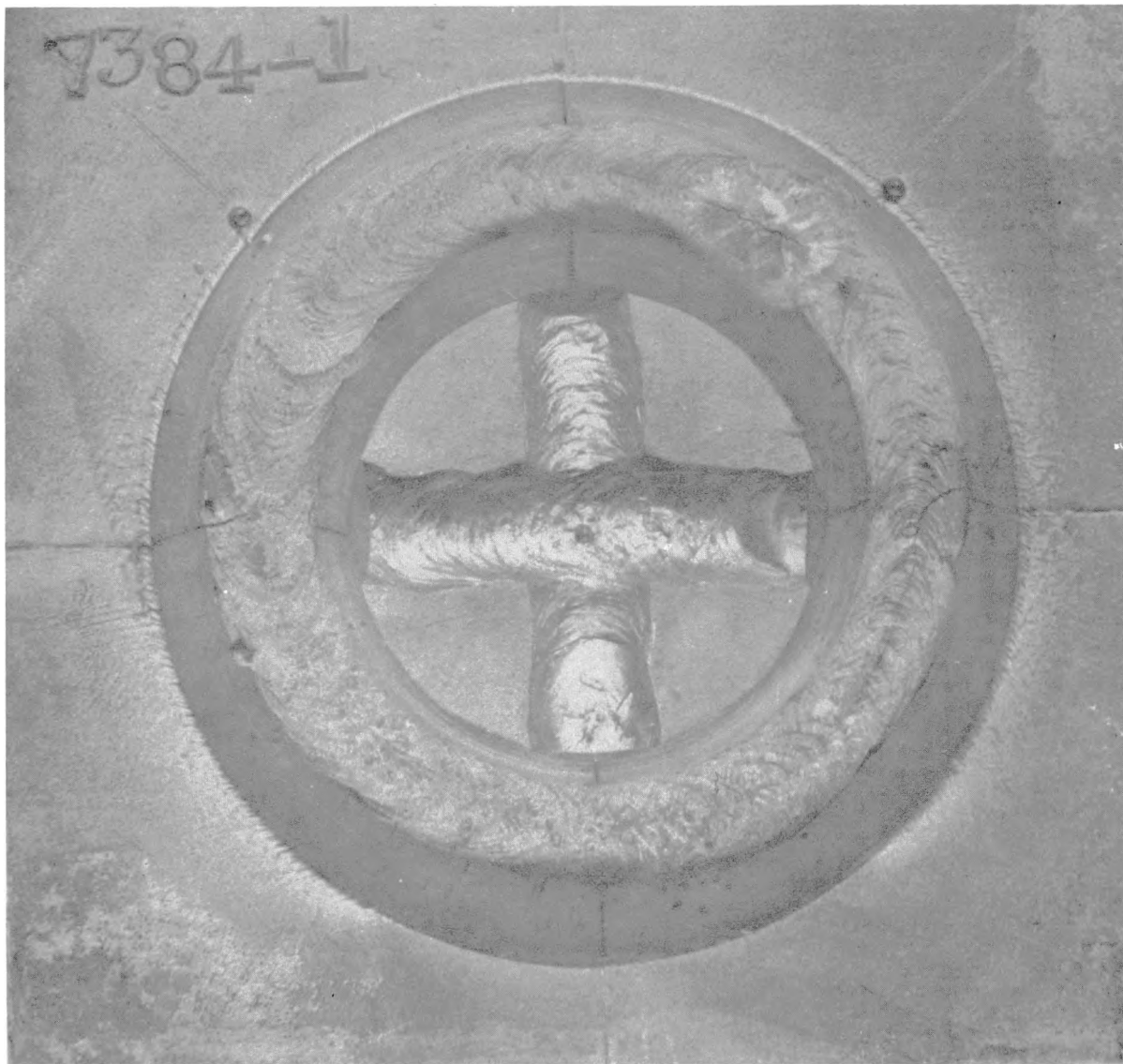


Figure 3. Typical appearance of cracks in segmented circular groove specimen. Approximately 2X.

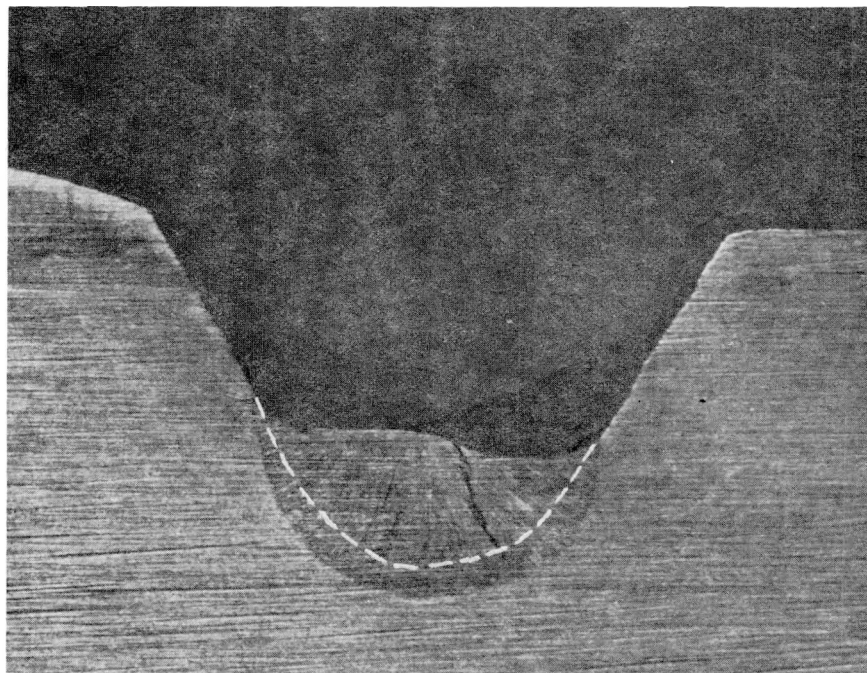


Figure 4. Photomicrograph of a cross section from a segmented circular-groove test specimen.

The area below the dotted line relative to the total weld bead area represents the proportion of base metal dilution. Note the crack extending from the top of the weld bead. Enlarged about 5X.

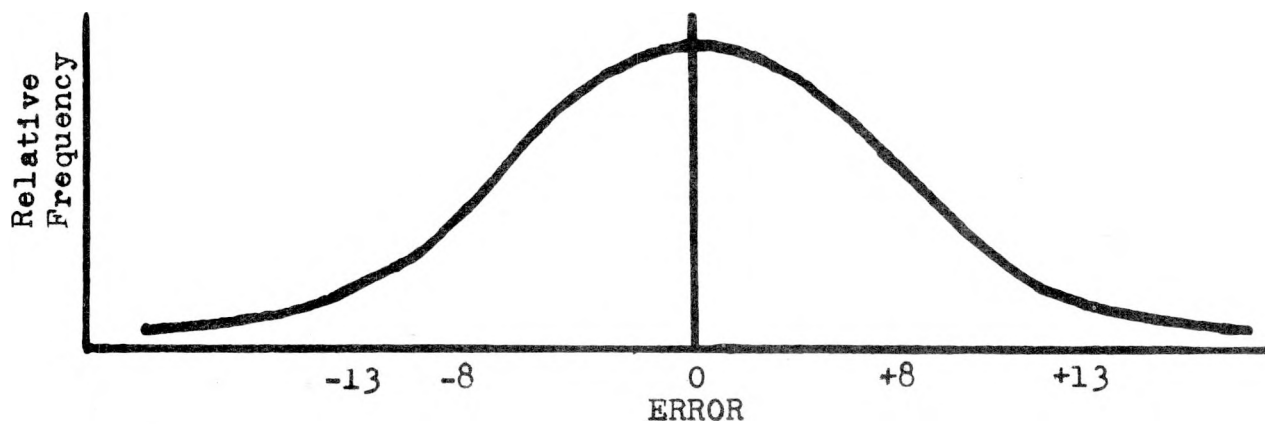


Figure 5. Normal frequency curve.

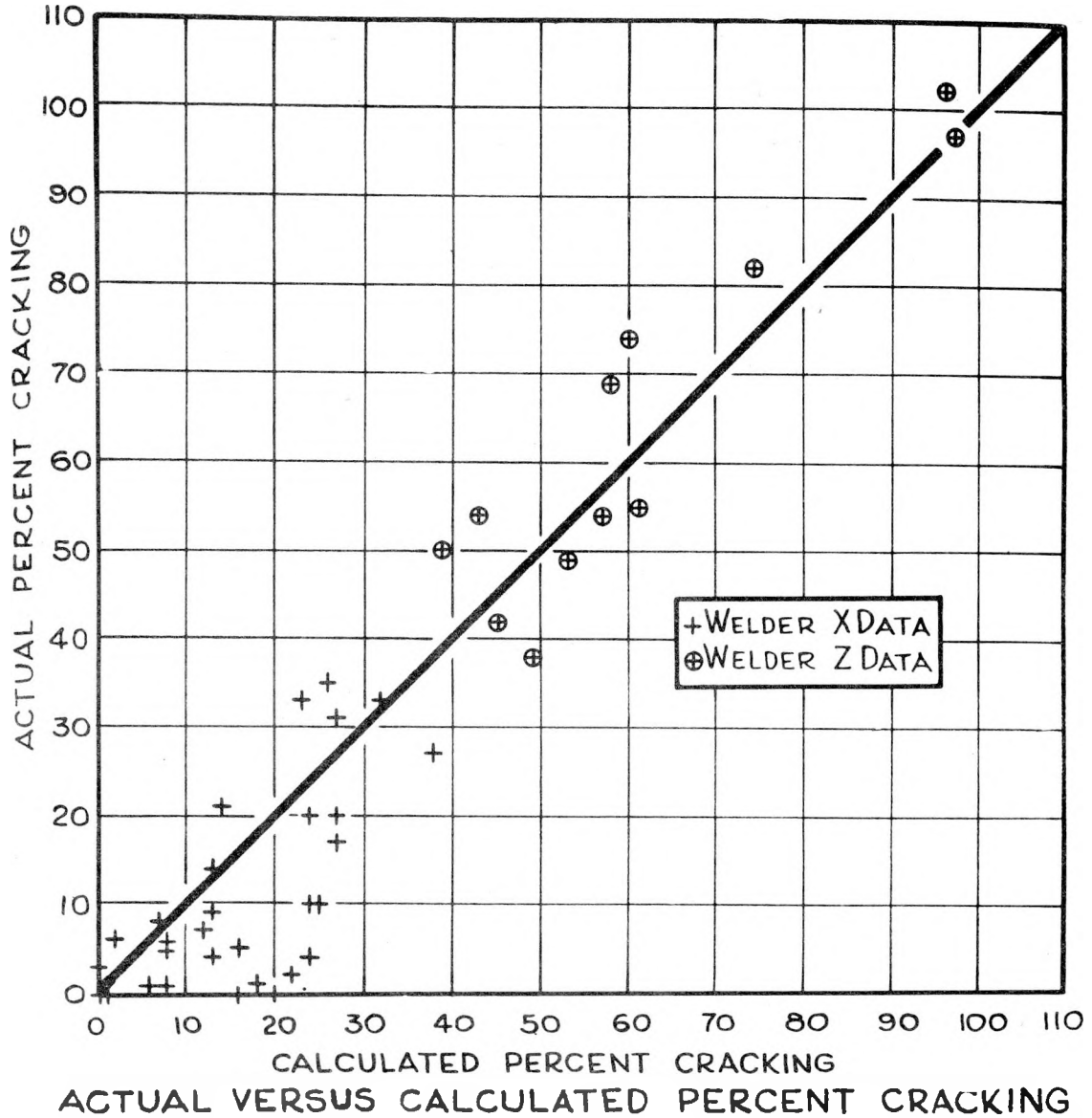
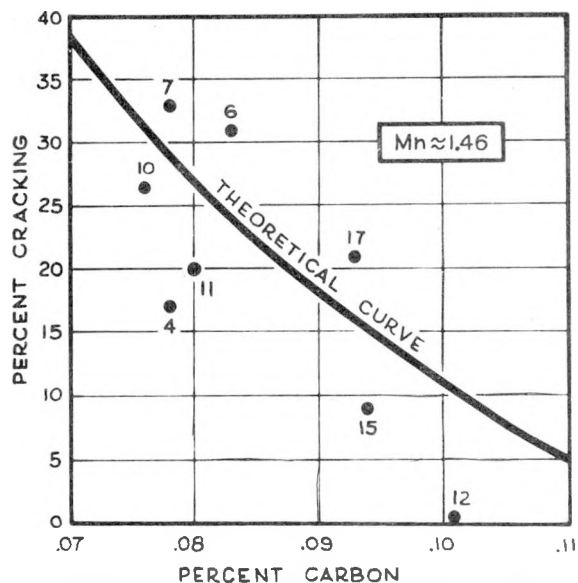
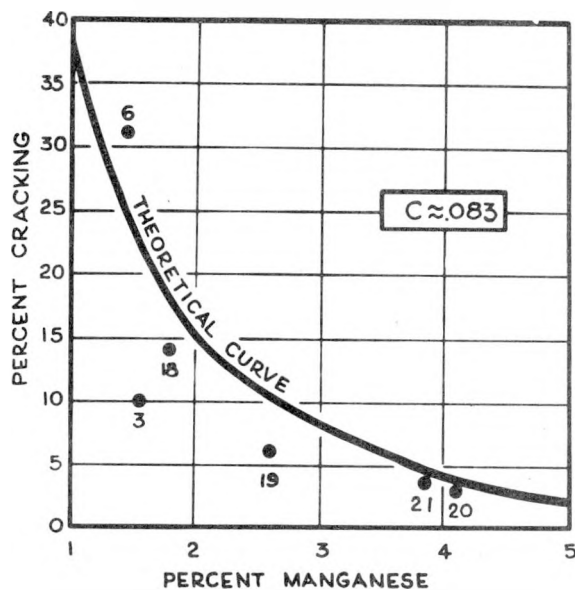


Figure 6. A comparison of the test data with the $X = Y$ line.

The welder Z cracking values are at higher level because the electrodes employed were the high phosphorus and high sulfur series.



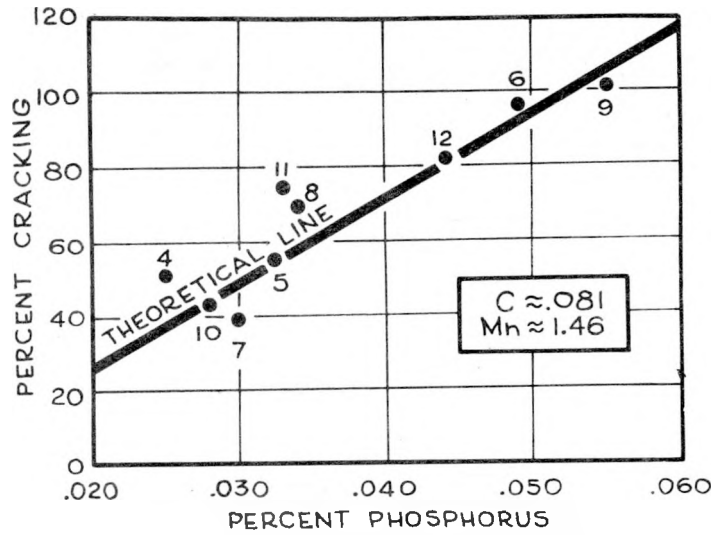
EFFECT OF CARBON CONTENT ON
SEGMENTED CIRCULAR GROOVE CRACKING



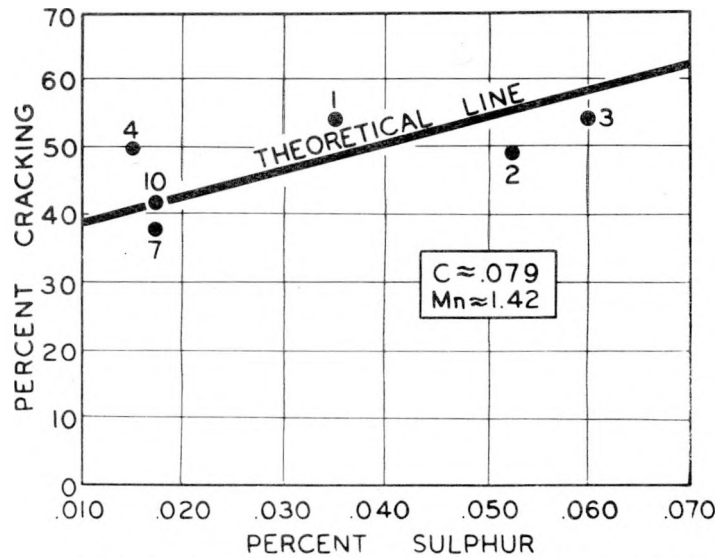
EFFECT OF MANGANESE CONTENT ON
SEGMENTED CIRCULAR GROOVE CRACKING

Figure 7. The effect of carbon and manganese variations on the measured segmented circular-groove cracking of fully austenitic Type 347 weld metal.

All elements but carbon were at standard levels for the top graph (except for high nickel). In like manner, all elements with the exception of manganese were at standard levels for the bottom graph. The numbers beside the points indicate welder "X" test numbers. The theoretical curve is a plot of the percent cracking equation (see Table 14) using average values for the points shown for all elements other than the major variable (carbon or manganese).



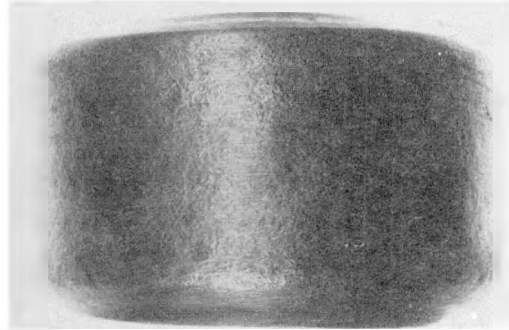
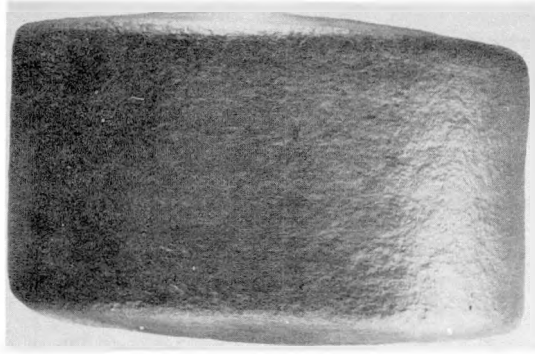
EFFECT OF PHOSPHORUS CONTENT ON SEGMENTED CIRCULAR GROOVE CRACKING



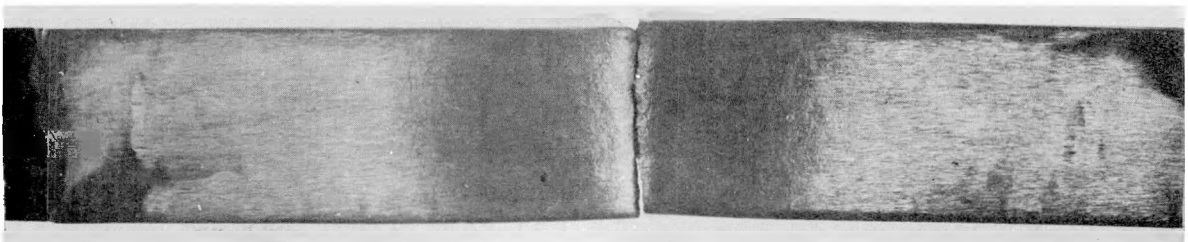
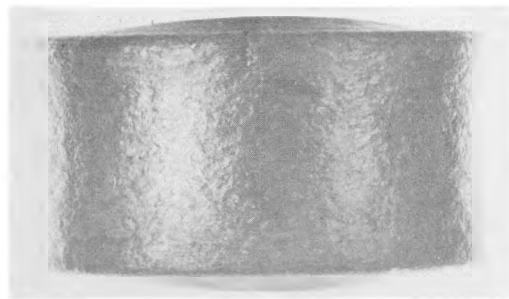
EFFECT OF SULPHUR CONTENT ON SEGMENTED CIRCULAR GROOVE CRACKING

Figure 8. The effect of phosphorus and sulfur content on the measured segmented circular-groove cracking of fully austenitic Type 347 weld metal at standard carbon and manganese levels.

The numbers beside the points indicate a welder "Z" test number. The theoretical line is a plot of the percent cracking equation (see Table 14) using average values for the points shown for all elements other than the major variable (phosphorus or sulfur).

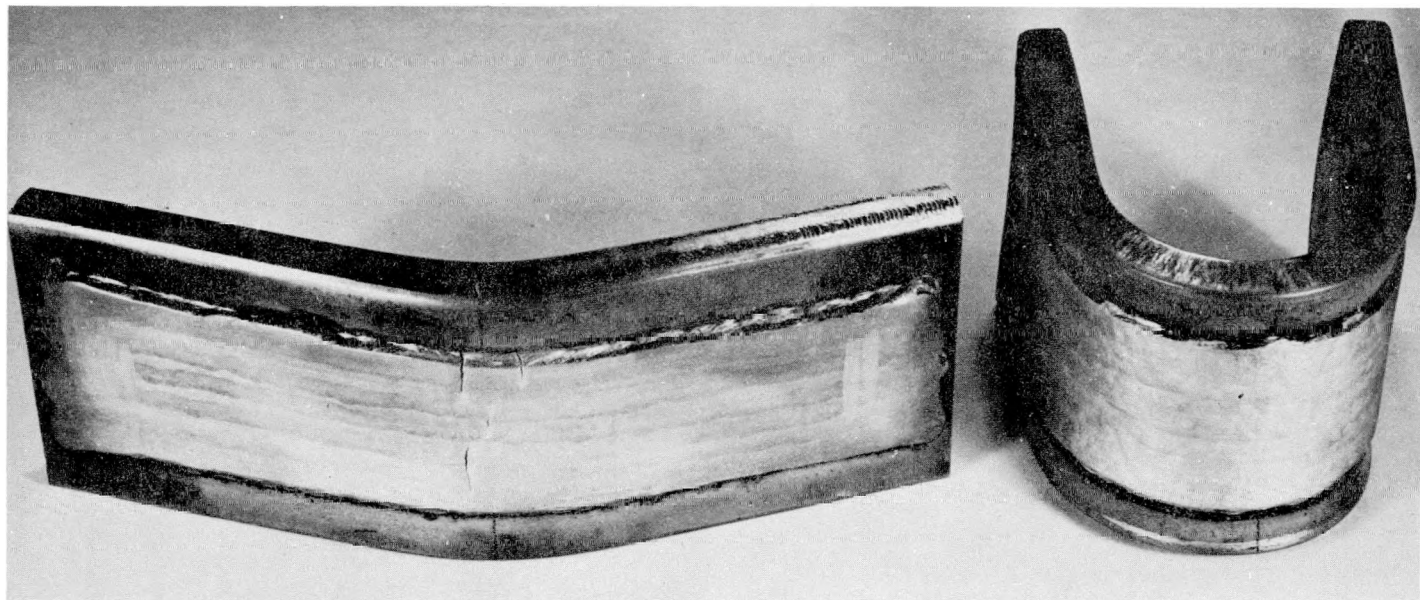


Overlays on Stainless Steel
Fully austenitic composition B top (note fissures).
Partially ferritic composition A bottom.



Overlays on Carbon Steel
Fully austenitic composition H top.
Partially ferritic composition A bottom.

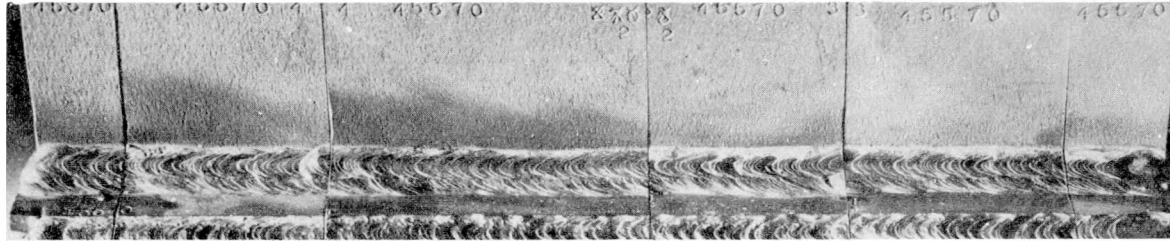
Figure 9: Typical appearance of fissure test specimens performed by Arcos and Crane Company.



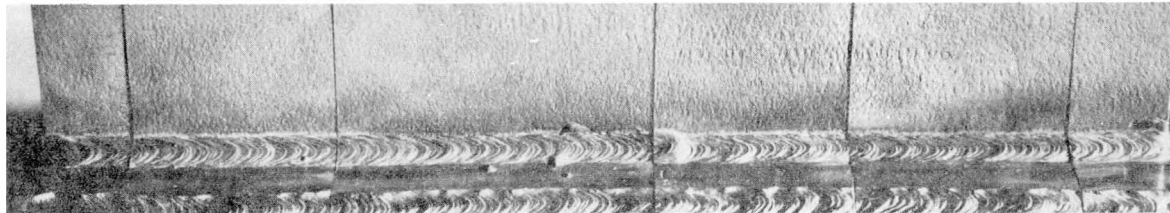
Overlay on Carbon Steel

Overlay on Stainless Steel

Figure 10 Typical appearance of fissure test specimens run by A.O. Smith Corp.
Electrode composition F.



Three pass side.



Single pass side.

Figure 11: Typical appearance of fillet welds deposited in the horizontal position. Electrode composition A.

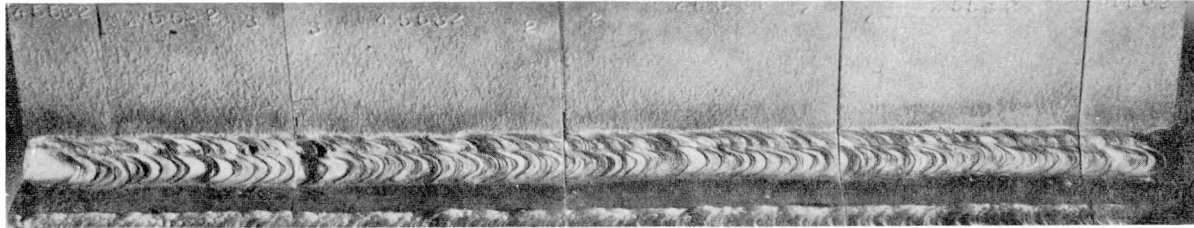


Single pass side.

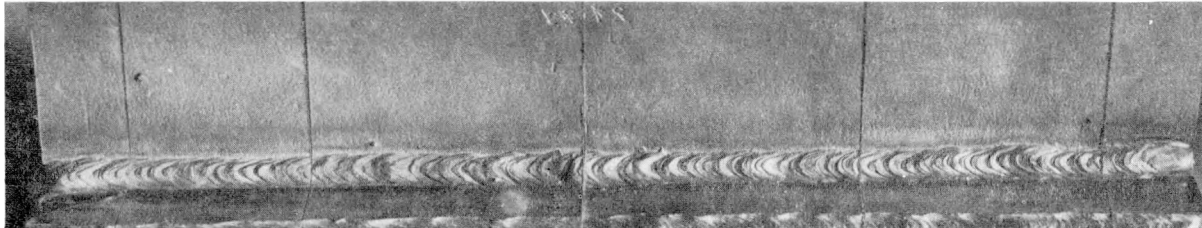


Three pass side.

Figure 12. Typical appearance of fillet welds made in the vertical position. Electrode composition A.

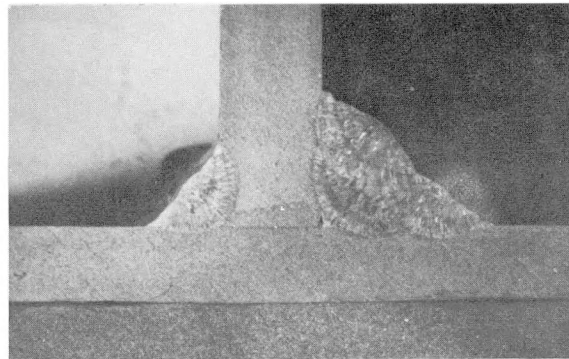


Three pass side.

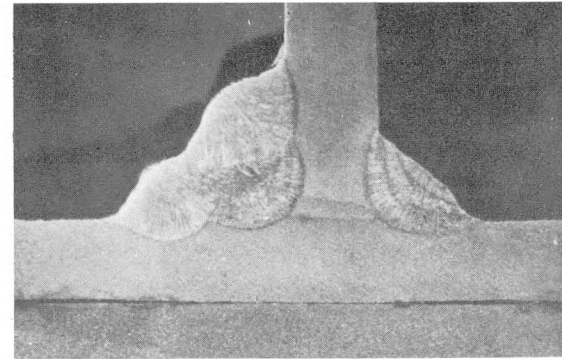


Single pass side.

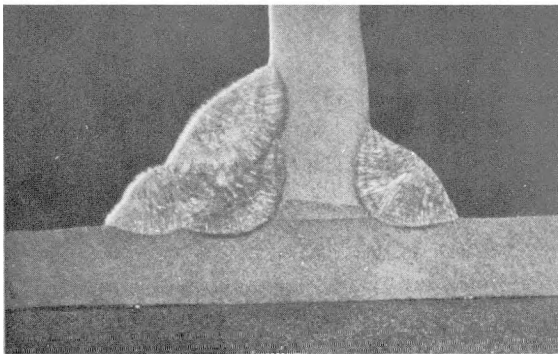
Figure 13: Typical appearance of fillet welds made in the overhead position. Composition A electrode.



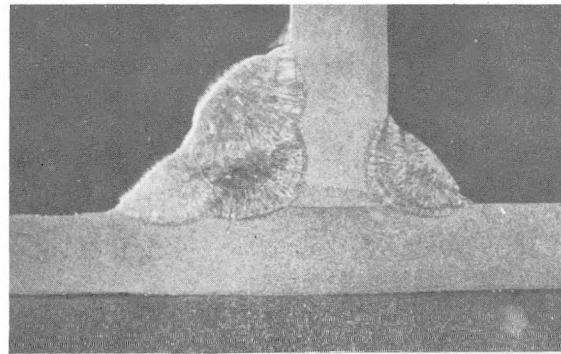
1" from start end.



at No. 2 crater.

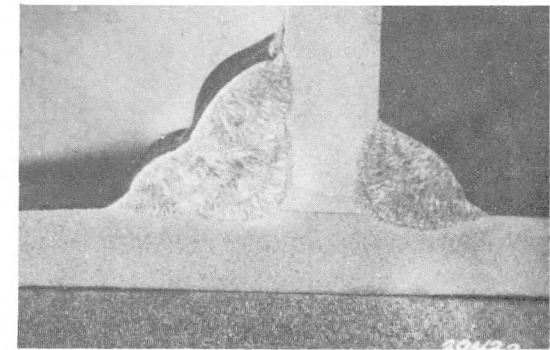


at No. 3 crater.



at No. 4 crater.

2X



1" from finish end.

Figure 14. Typical appearance of cross sections of fillet welds.
Composition D electrode.



Figure 15. Butt weld test plates before welding.

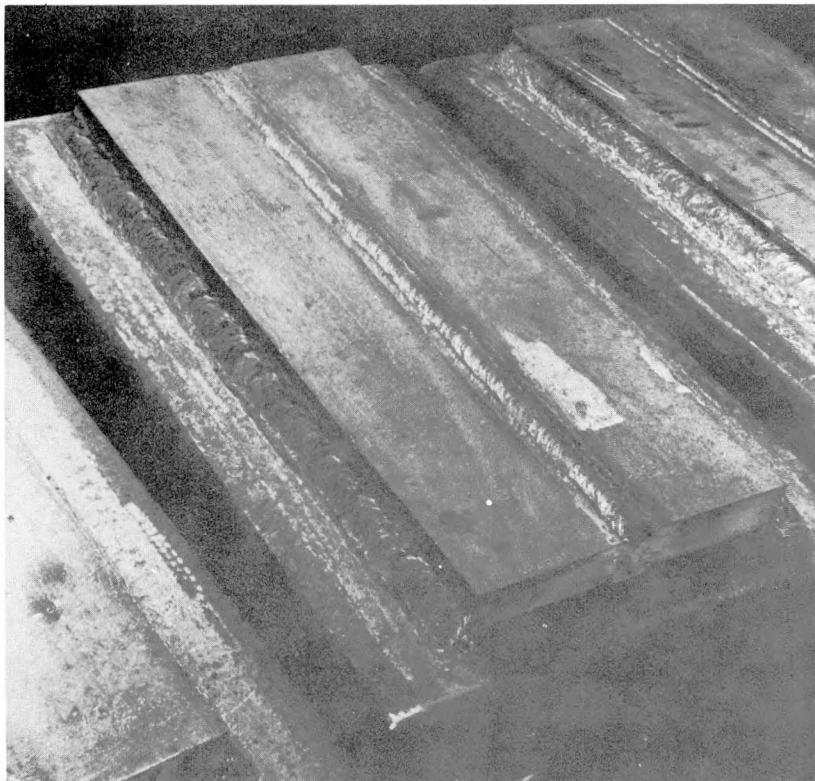
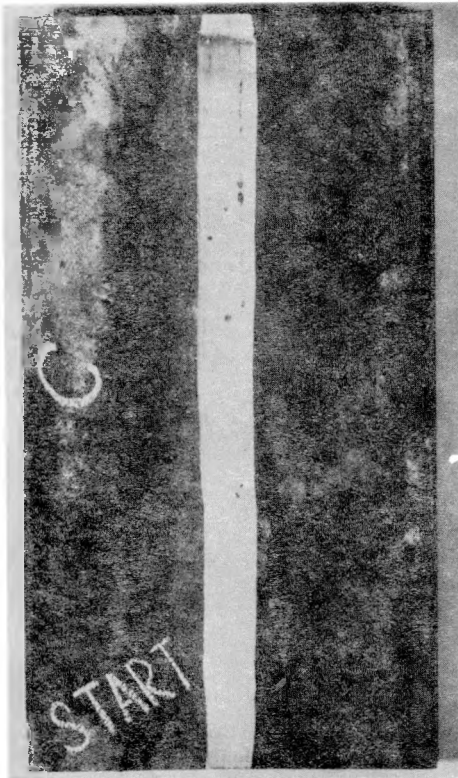
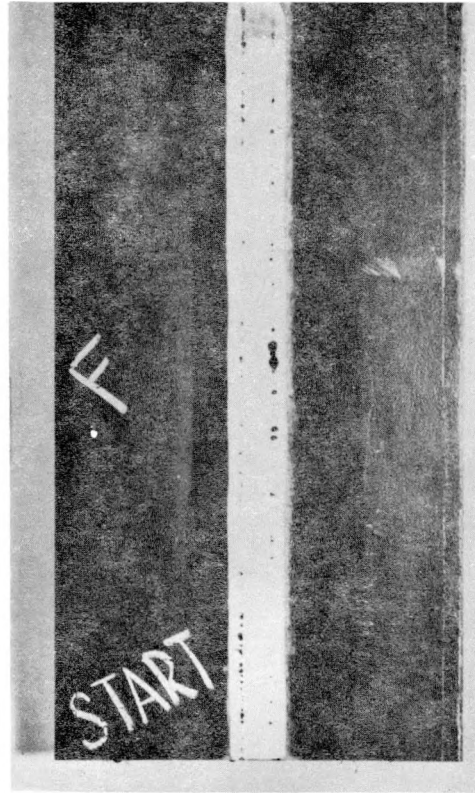


Figure 16. Butt weld test plates after welding.

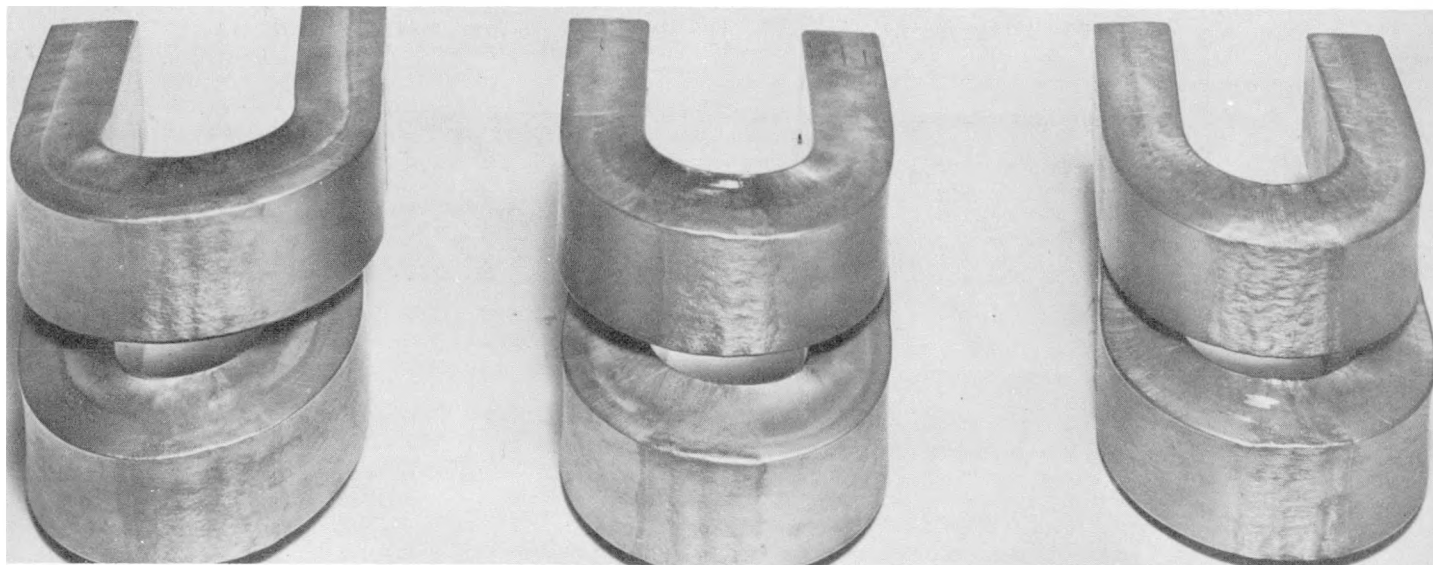


Test Plate C



Test Plate F

Figure 17. Example of defects revealed by Dy-Check inspection.

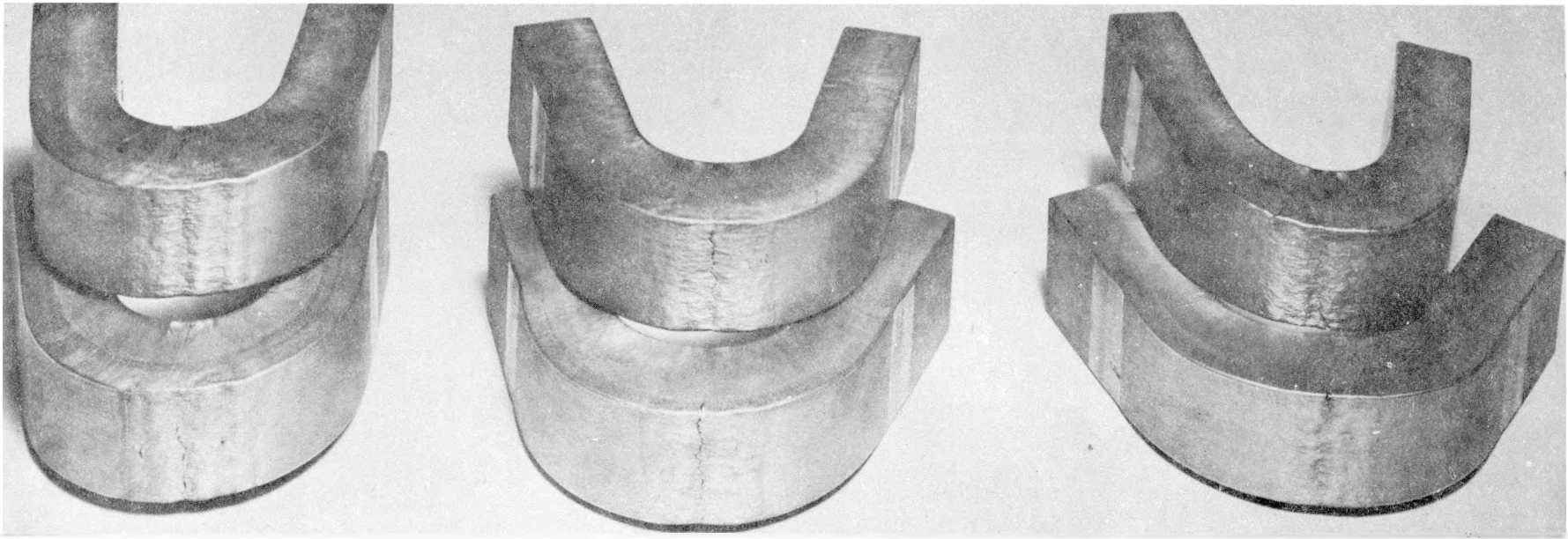


Composition A

Composition D

Composition F

Figure 18. Free face bend specimens from butt welds deposited with partially ferritic electrodes.

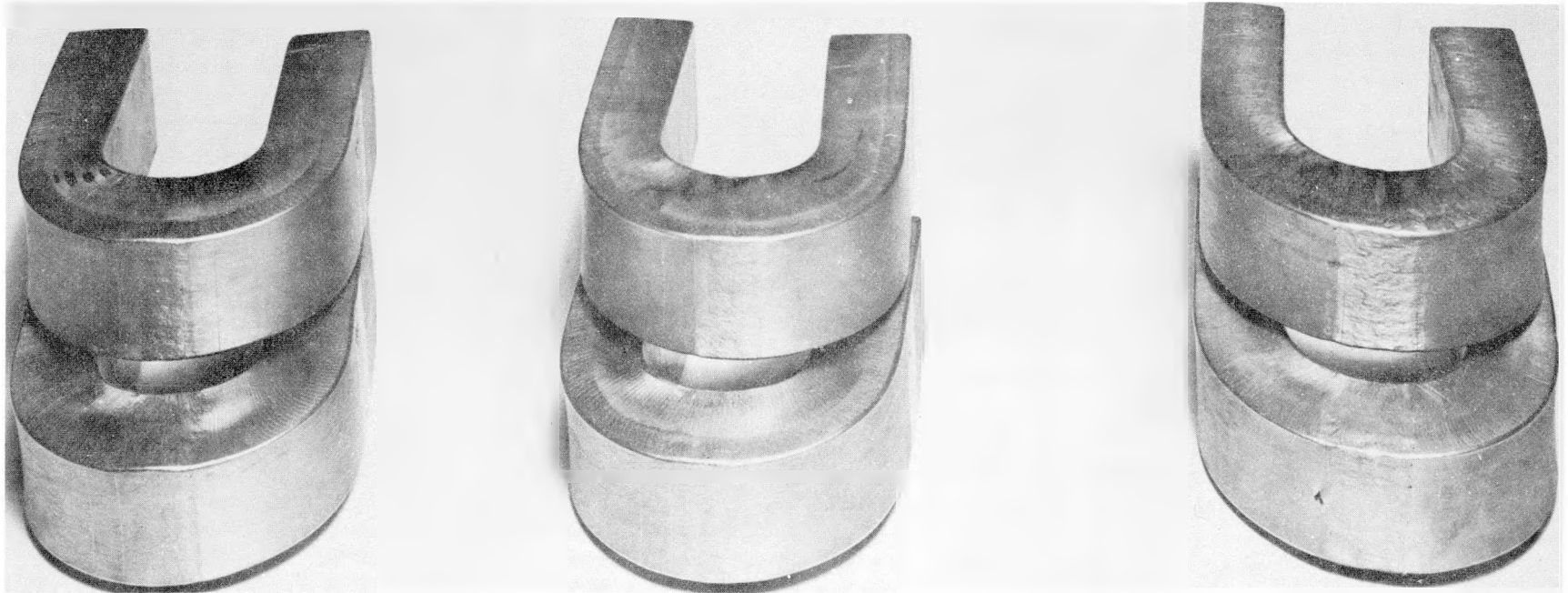


Composition H

Composition B

Composition C

Figure 19. Free face bend specimens from butt welds deposited with fully austenitic electrodes.

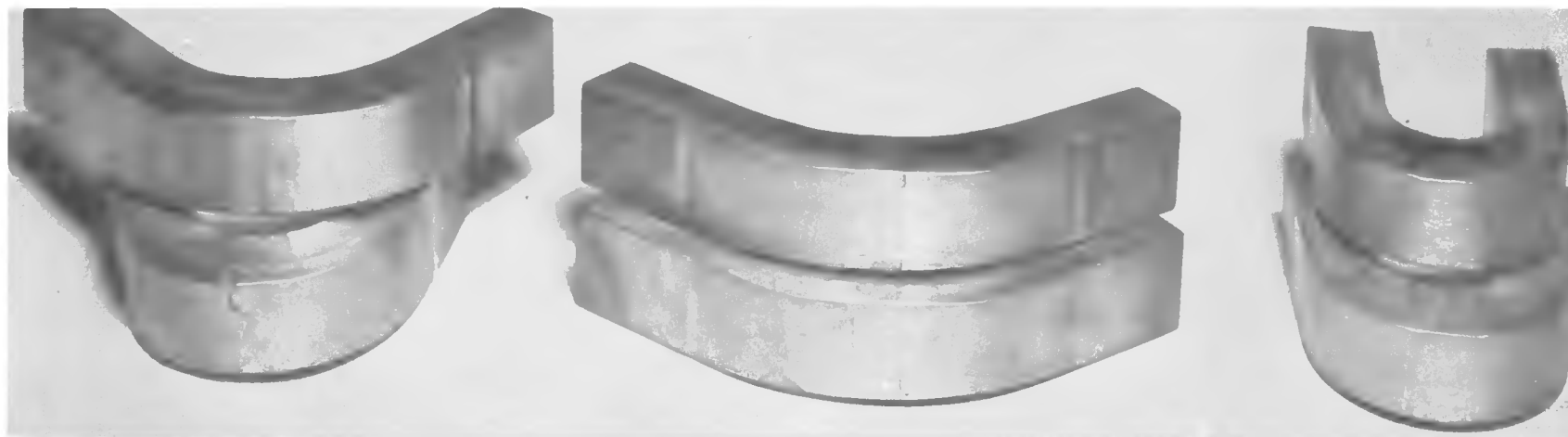


Composition A

Composition D

Composition F

Figure 20. Free root bend specimens from butt welds deposited with partially ferritic electrodes.

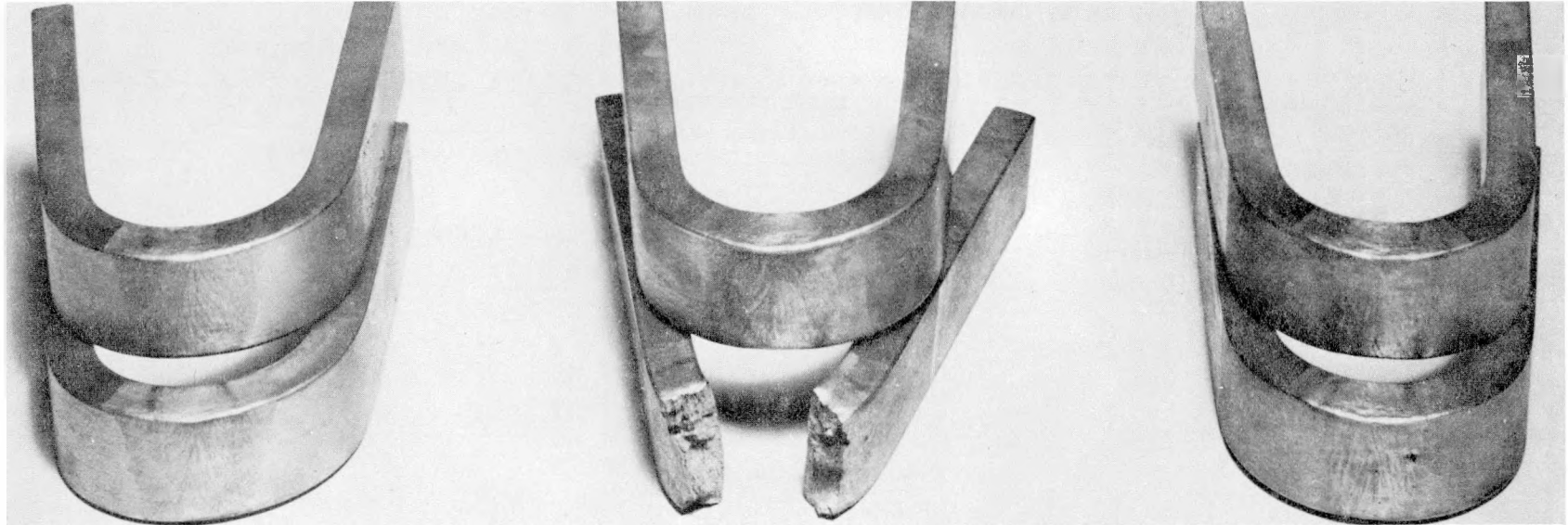


Composition H

Composition B

Composition C

Figure 21. Free root bend specimens from butt welds deposited with fully austenitic electrodes.



Composition A

Composition B

Composition C

Figure 22. Guided side bend specimens from butt welds.

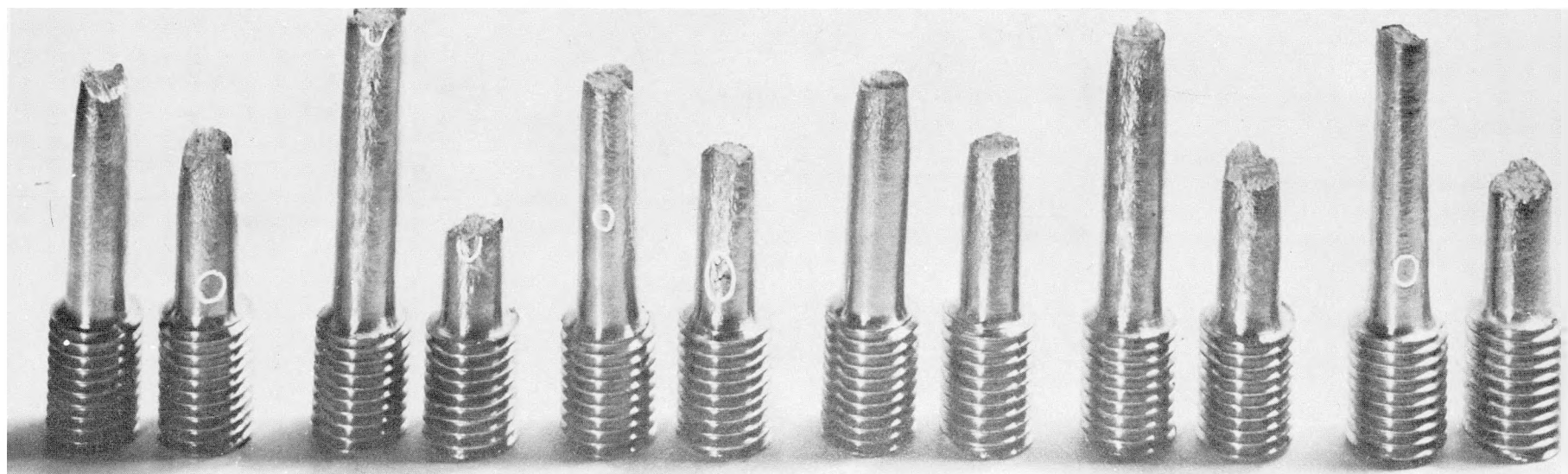


Composition D

Composition F

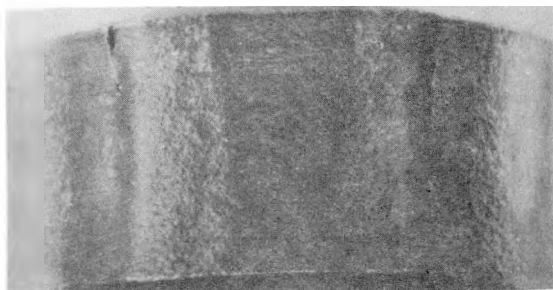
Composition H

Figure 23. Guided side bend specimens from butt welds.

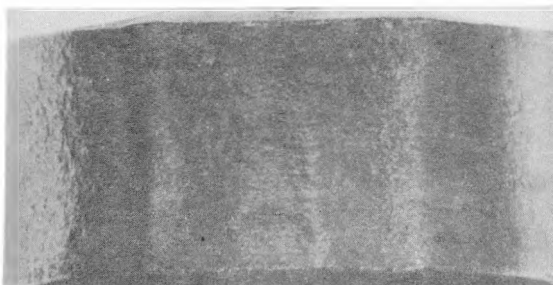


Composition A Composition B Composition C Composition D Composition F Composition H

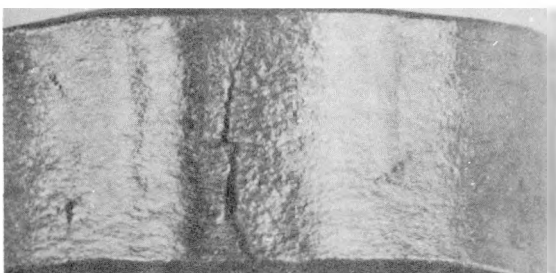
Figure 24. All-weld-metal .505" tensile bars cut from butt welds. Defects found by Zyglo prior to testing are circled.



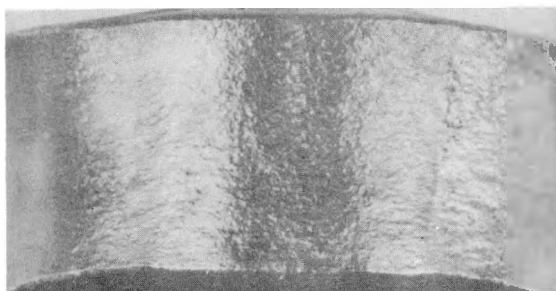
Composition A
45% Elongation
Bend Angle 180°
Specimen A5



Composition A
45% Elongation
Bend Angle 180°
Specimen A8

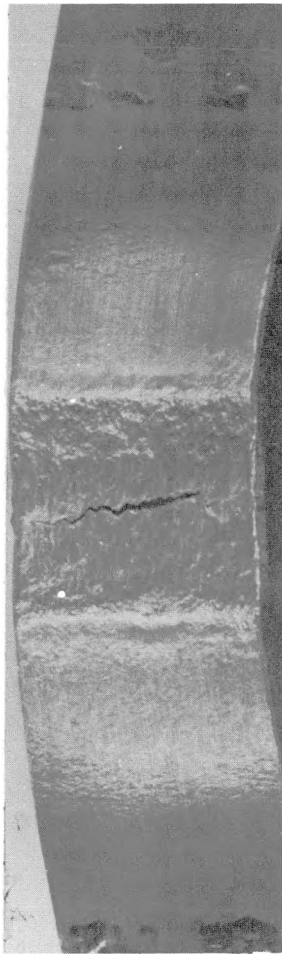


Composition D
40% Elongation
Bend Angle 180°
Specimen D8



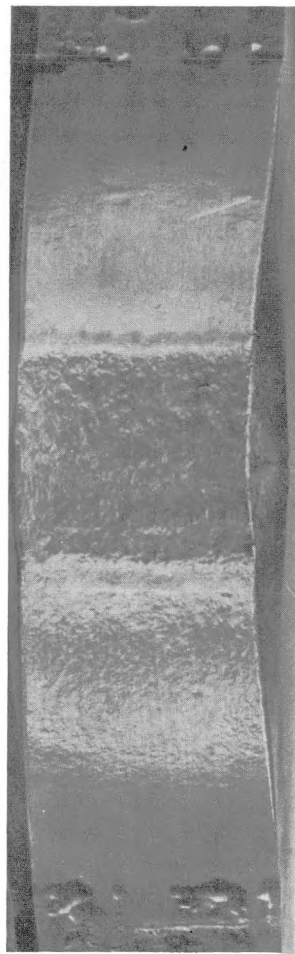
Composition D
39% Elongation
Bend Angle 180°
Specimen D5

Figure 25. Free face bend specimens from pipe welds deposited with partially ferritic electrodes A and D.



Composition B

37% Elongation
Bend Angle 80°
Specimen B5

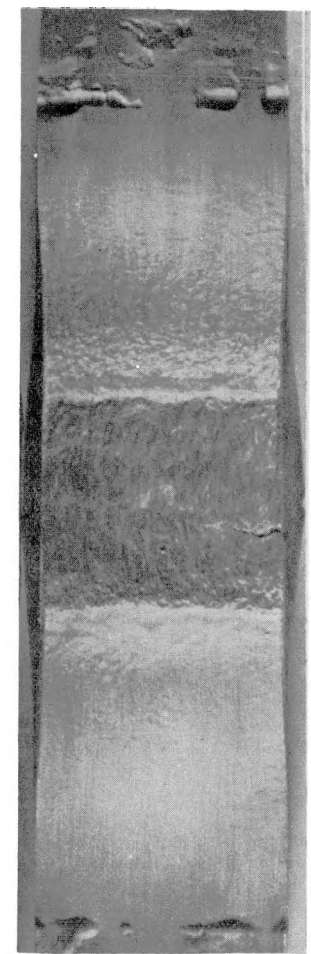


34% Elongation
Bend Angle 76°
Specimen B8



Composition C

33% Elongation
Bend Angle 79°
Specimen C8

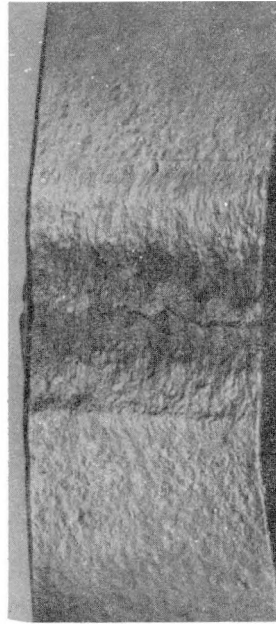


30% Elongation
Bend Angle 73°
Specimen C5

Figure 26. Free face bend specimens from pipe welds deposited with fully austenitic electrodes B and C.

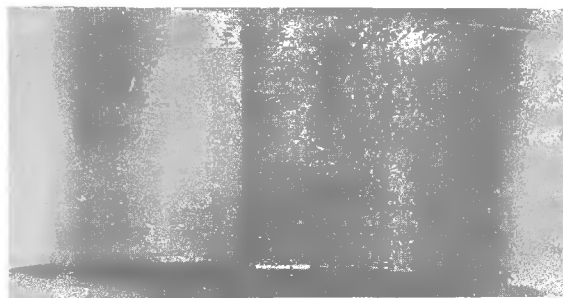


37% Elongation
Bend Angle 80°
Specimen H8

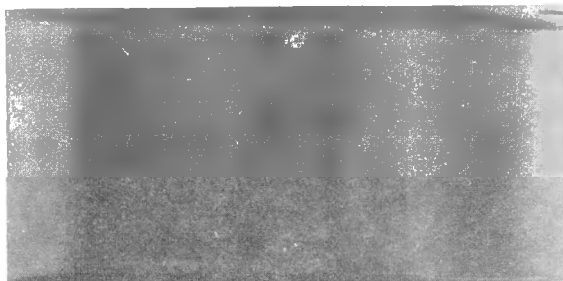


37% Elongation
Bend Angle 80°
Specimen H5

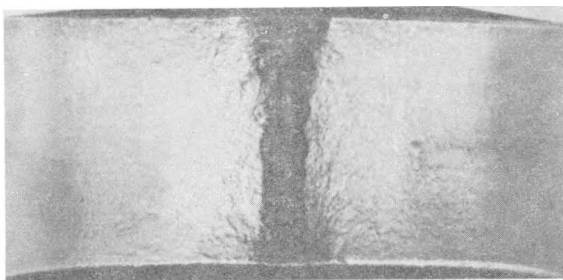
Figure 27. Free face bend specimens from pipe weld deposited with fully austenitic electrode H.



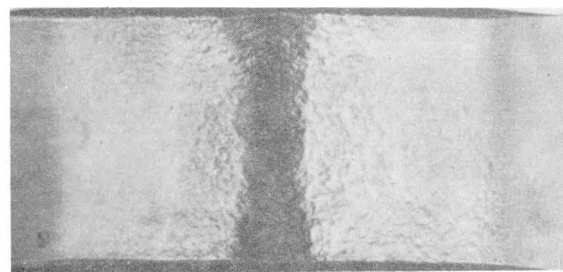
Composition A
36% Elongation
Specimen A6



Composition A
38% Elongation
Specimen A7

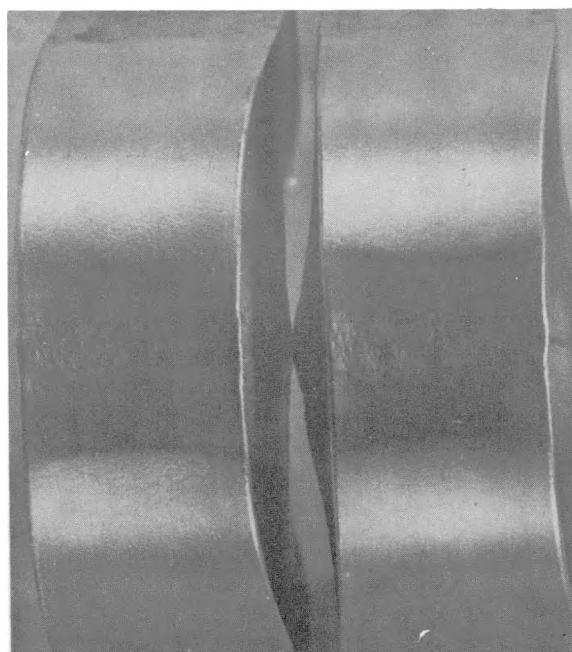


Composition D
36% Elongation
Specimen D6



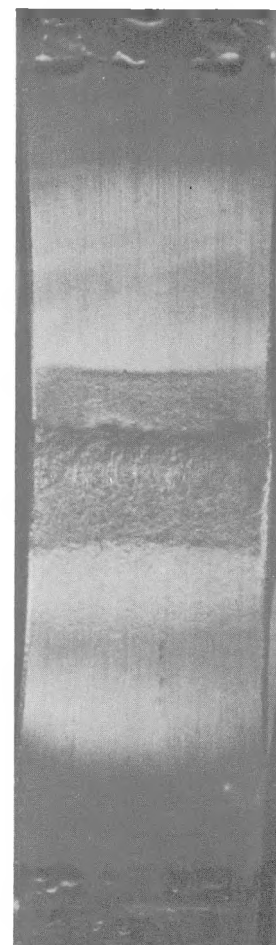
Composition D
33% Elongation
Specimen D7

Figure 28. Free root bend specimens from pipe welds deposited with partially ferritic electrodes A and D.

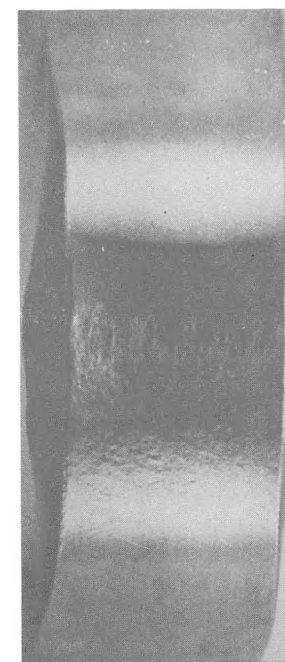


Composition B
Specimen B6
37% Elongation

Composition B
Specimen B7
33% Elongation

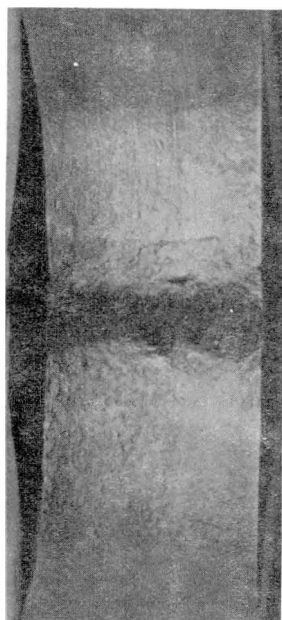


Composition C
Specimen C6
28% Elongation

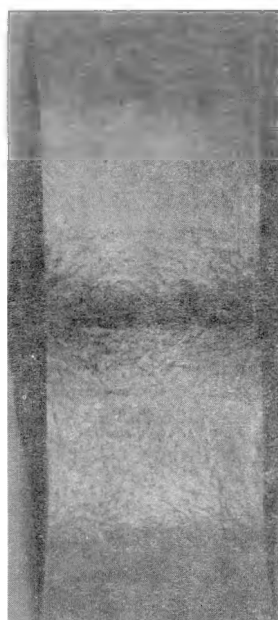


Composition C
Specimen C7
29% Elongation

Figure 29. Free root bend specimens from pipe welds deposited with fully austenitic electrodes B and C.

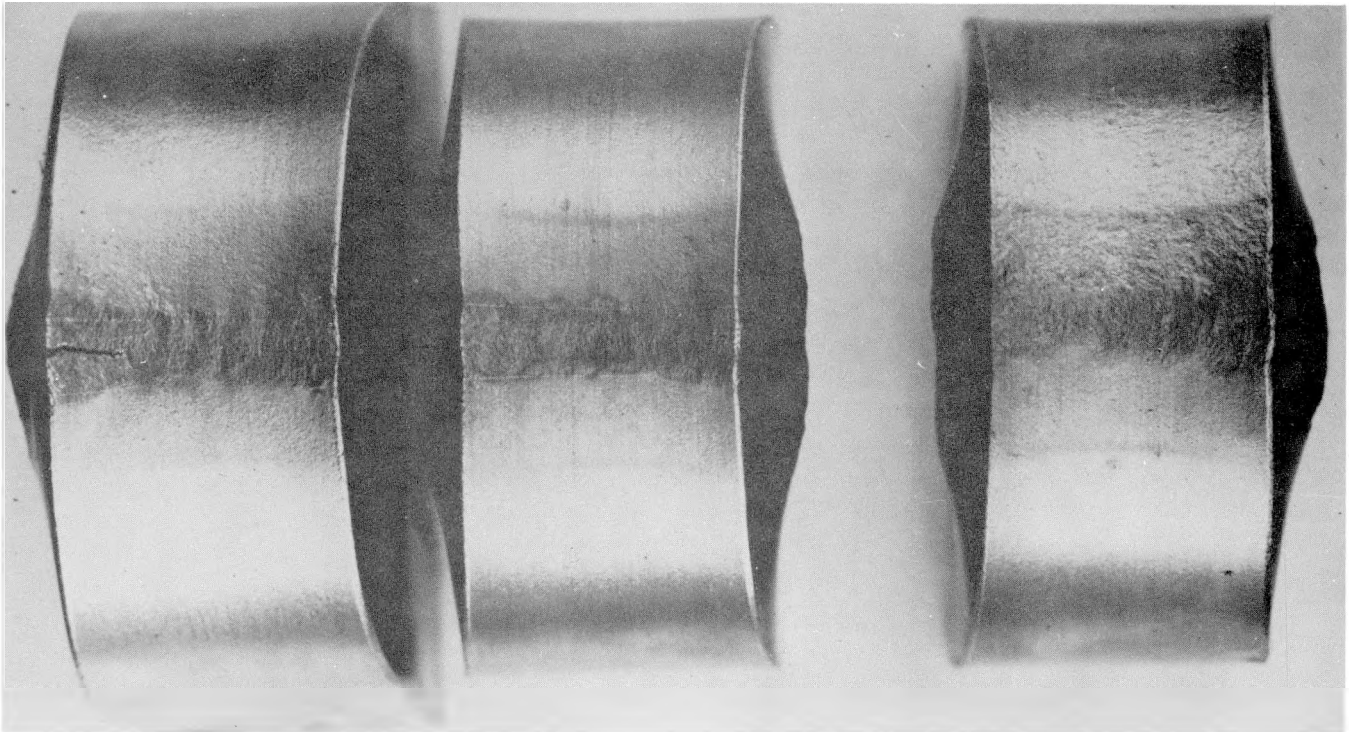


Compositon H
Specimen H6
33% Elongation



Composition H
Specimen H7
37% Elongation

Figure 30. Free root bend specimens from pipe welds deposited with fully austenitic electrode H.



Composition B
Specimen B6
42% Elongation

Composition B
Specimen B7
38% Elongation

Composition C
Specimen C7
37-1/2% Elongation

Figure 31. Free root bend specimens from pipe welds deposited with fully austenitic electrodes B and C which were bent to 180°.

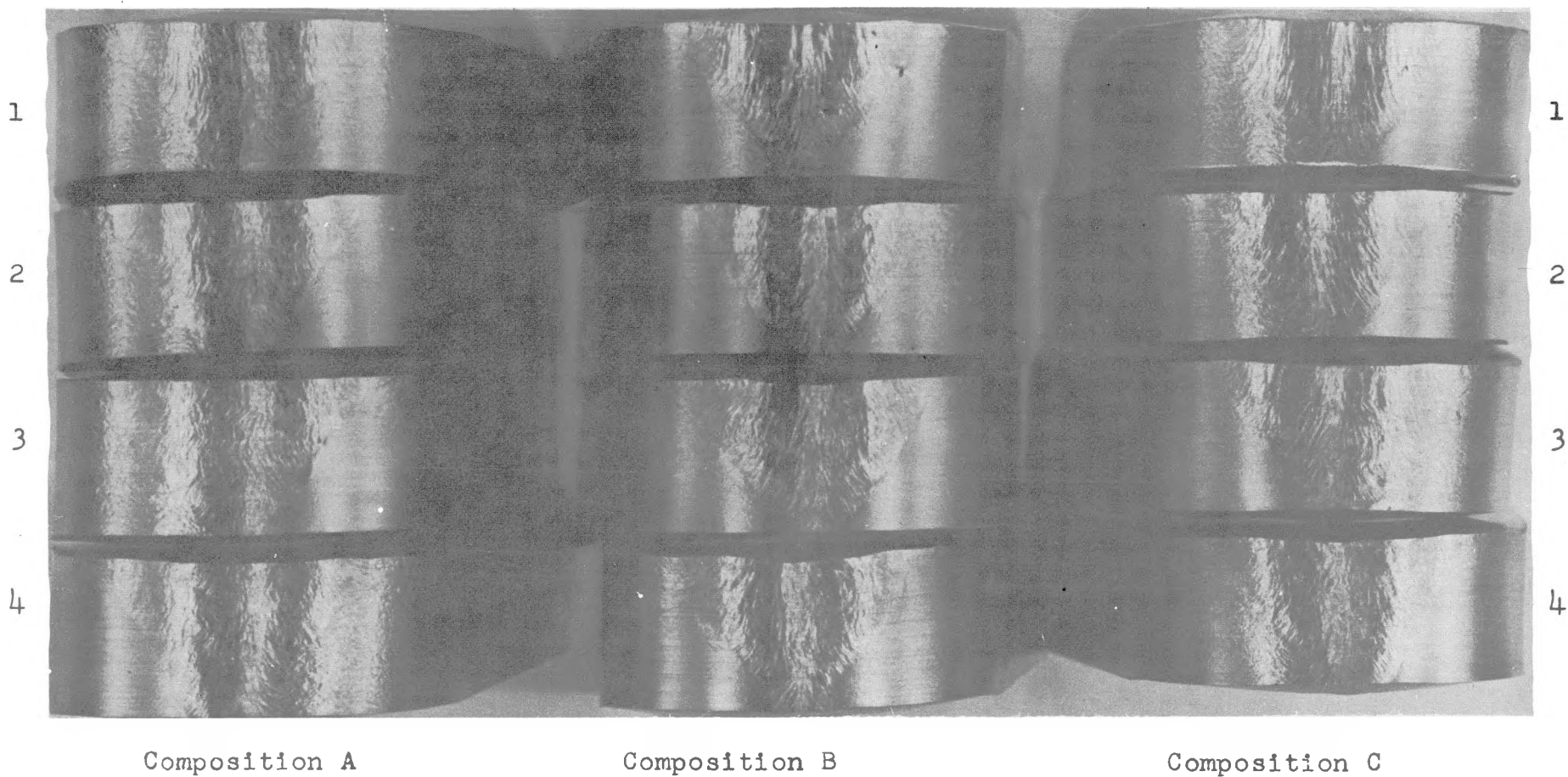
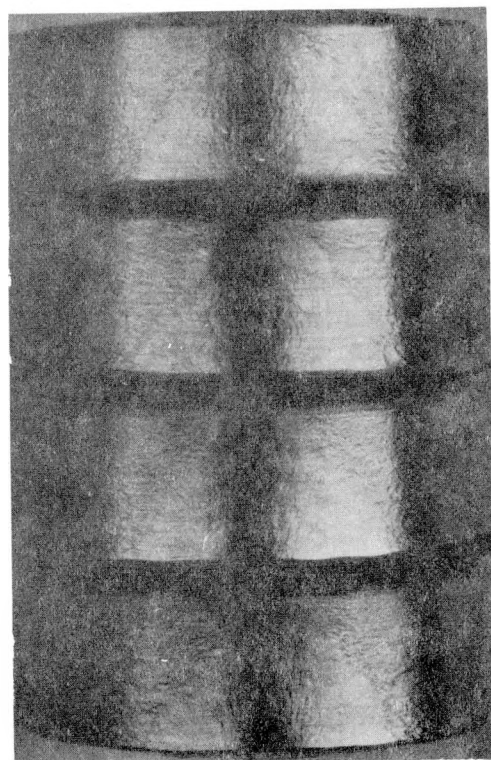
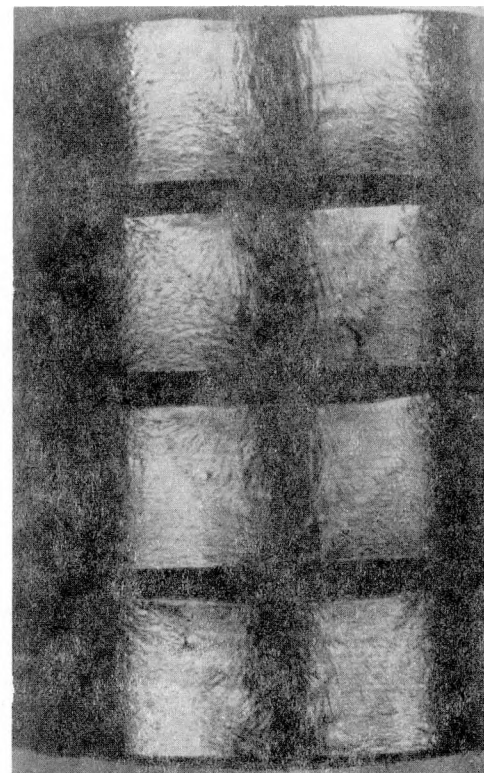


Figure 32. Guided side bend tests from pipe welds deposited with partially ferritic electrode A and fully austenitic electrodes B and C.

Note: Specimen 1 taken from flat position of welding.
Specimens 2 and 4 taken from vertical position of welding.
Specimen 3 taken from overhead position of welding.



Composition D



Composition H

Figure 33. Guided side bend tests from pipe welds deposited with partially ferritic electrode D and fully austenitic electrode H.

Note: Specimen 1 taken from flat position of welding.
Specimen 2 and 4 taken from vertical position of welding.
Specimen 3 taken from overhaed position of welding.

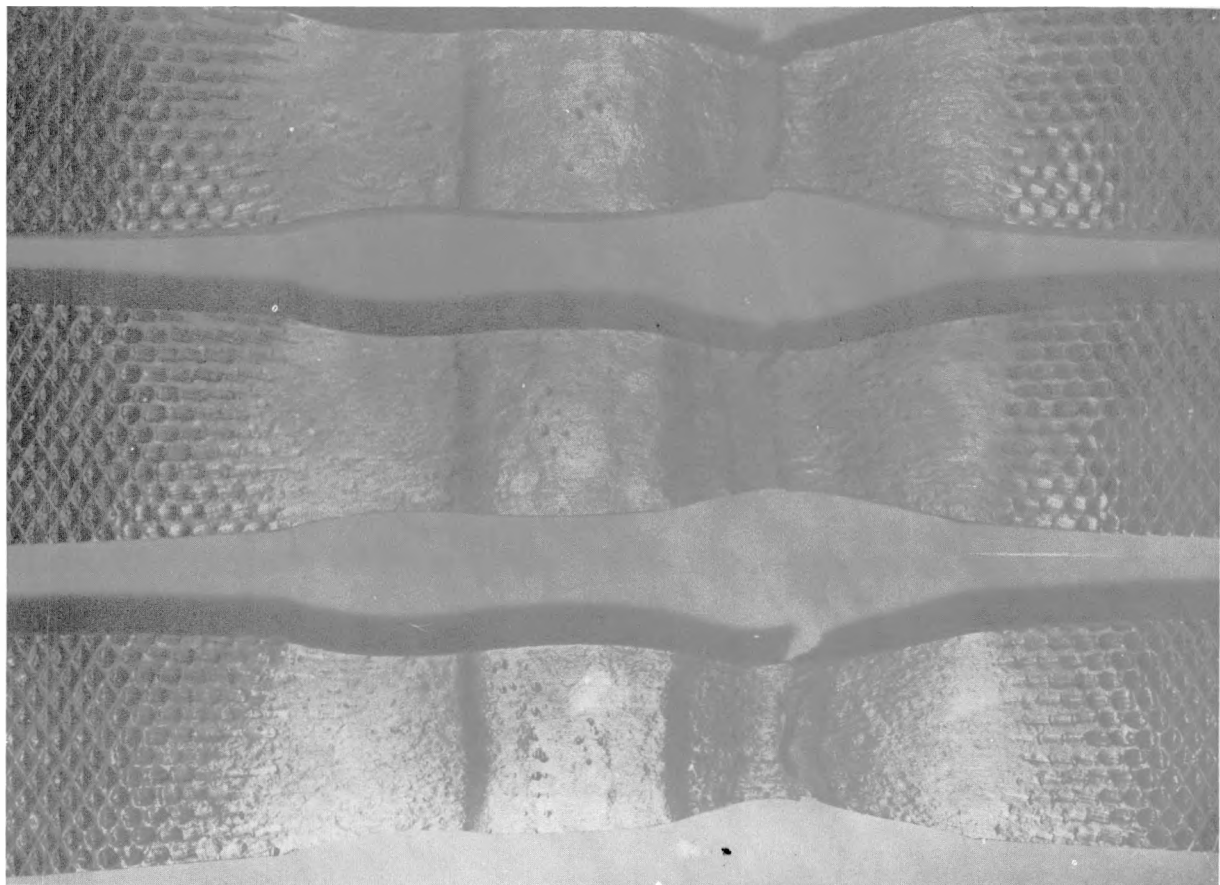


Figure 34. Transverse tensile specimens from pipe weld deposited with partially ferritic composition A electrodes.

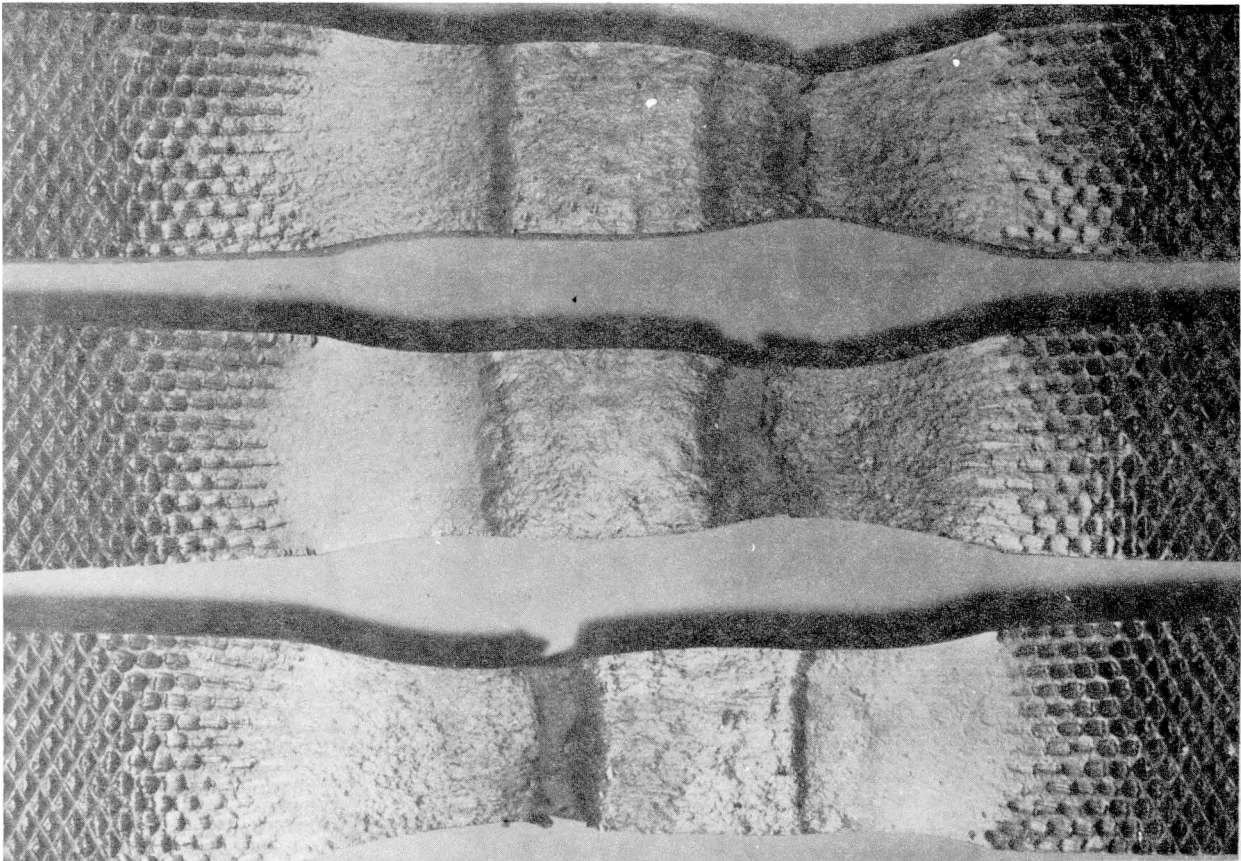
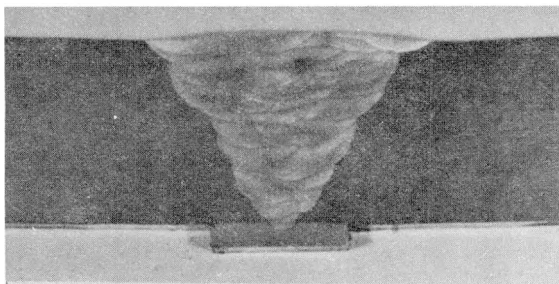
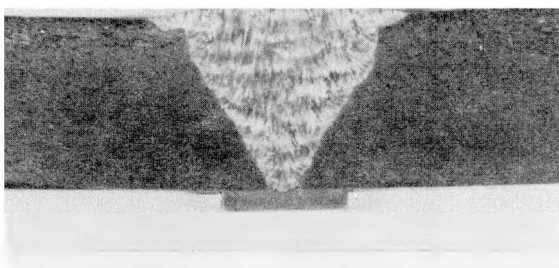


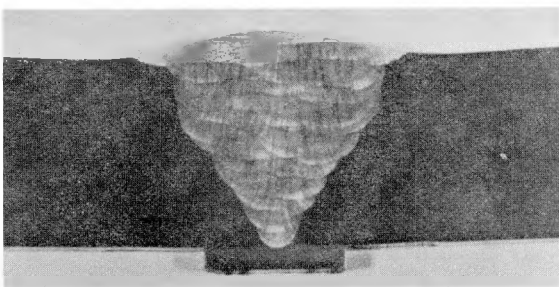
Figure 35. Transverse tensile specimens from pipe weld deposited with fully austenitic composition C electrode.



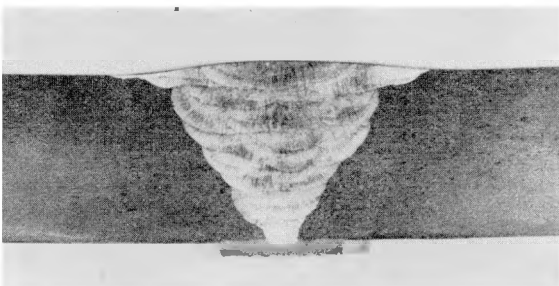
Partially ferritic
Composition A



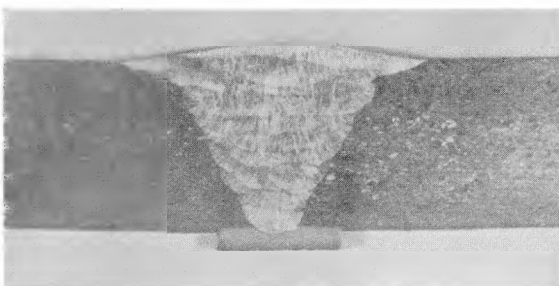
Fully austenitic
Composition B



Fully austenitic
Composition C

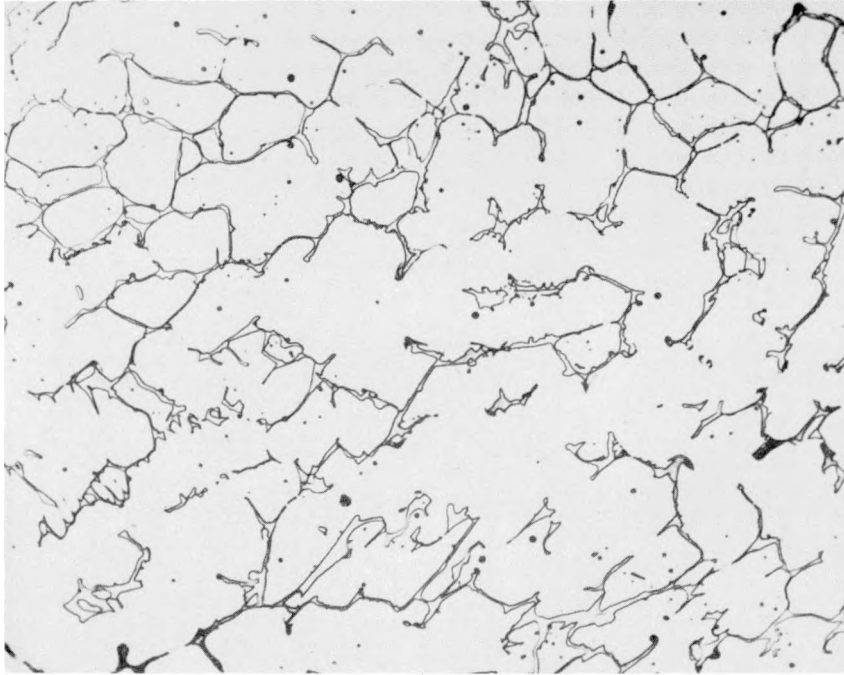


Partially ferritic
Composition D



Fully austenitic
Composition H

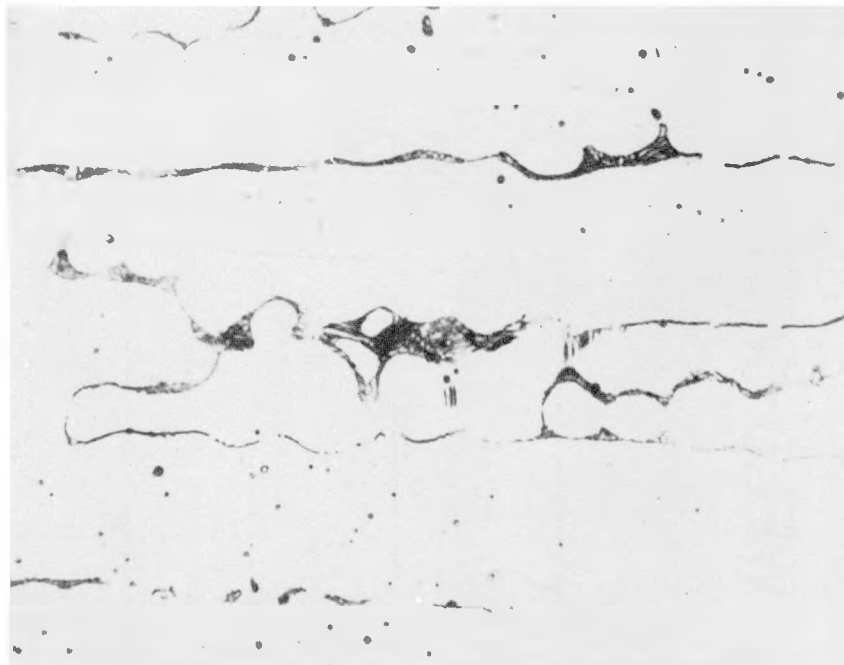
Figure 36. Typical macrosections of pipe welds deposited with the various electrodes. 1X



HCL-PICRAL

600X

Microstructure typical of partially ferritic compositions A and D.



HCL-PICRAL

1500X

Microstructure typical of fully austenitic compositions B, C, and H.

Figure 37. Microstructures typical of the partially ferritic and fully austenitic weld deposits.

ALL-WELD-METAL CORROSION SPECIMEN

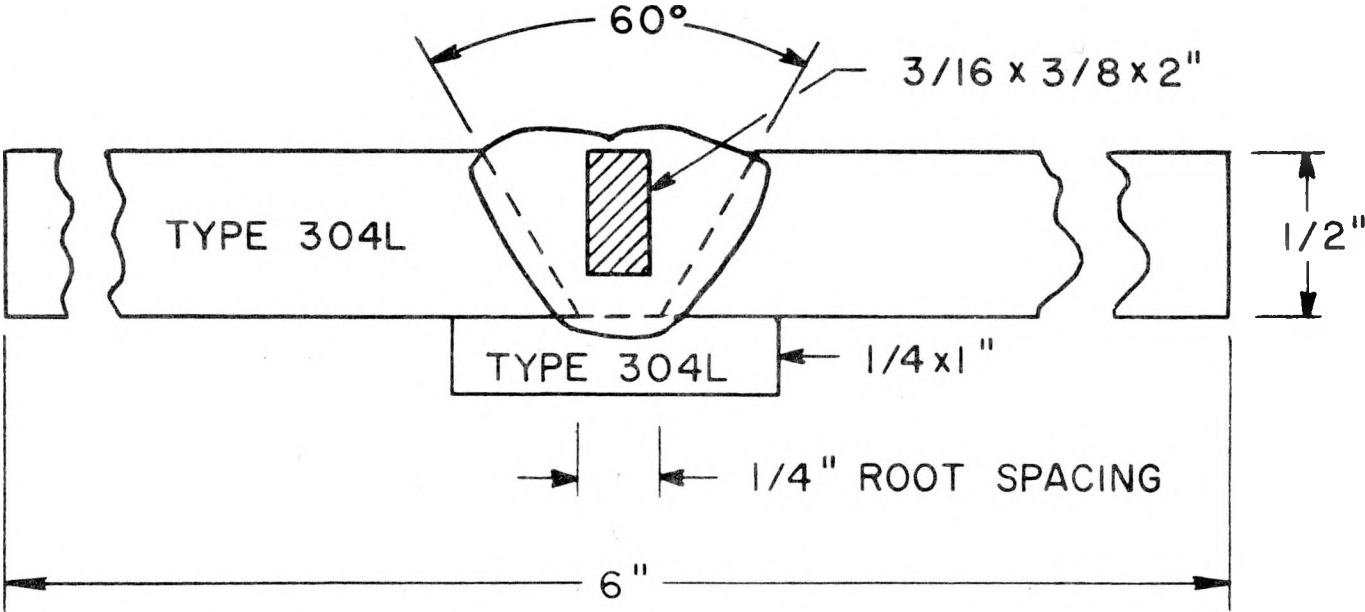


Figure 38. Specimen design for corrosion test program.

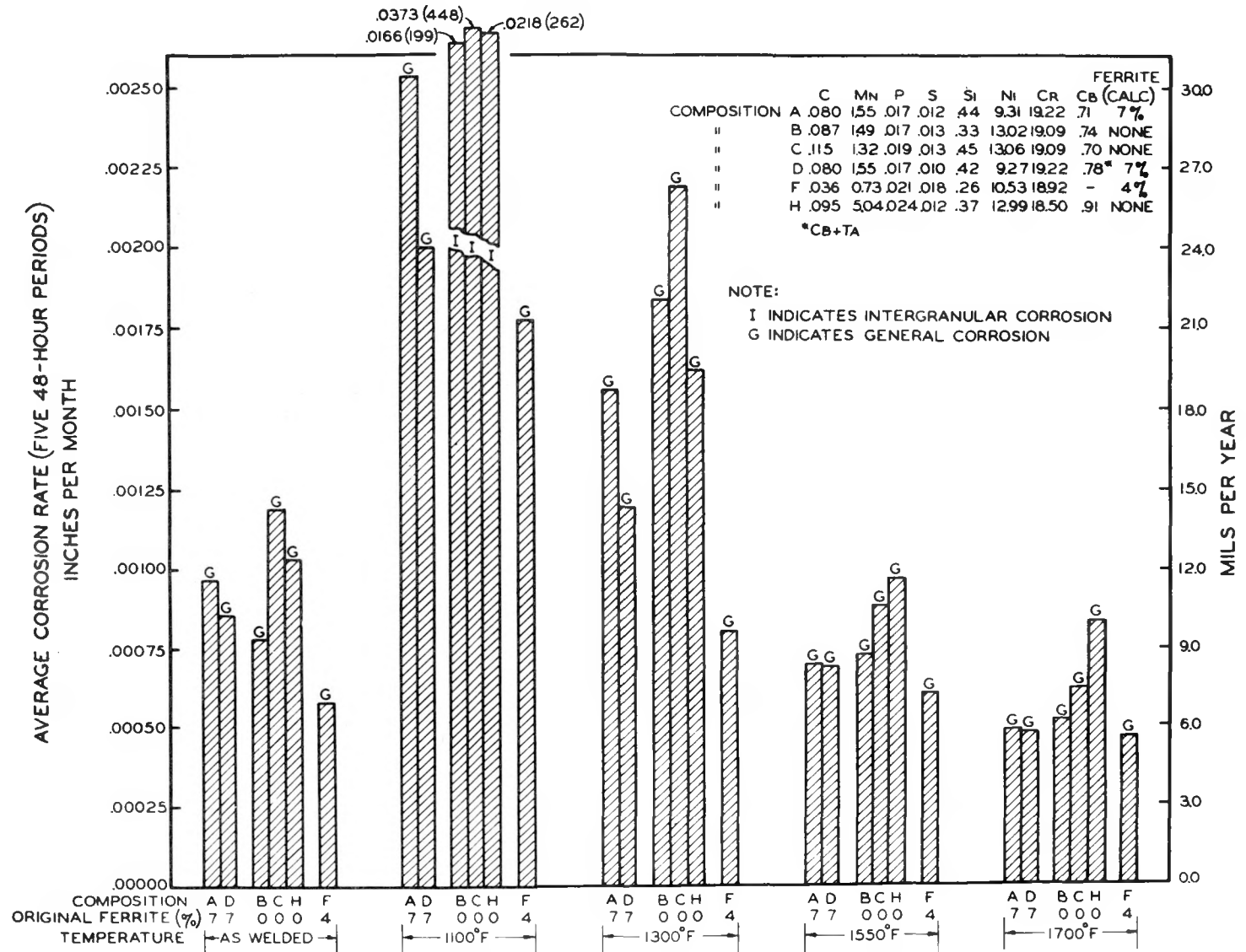


Figure 39 EFFECT OF 8-HOUR HEAT TREATMENTS ON THE NITRIC ACID CORROSION RATE OF MODIFIED TYPE 347 WELD DEPOSITS

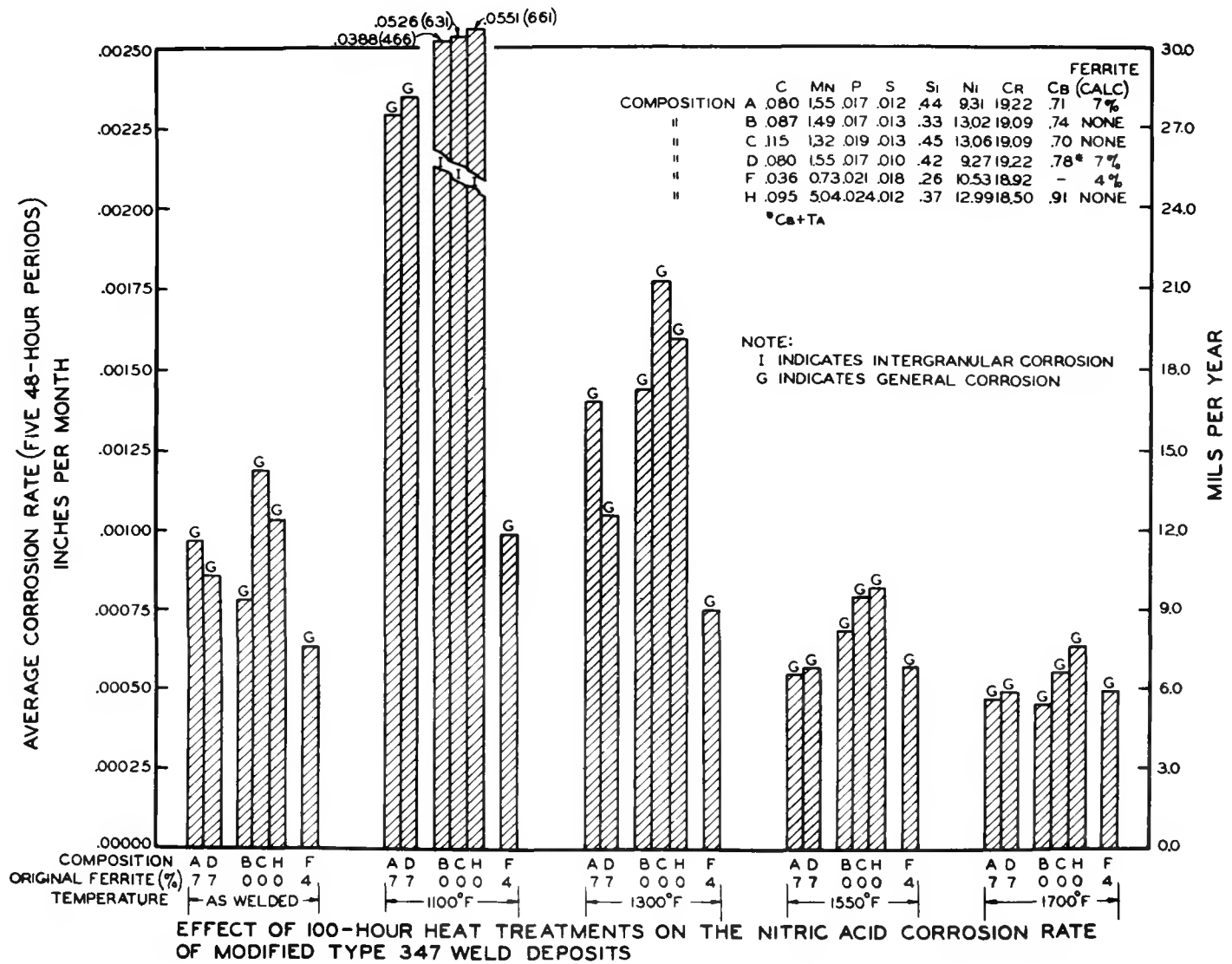


Figure 40

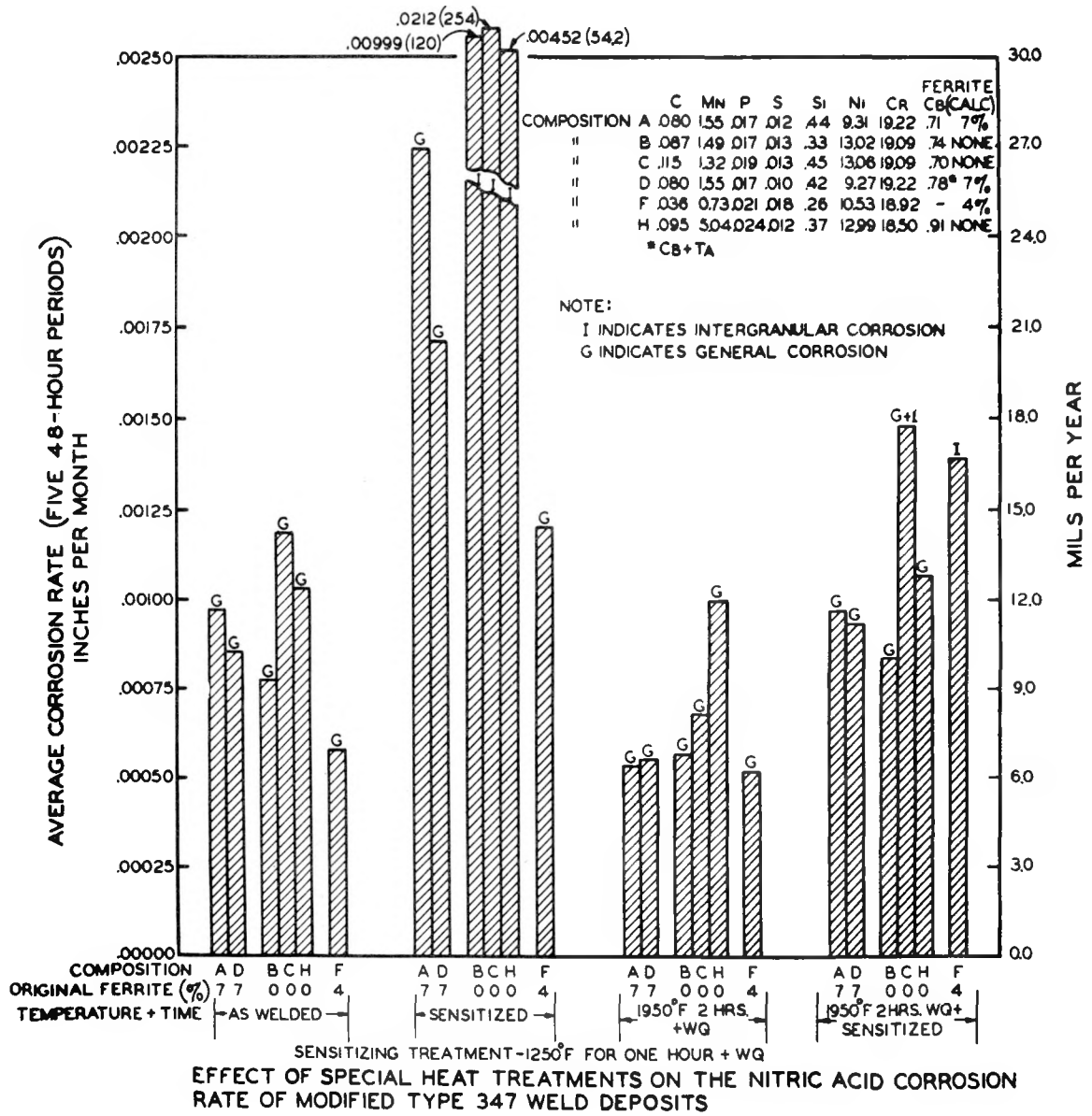
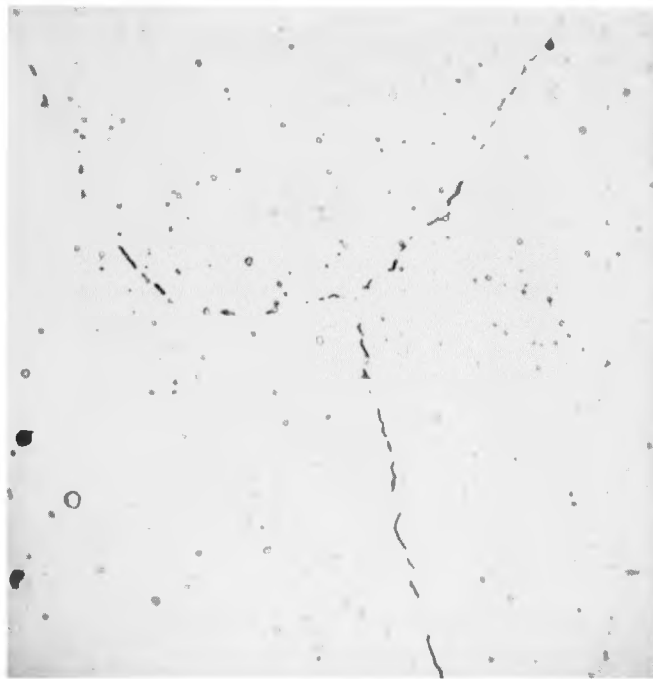


Figure 41

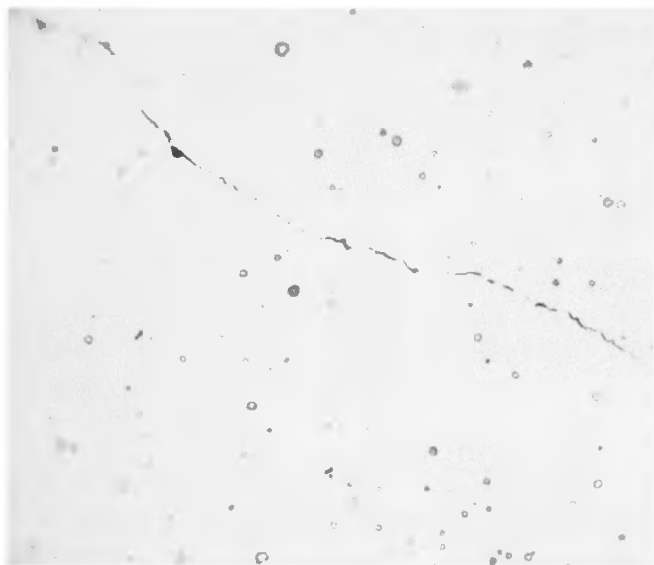


P3985 Chromic Acid Electrolytic 1500X

Figure 42. Microstructure of composition F weld deposit sensitized 1 hour at 1250°F. Carbides are precipitated around the ferrite islands in an austenitic matrix.



P3987 Chromic Acid Electrolytic 1500X



P3986 Chromic Acid Electrolytic 1500X

Figure 43. Microstructures of Composition F weld deposit after heat treating 2 hours at 1950°F followed by sensitizing at 1250°F for 1 hour. The carbides are precipitated intergranularly.

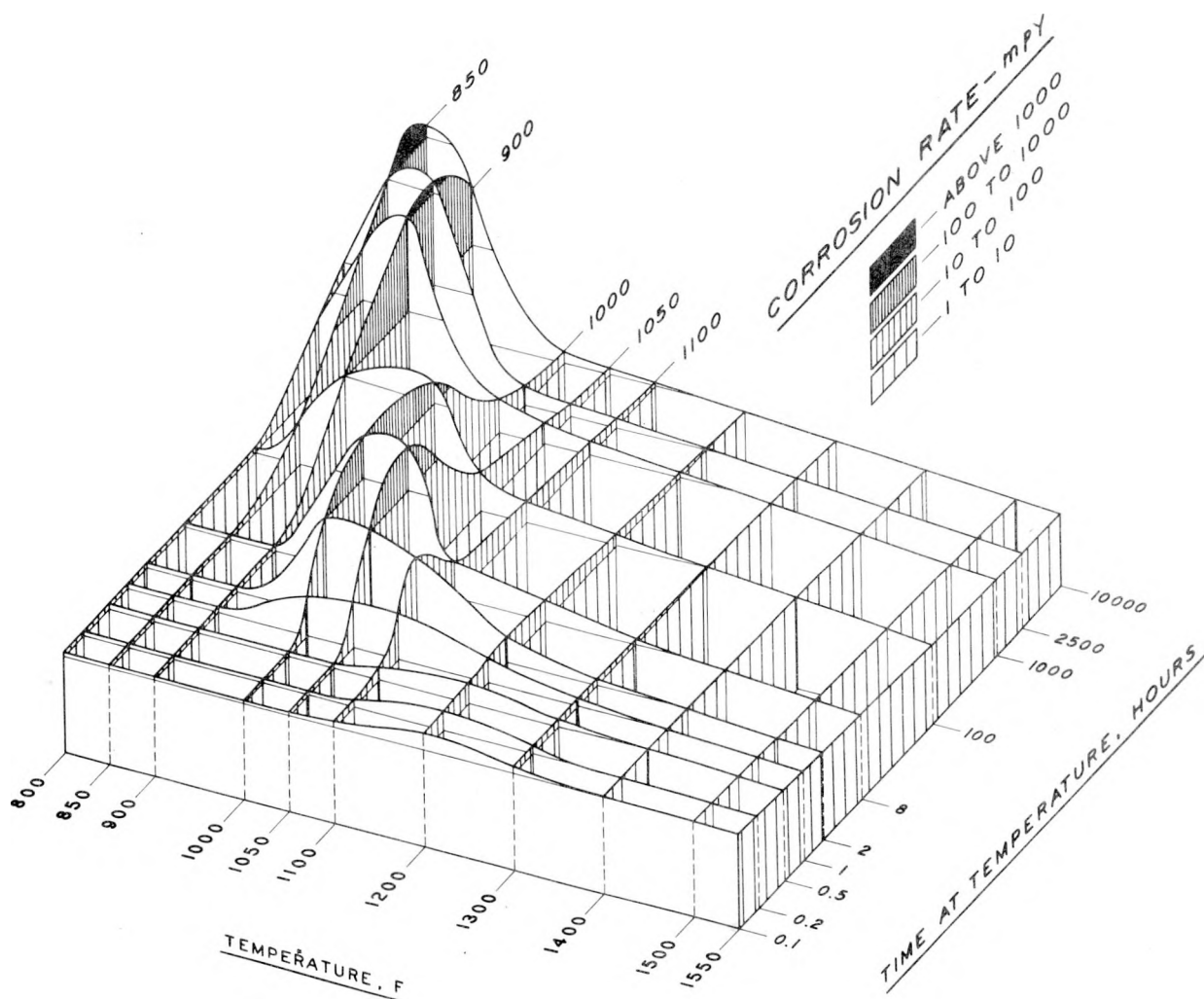


Figure 44. Three-dimensional drawing illustrating the time-temperature-sensitization relationship for .036% carbon 18-8 weld metal which was aged in the as-welded condition prior to corrosion testing (vertical scale is logarithmic, same base as time scale).

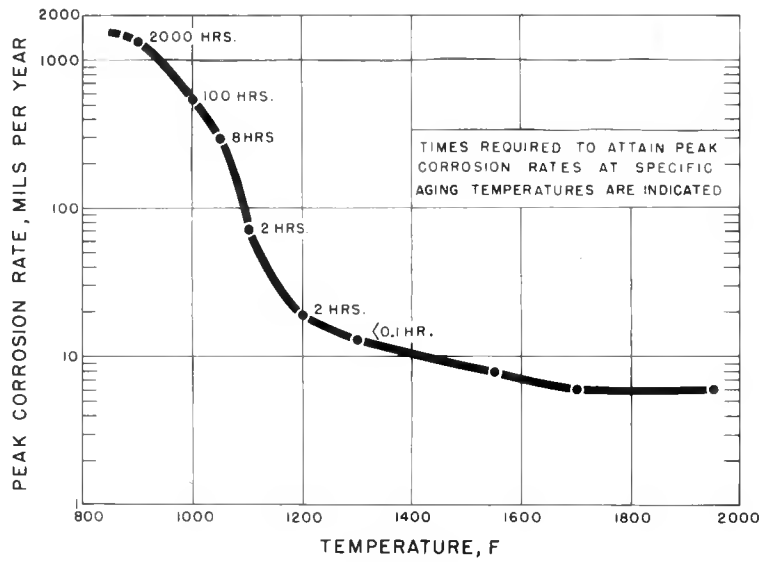


Figure 45. Peak corrosion rate vs. aging temperature for 0.036% carbon 18-8 weld metal which was aged in the as-welded condition.

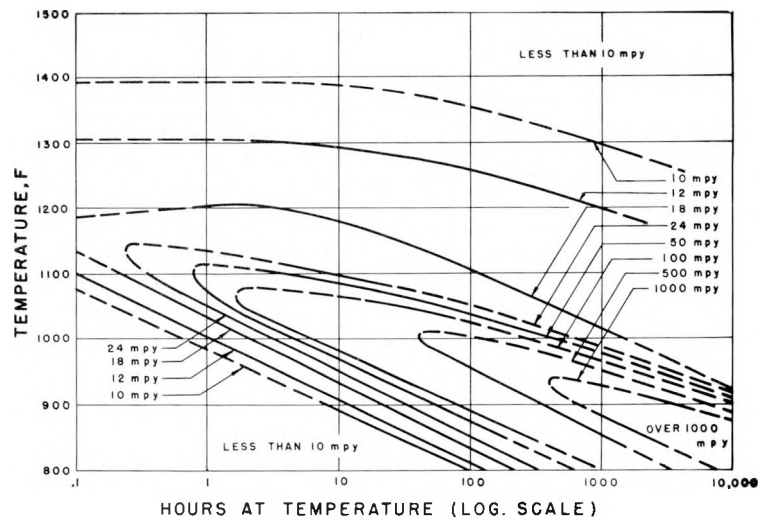


Figure 46. Time temperature-sensitization diagram for 0.036% carbon 18-8 weld metal which was aged in the as-welded condition.

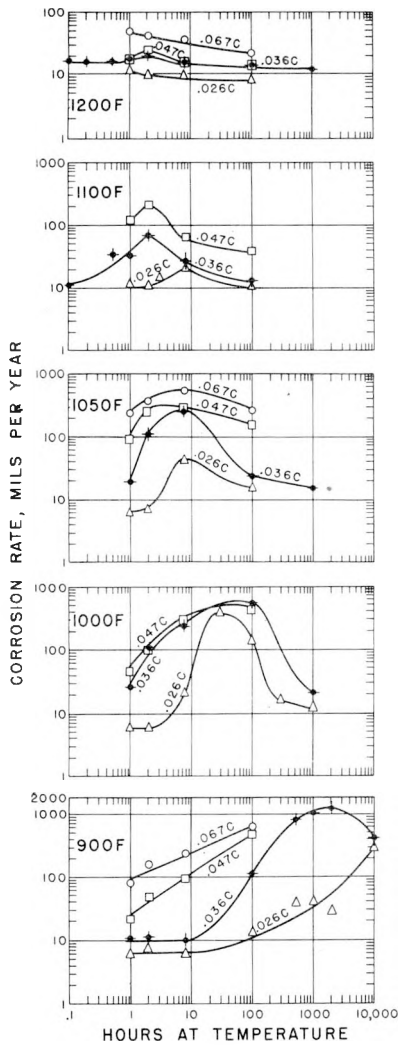


Figure 47. Corrosion rate vs. time-at-temperature curves illustrating the effects of carbon level and aging time on the corrosion resistance of 18-8 weld metals which were aged in the as-welded condition.

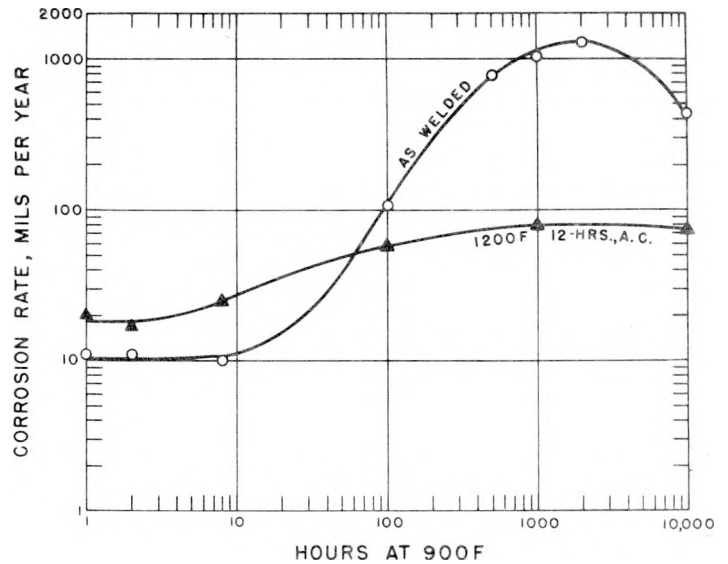


Figure 48. The effect of stabilizing heat treatments and subsequent aging at 1000°F on the corrosion resistance of 0.036% carbon 18-8 weld metal.

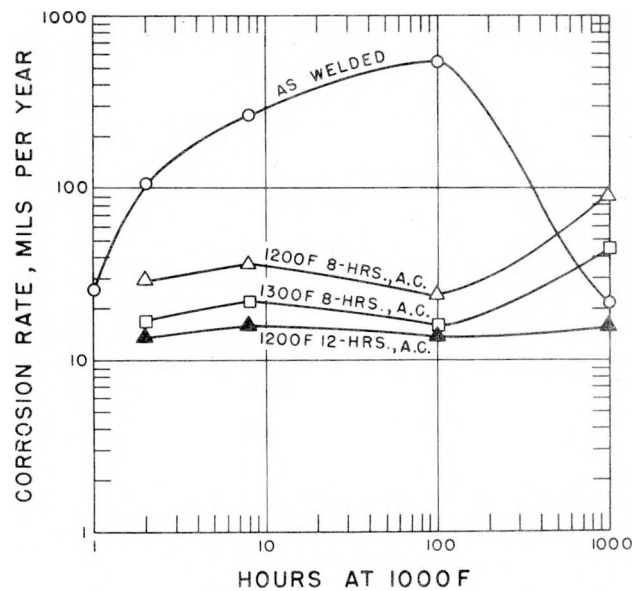
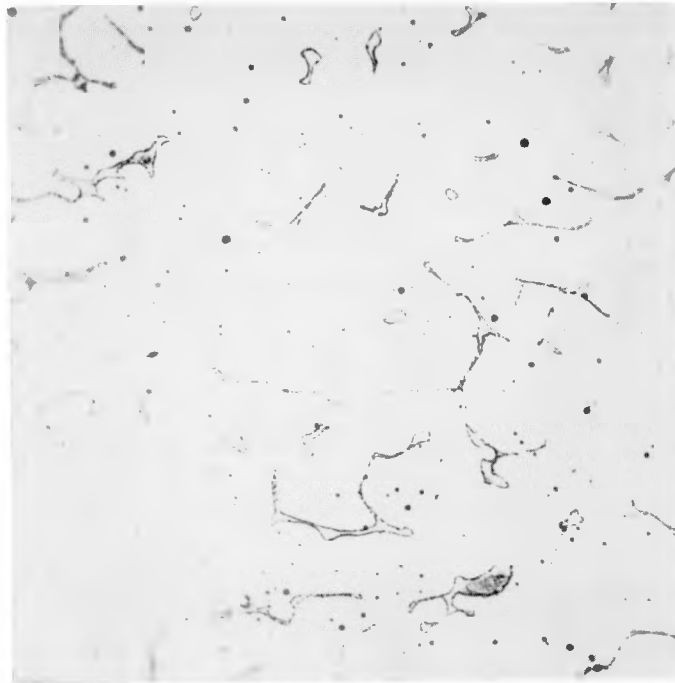
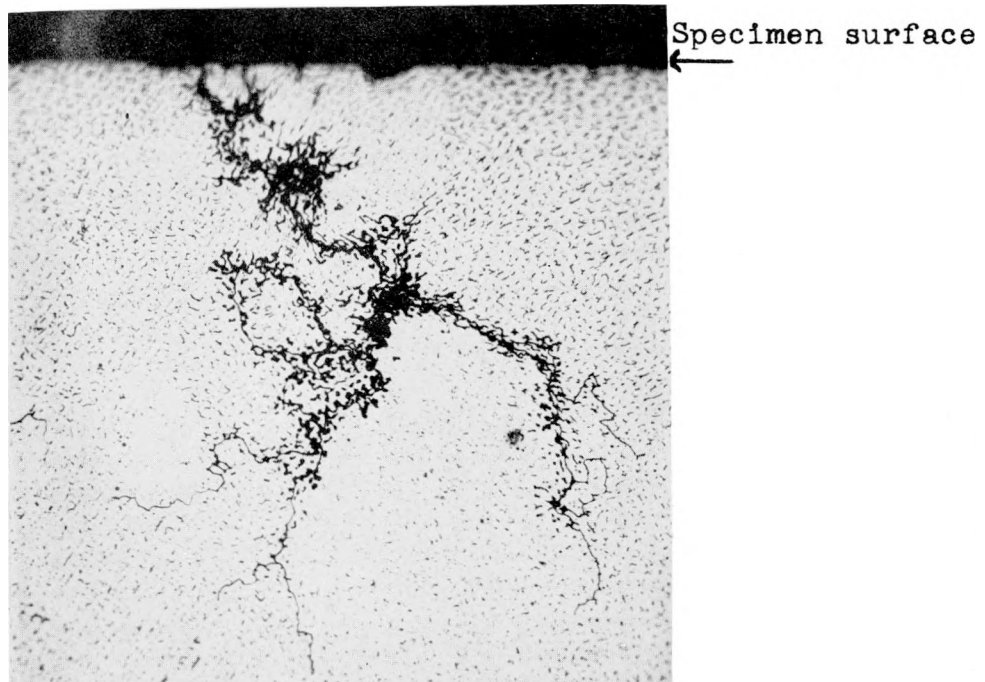


Figure 49. The effect of a stabilizing heat treatment and subsequent aging at 900°F on the corrosion resistance of 0.036% carbon 18-8 weld metal.



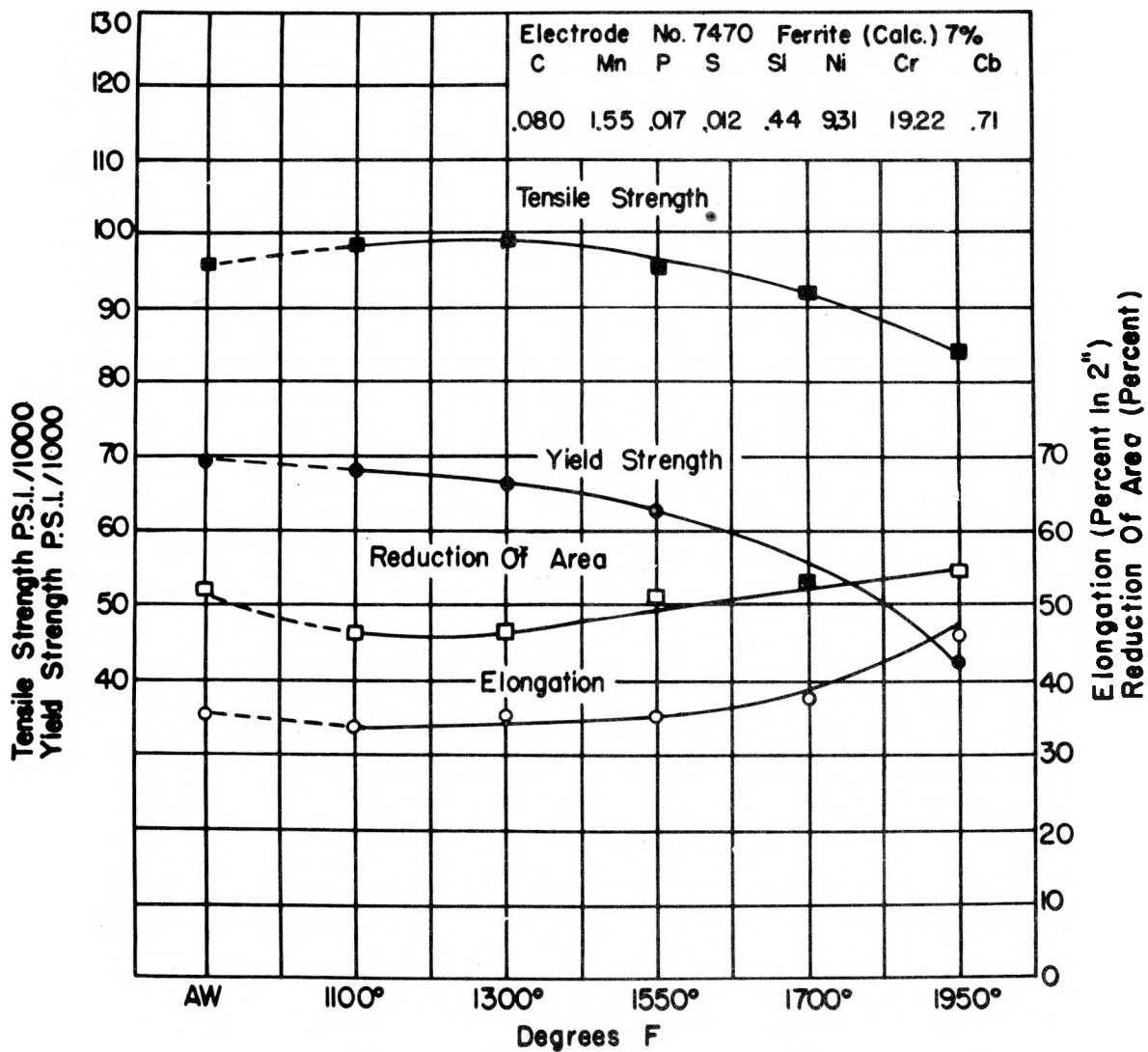
540 mpy 0.036% Carbon X1000

Figure 50. Microstructure of 18-8 weld metal which was aged at 1000°F for 100 hours. Notice the carbide precipitation at the ferrite-austenite interfaces and the intergranular carbides along the austenitic grain boundaries (10% chromic acid etch).



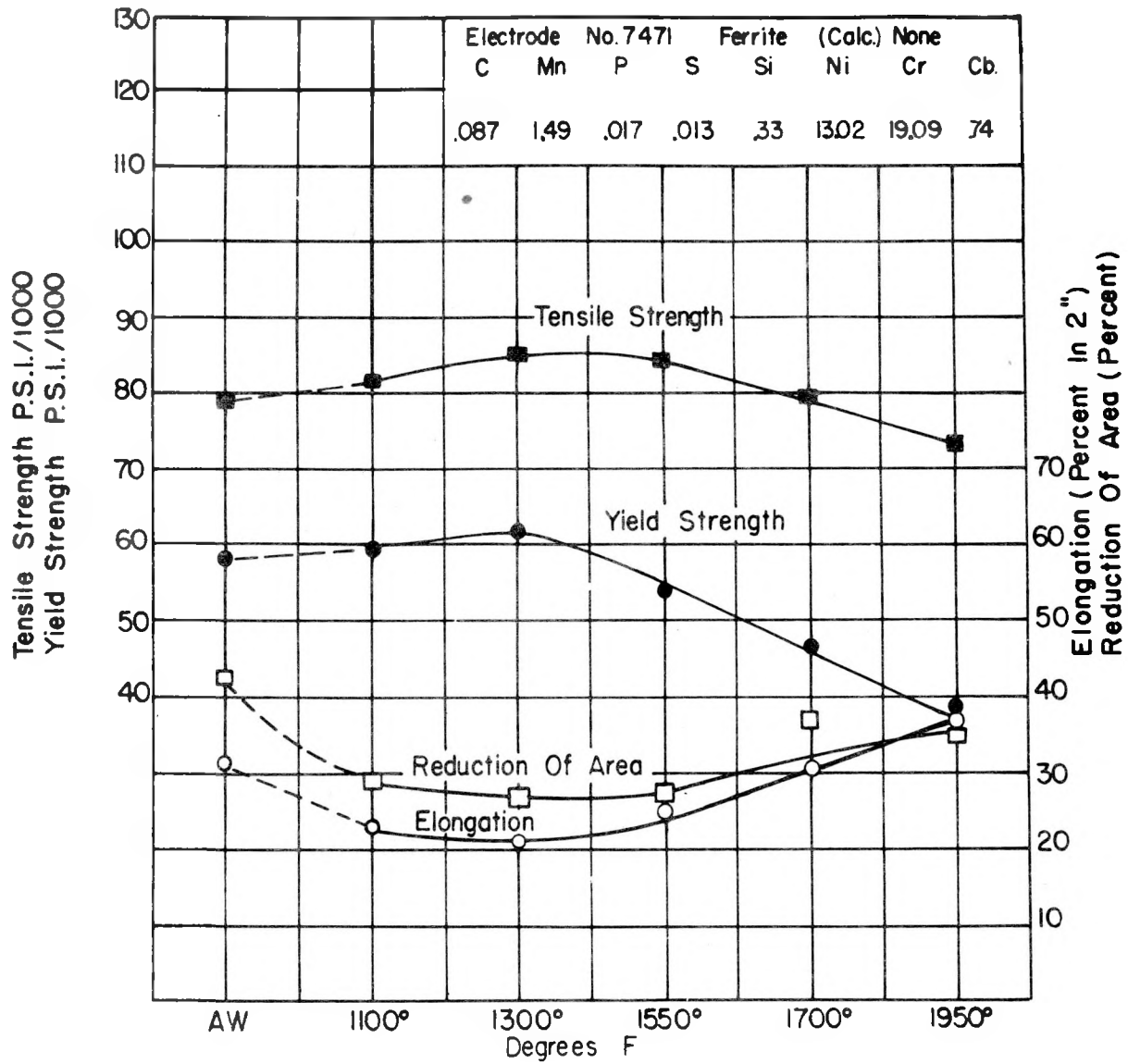
1043 mpy 0.036% Carbon X250

Figure 51. Photomicrograph of 18-8 weld metal illustrating severe intergranular corrosion on material aged at 900°F for 1000 hours (10% chromic acid etch).



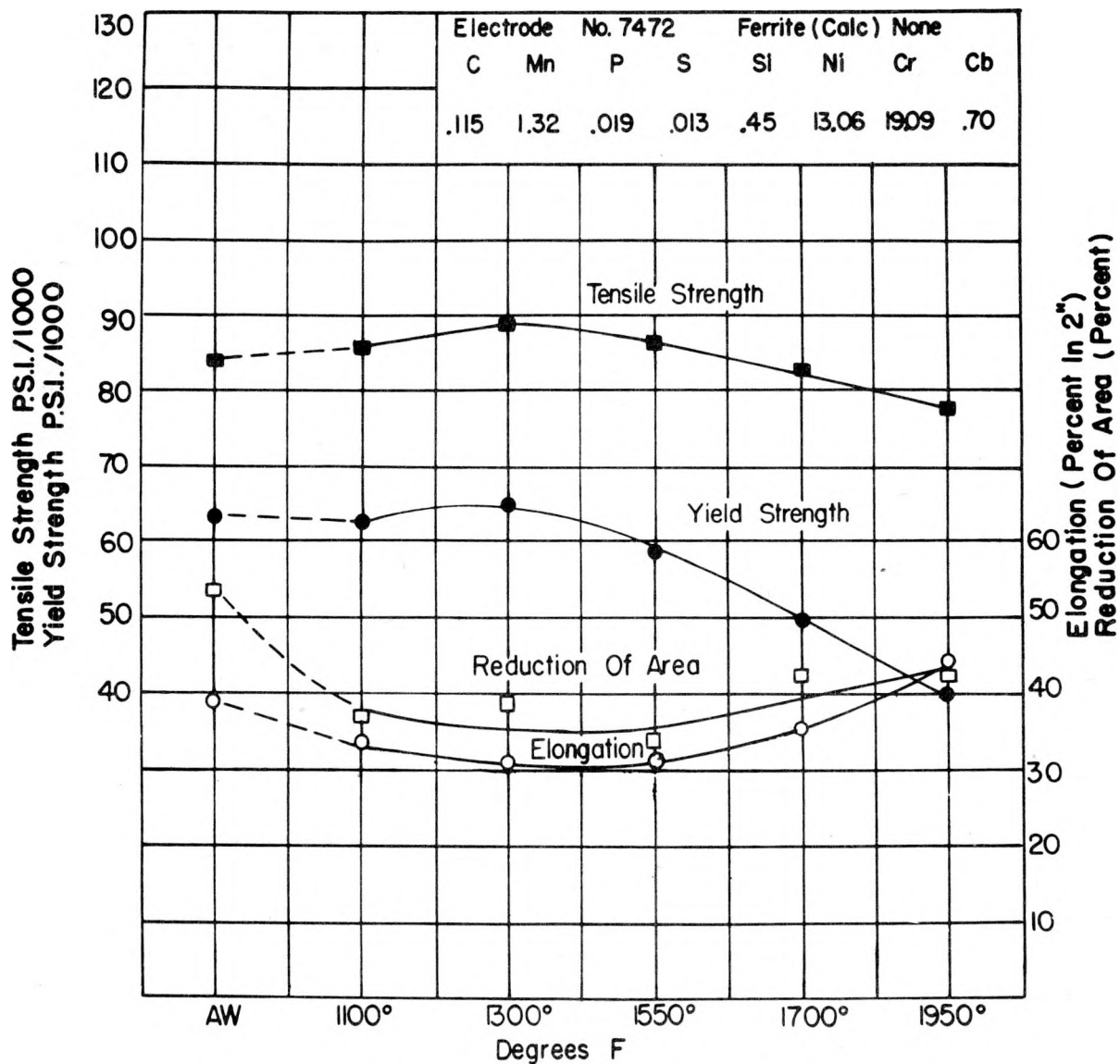
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "A" Weld Metal.

Fig. 52.



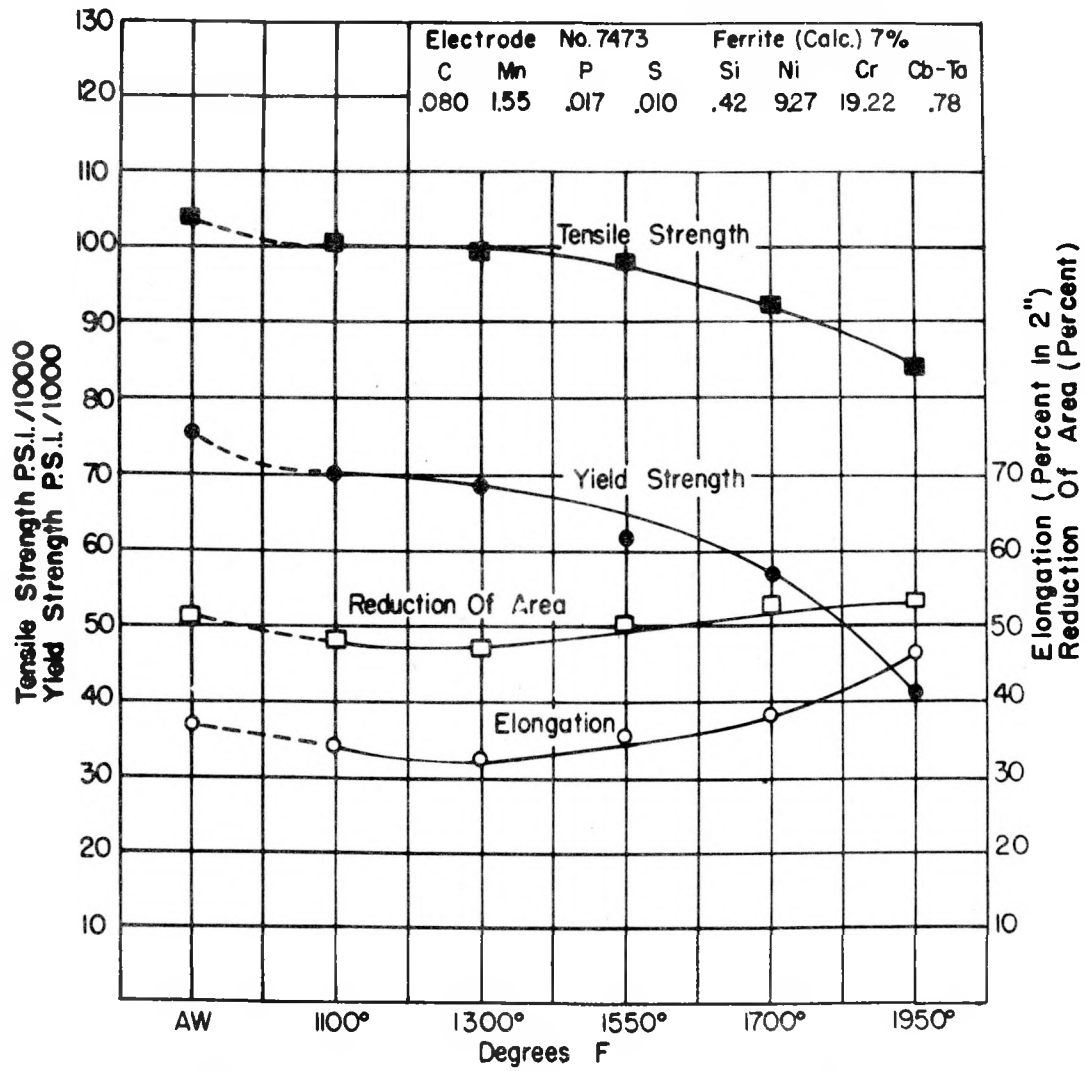
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "B" Weld Metal.

Fig. 53



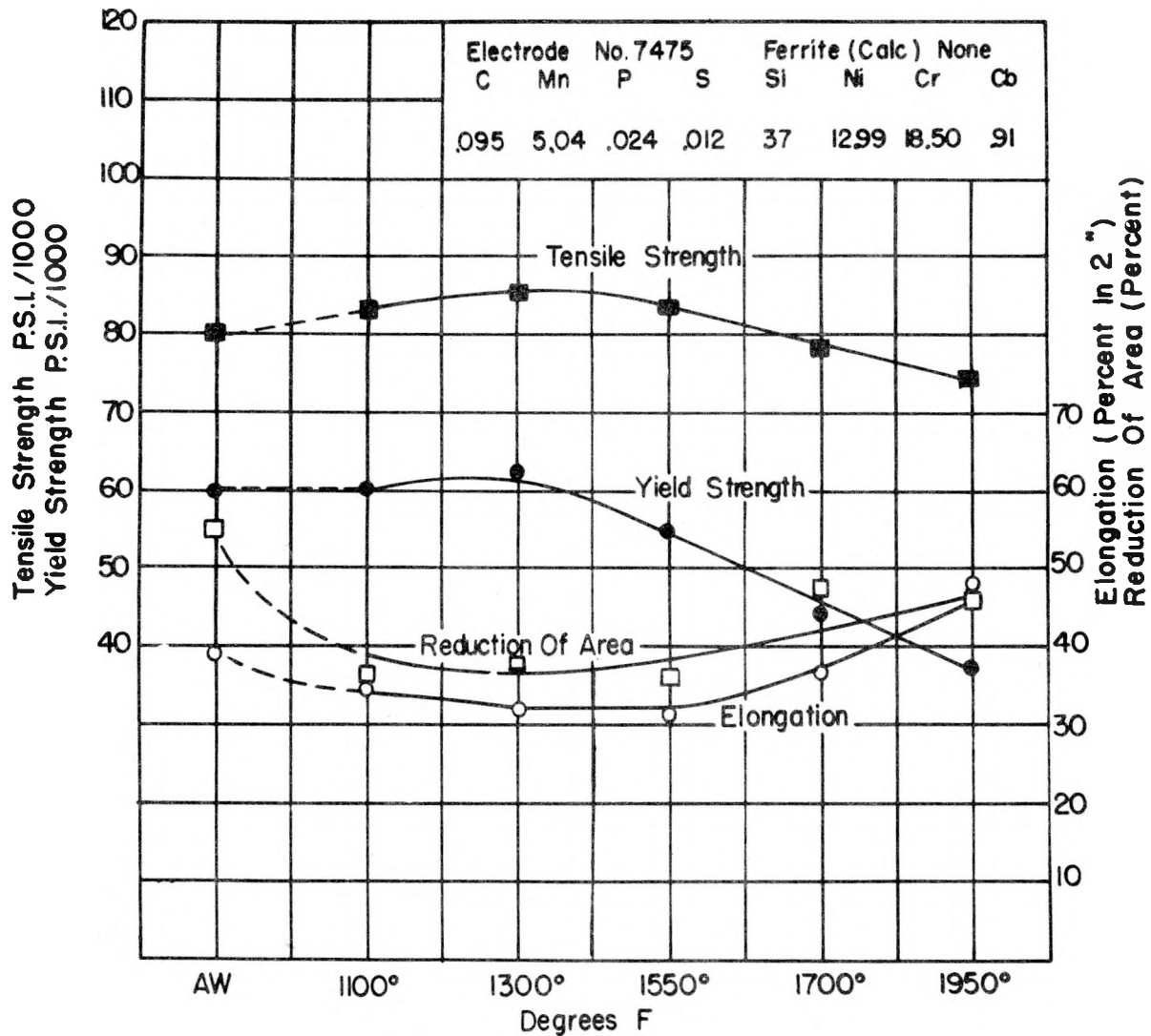
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "C" Weld Deposits.

Fig. 54



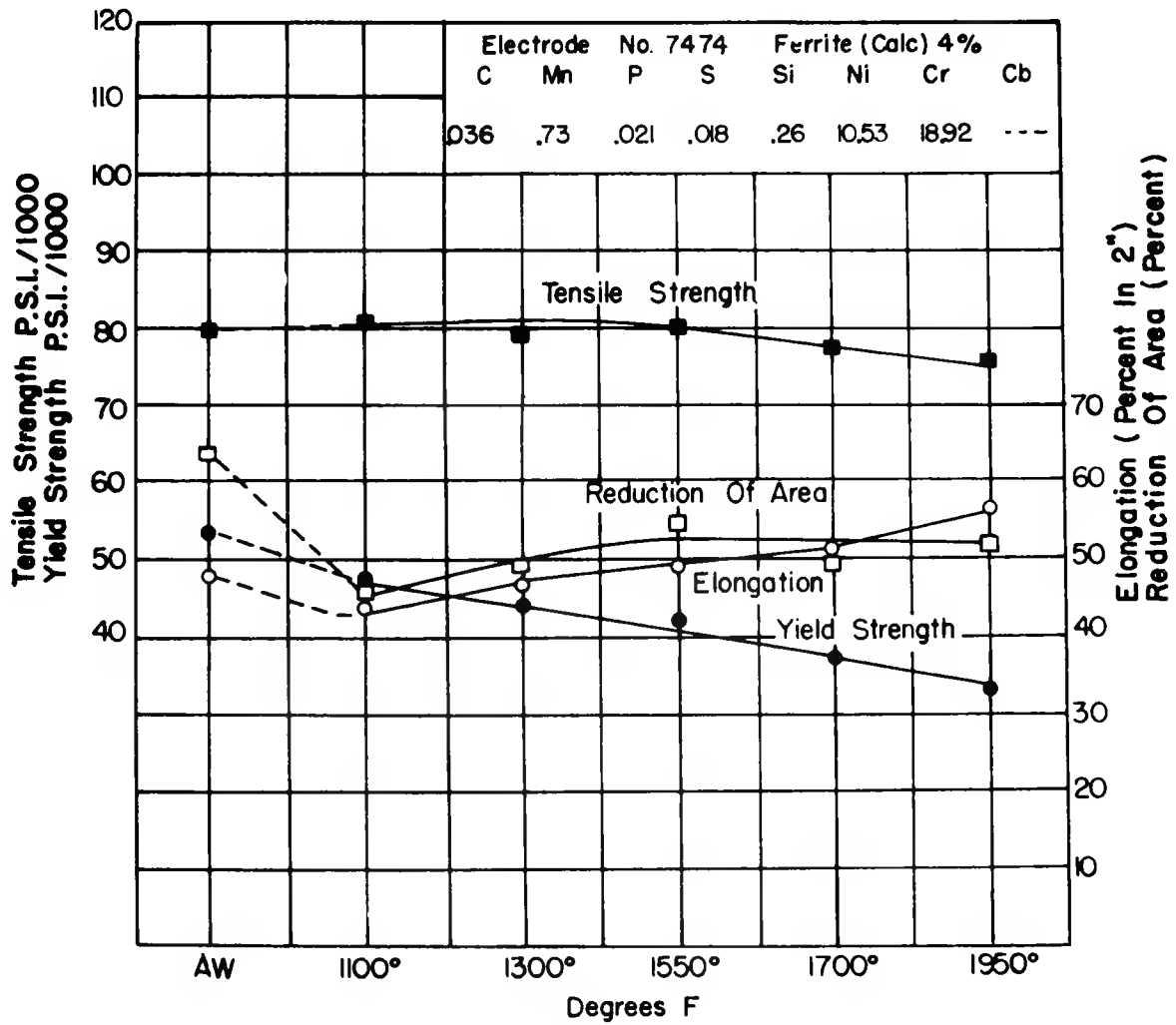
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "D" Weld Metal.

Fig. 55



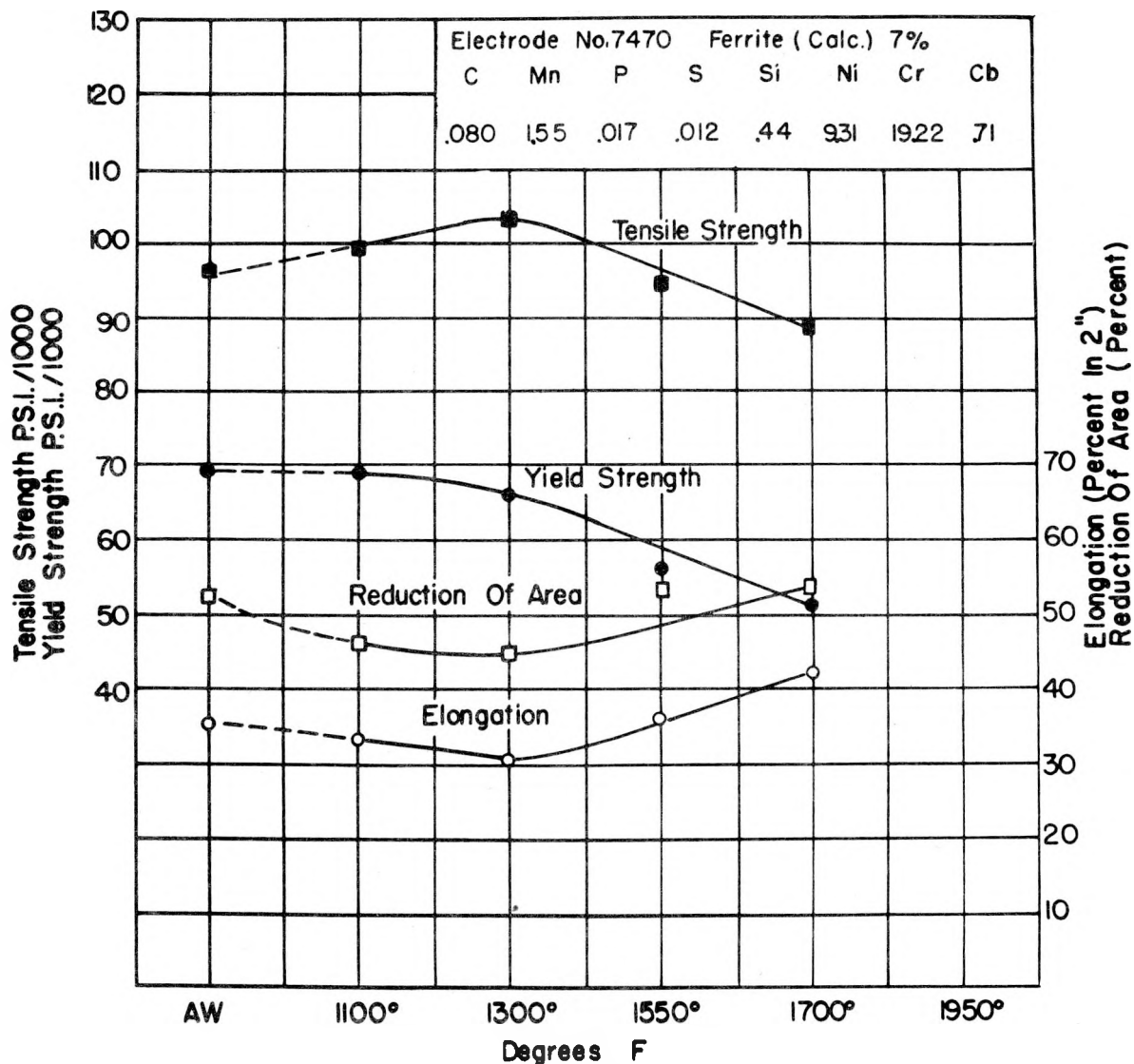
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "H" Weld Metal.

Fig. 56



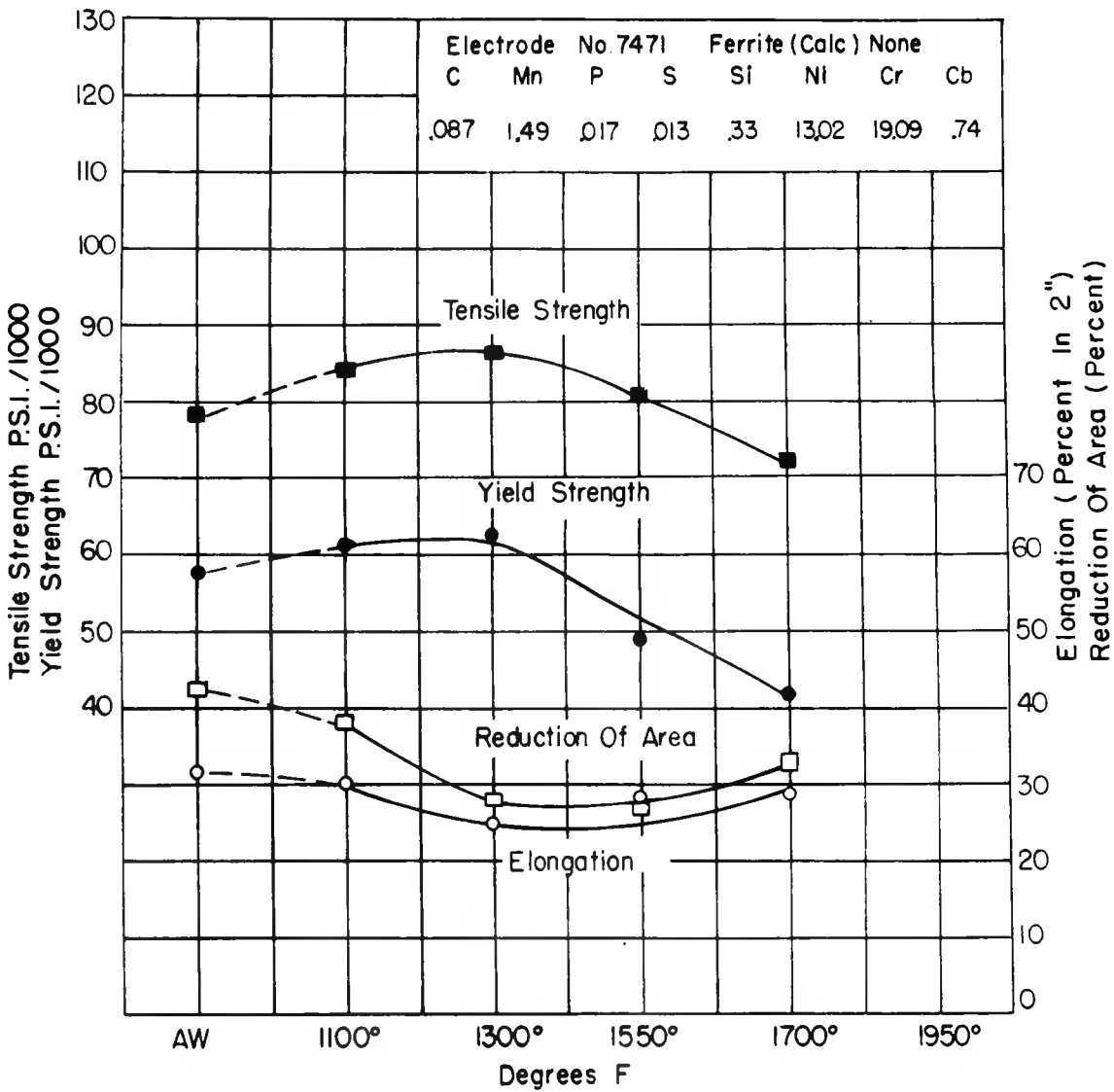
Effect Of 8-Hour Heat Treatments On The Mechanical Properties Of Composition "F" Weld Metal.

Fig. 57



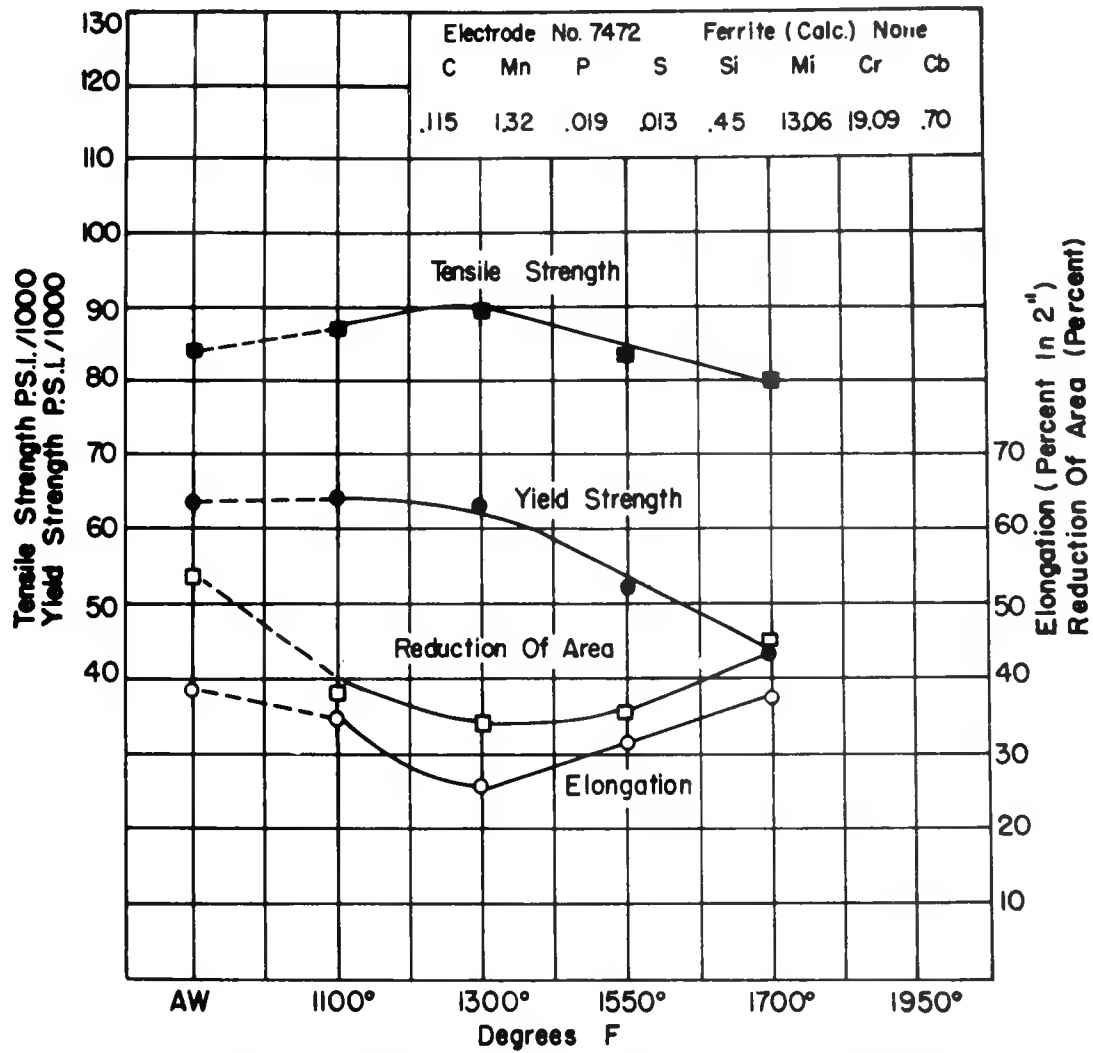
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition "A" Weld Metal.

Fig. 58



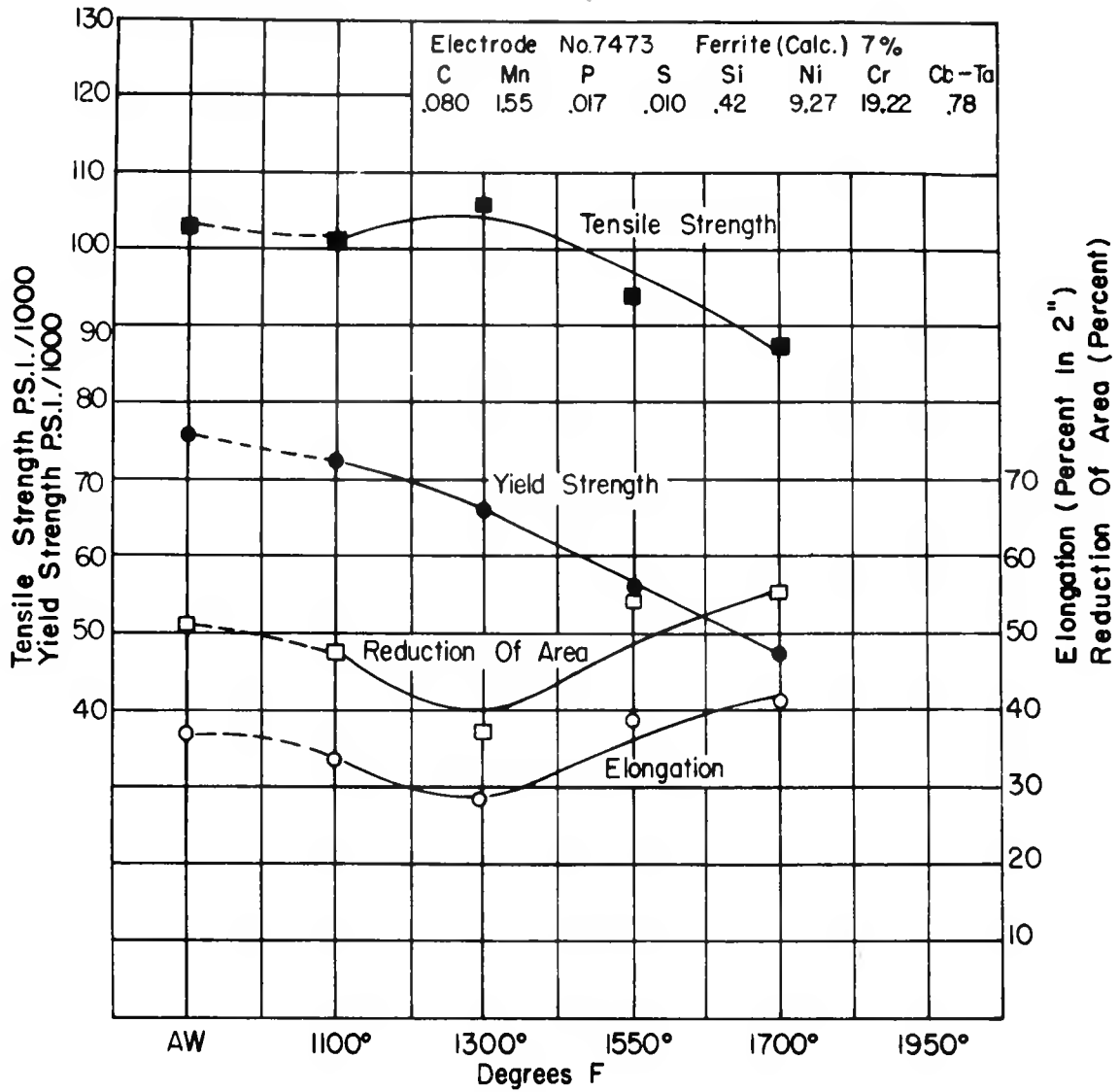
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition "B" Weld Metal.

Fig. 59



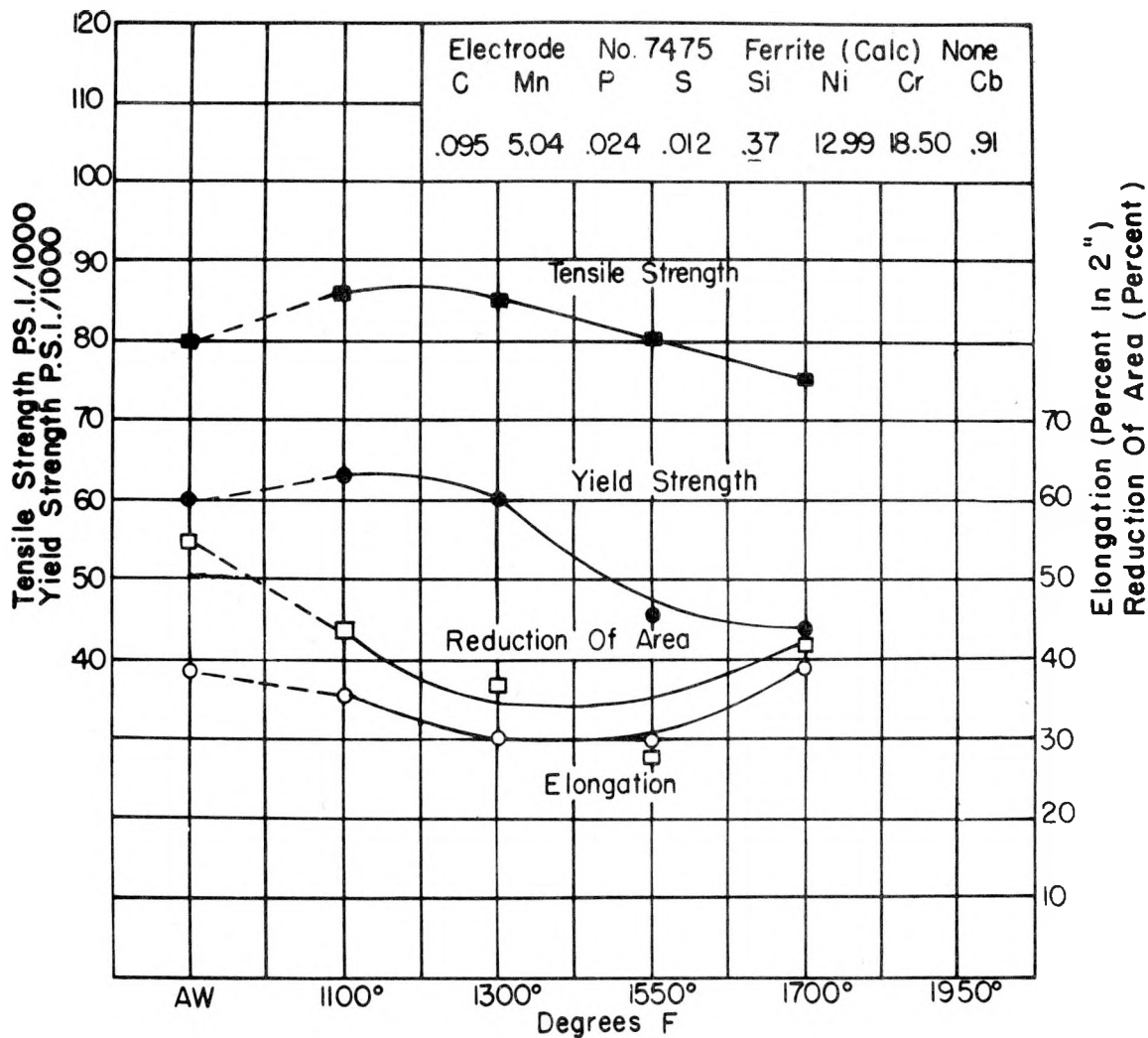
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition C Weld Metal.

Fig. 60



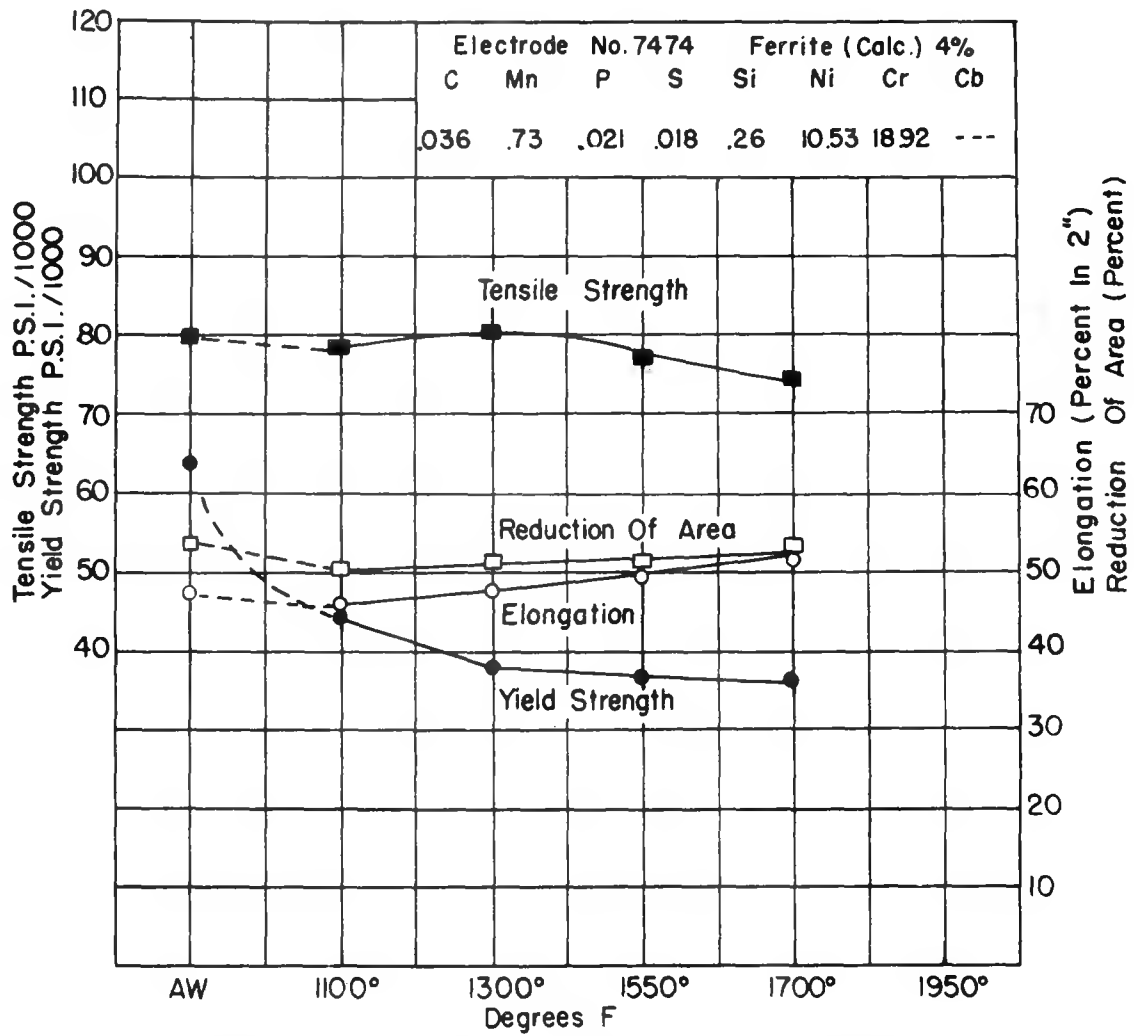
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition "D" Weld Metal.

Fig. 61



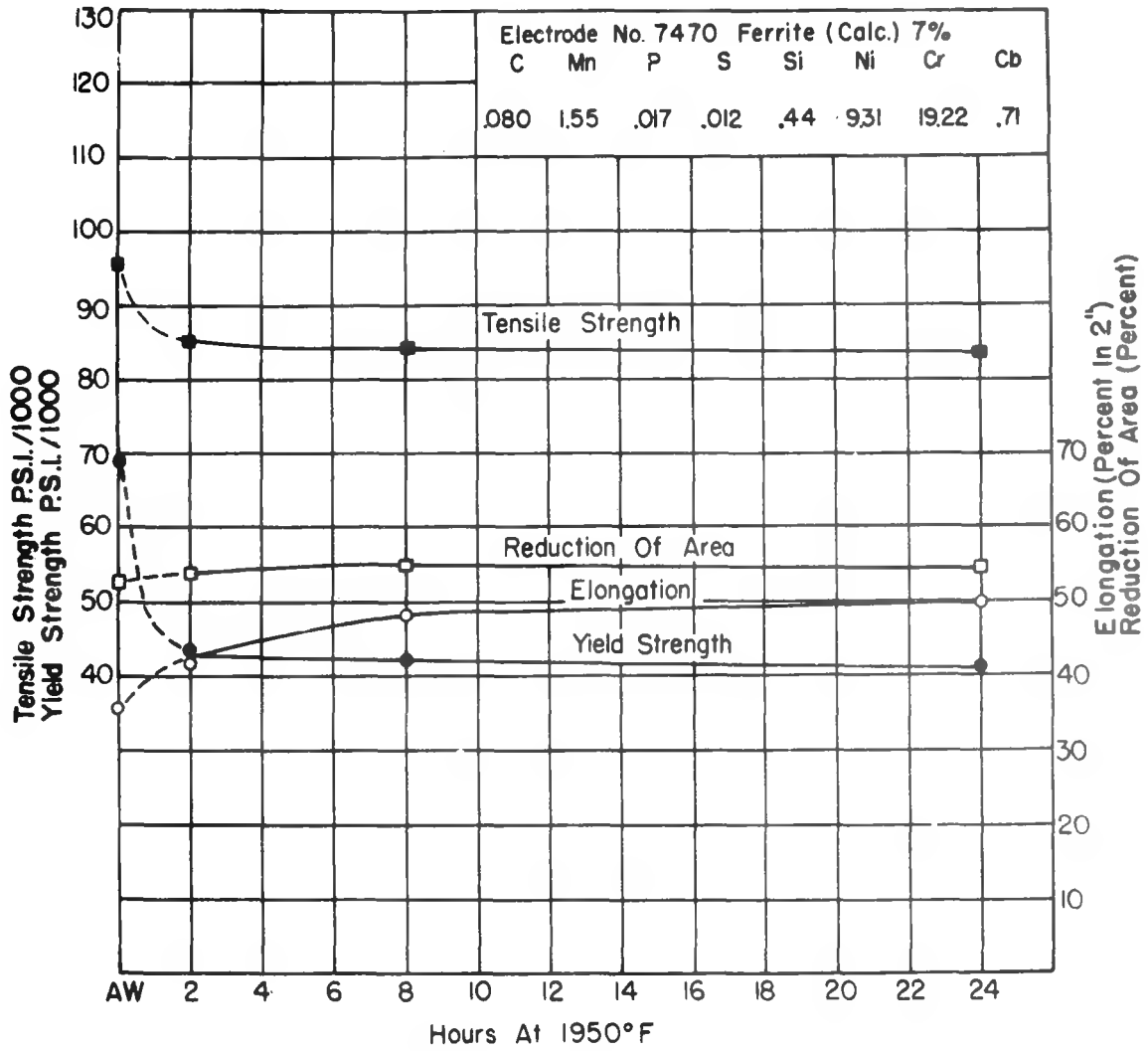
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition "H" Weld Metal.

Fig. 62



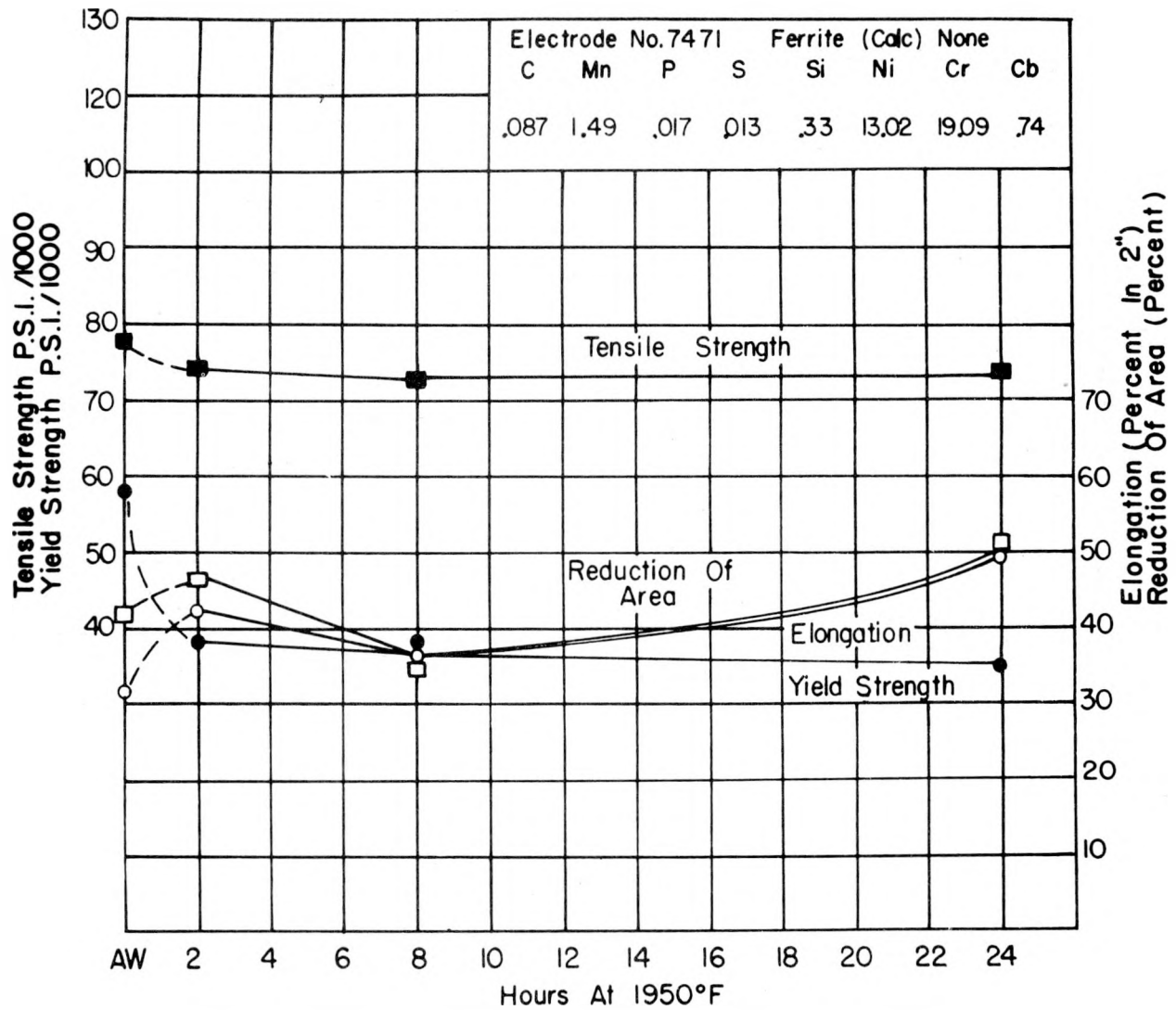
Effect Of 100-Hour Heat Treatments On The Mechanical Properties Of Composition "F" Weld Metal.

Fig. 63



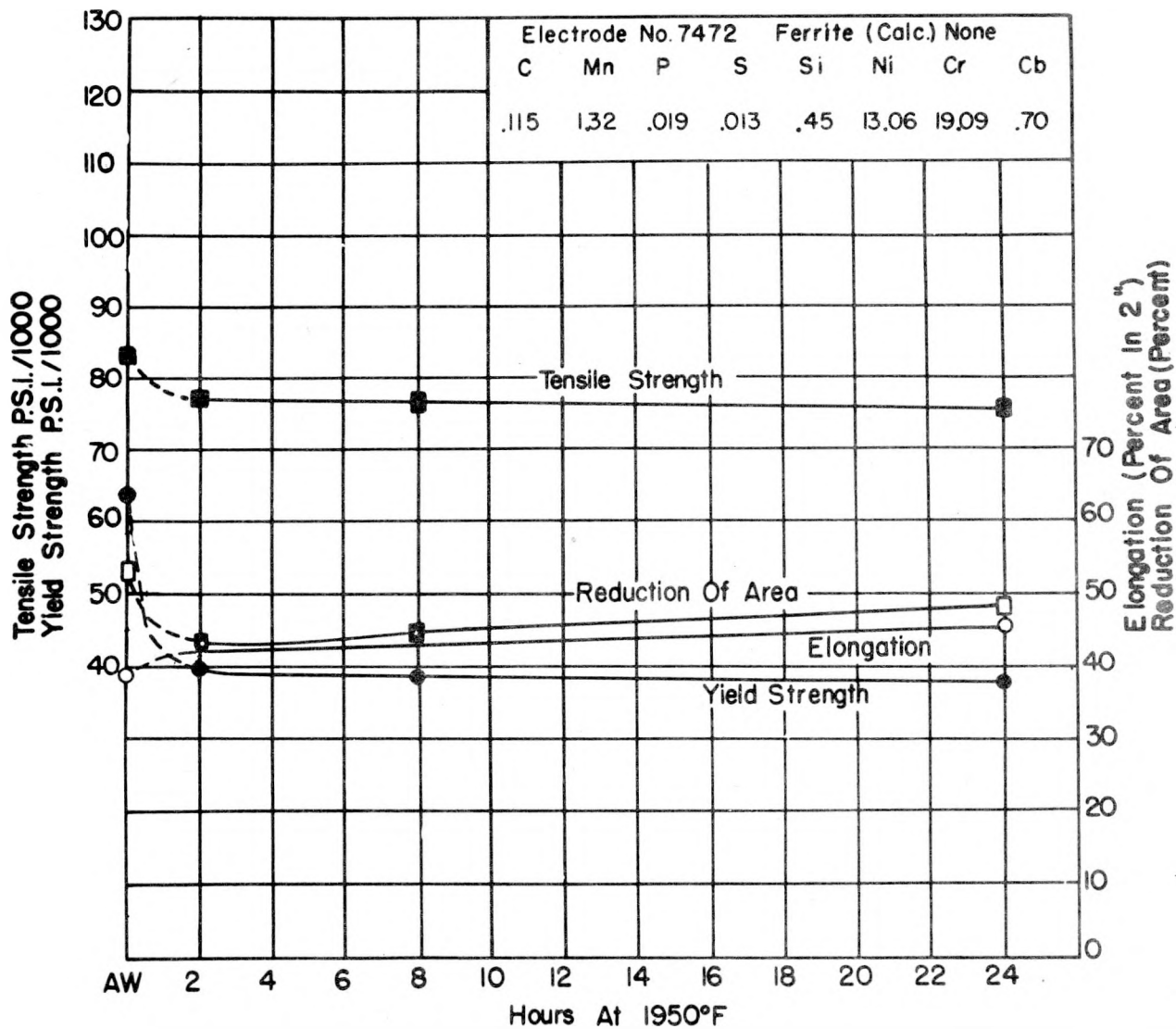
Effect Of Time At 1950°F On The Mechanical Properties Of Composition "A" Weld Metal.

Fig. 64



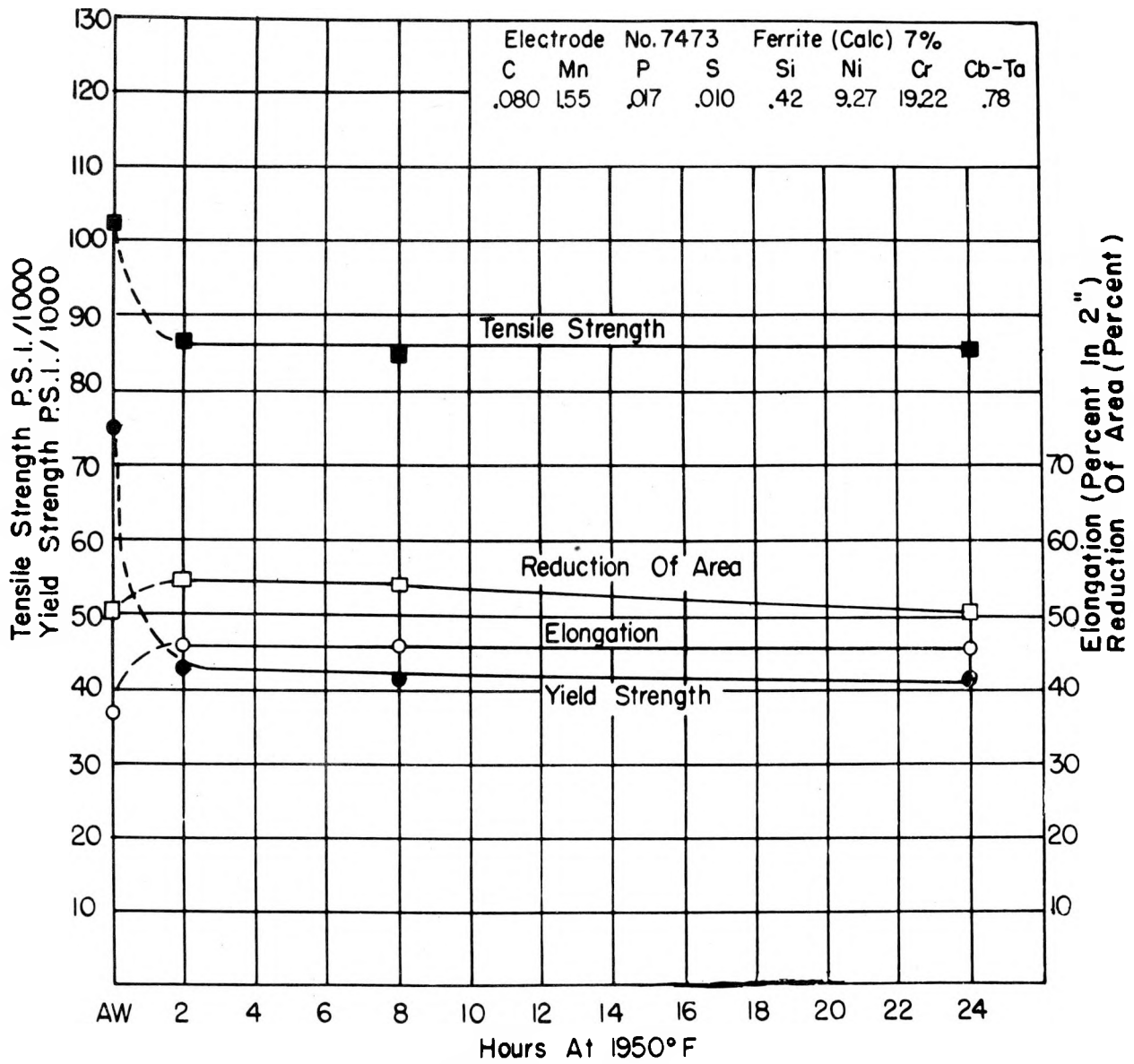
Effect Of Time At 1950°F On The Mechanical Properties Of Composition "B" Weld Metal.

Fig.65



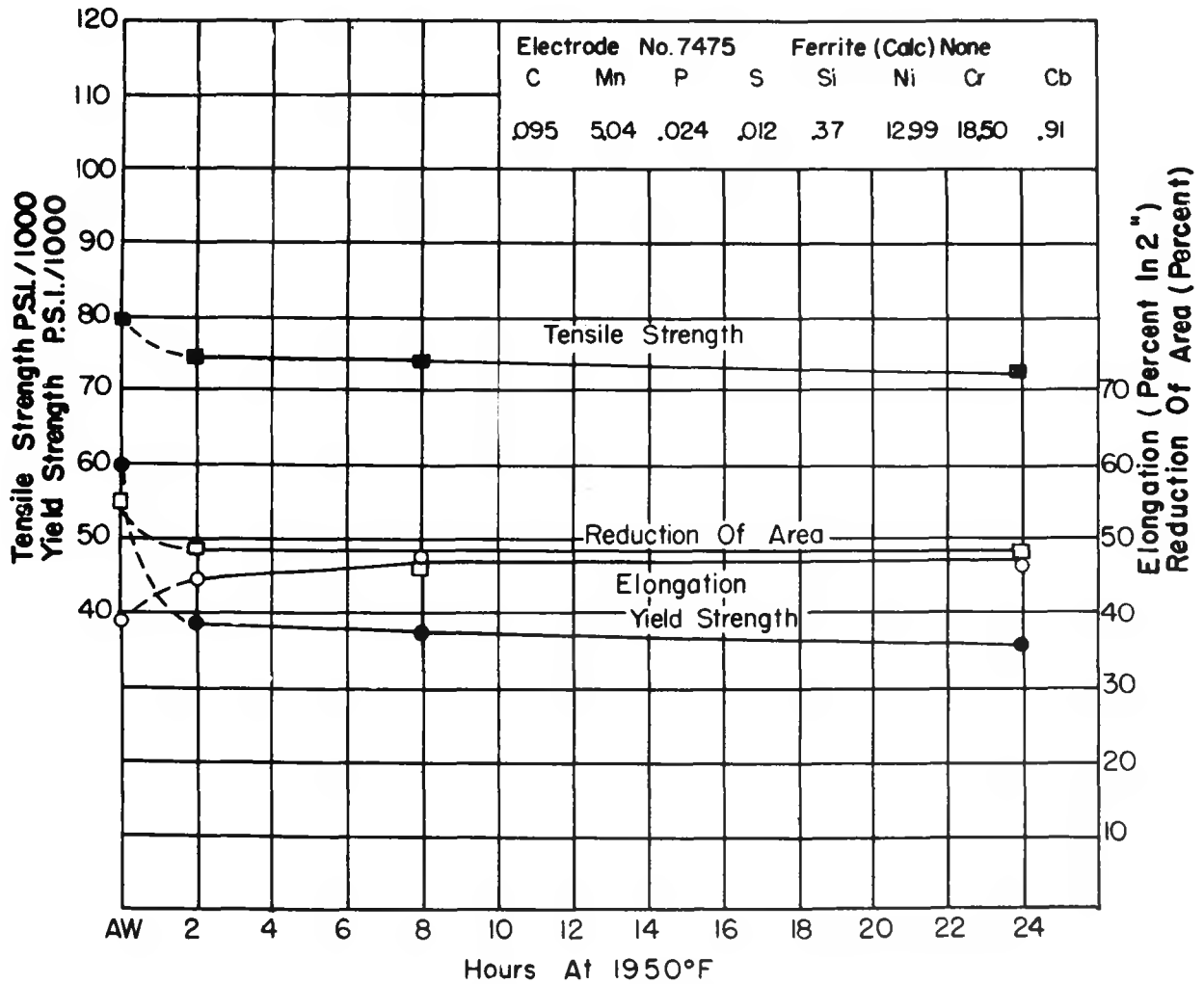
Effect Of Time At 1950°F On The Mechanical Properties Of Composition "C" Weld Metal.

Fig. 66



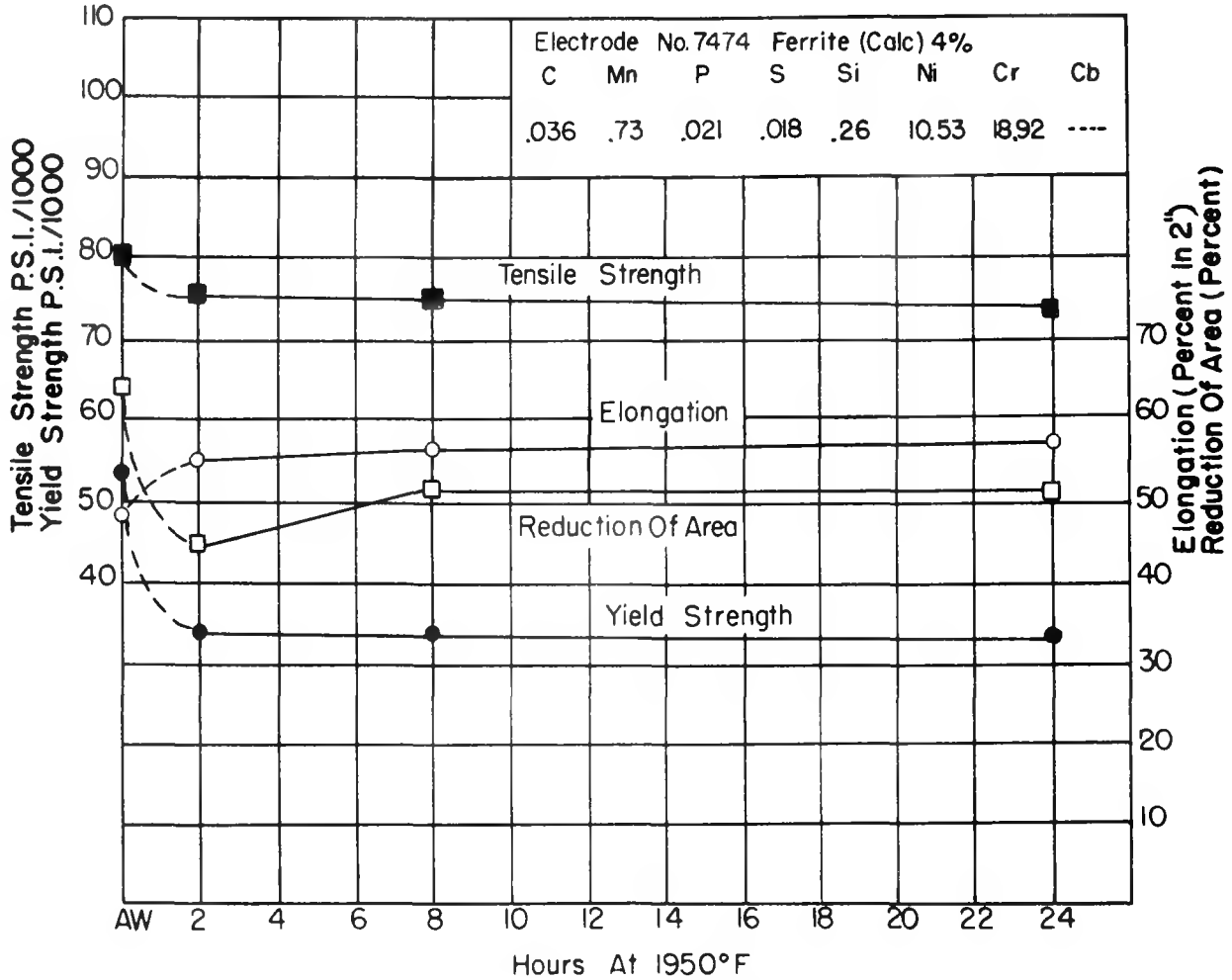
Effect Of Time At 1950°F On The Mechanical Properties Of Composition "D" Weld Metal.

Fig. 67



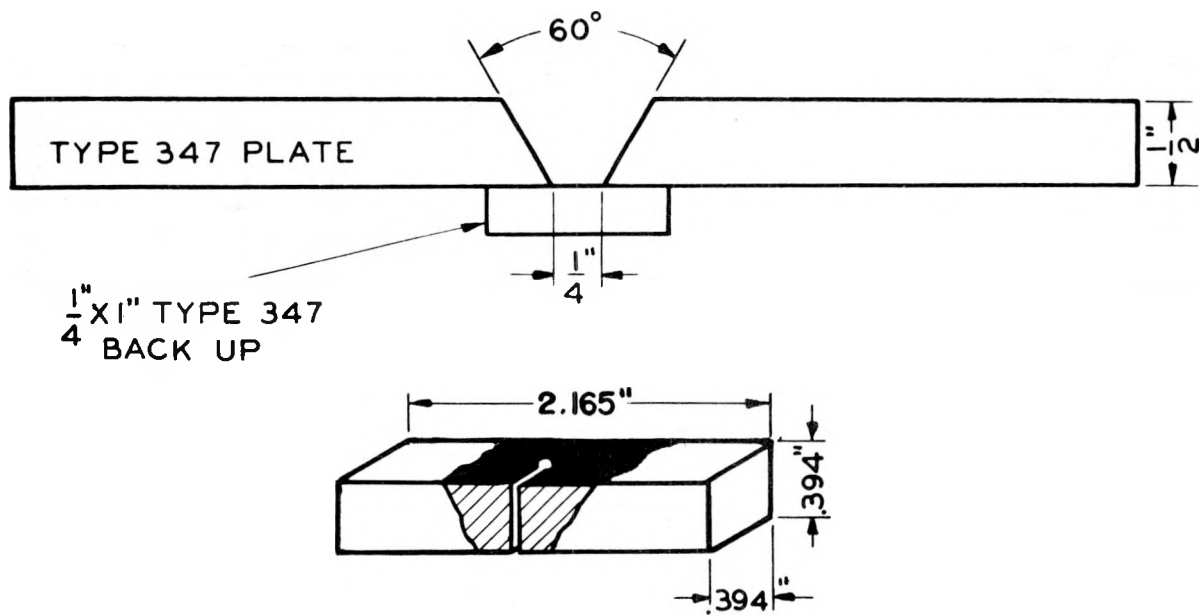
Effect Of Time At 1950°F On The Mechanical Properties Of Composition "H" Weld Metal.

Fig.68

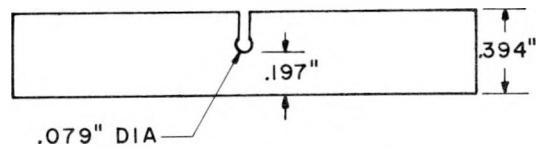


Effect Of Time At 1950°F On The Mechanical Properties Of Composition "F" Weld Metal.

Fig.69



JOINT DESIGN AND LOCATION OF NOTCH
IN IMPACT SPECIMEN



DRILL SIZE AND DEPTH BELOW THE NOTCH

Figure 70

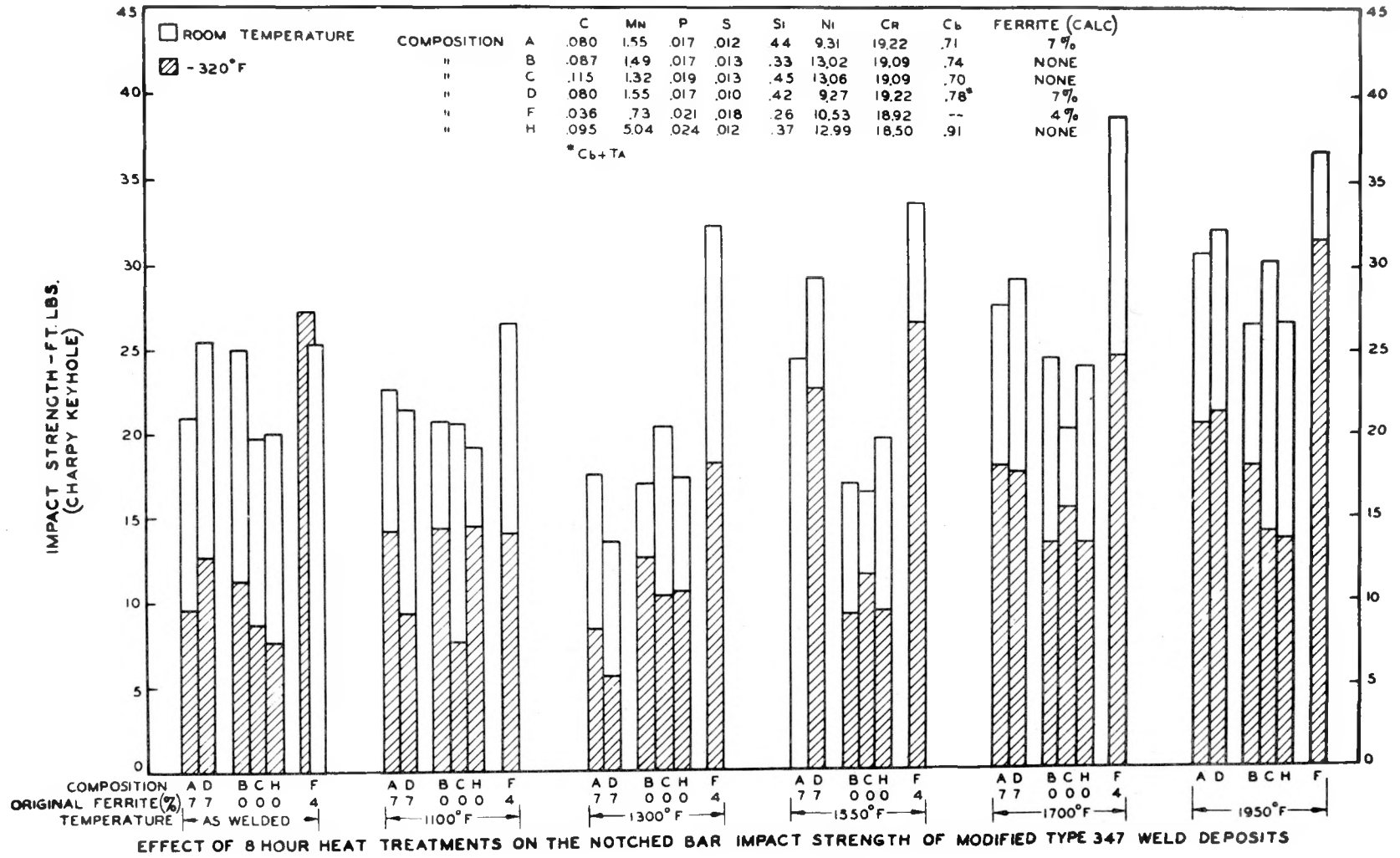


Figure 71

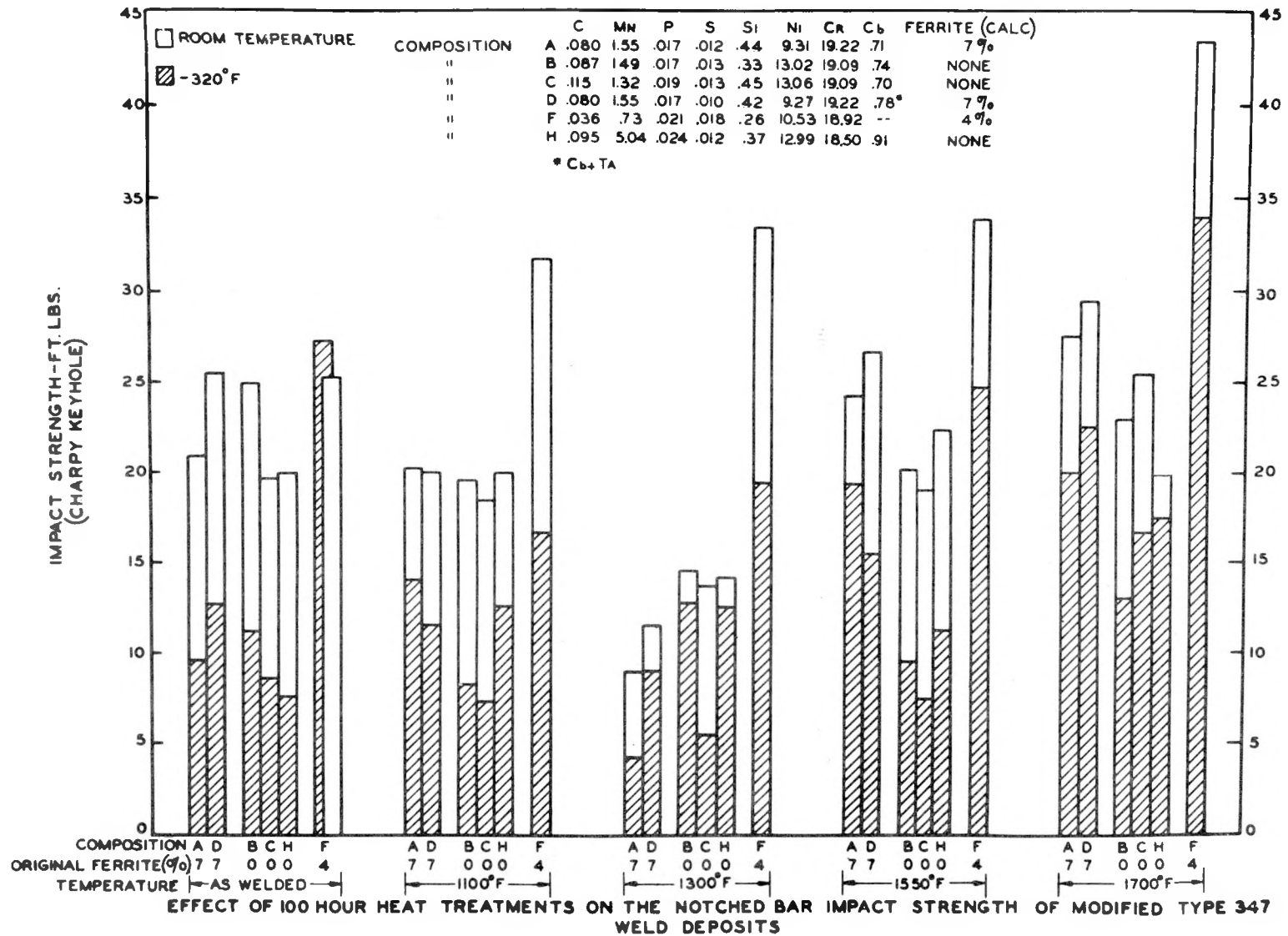


Figure 72

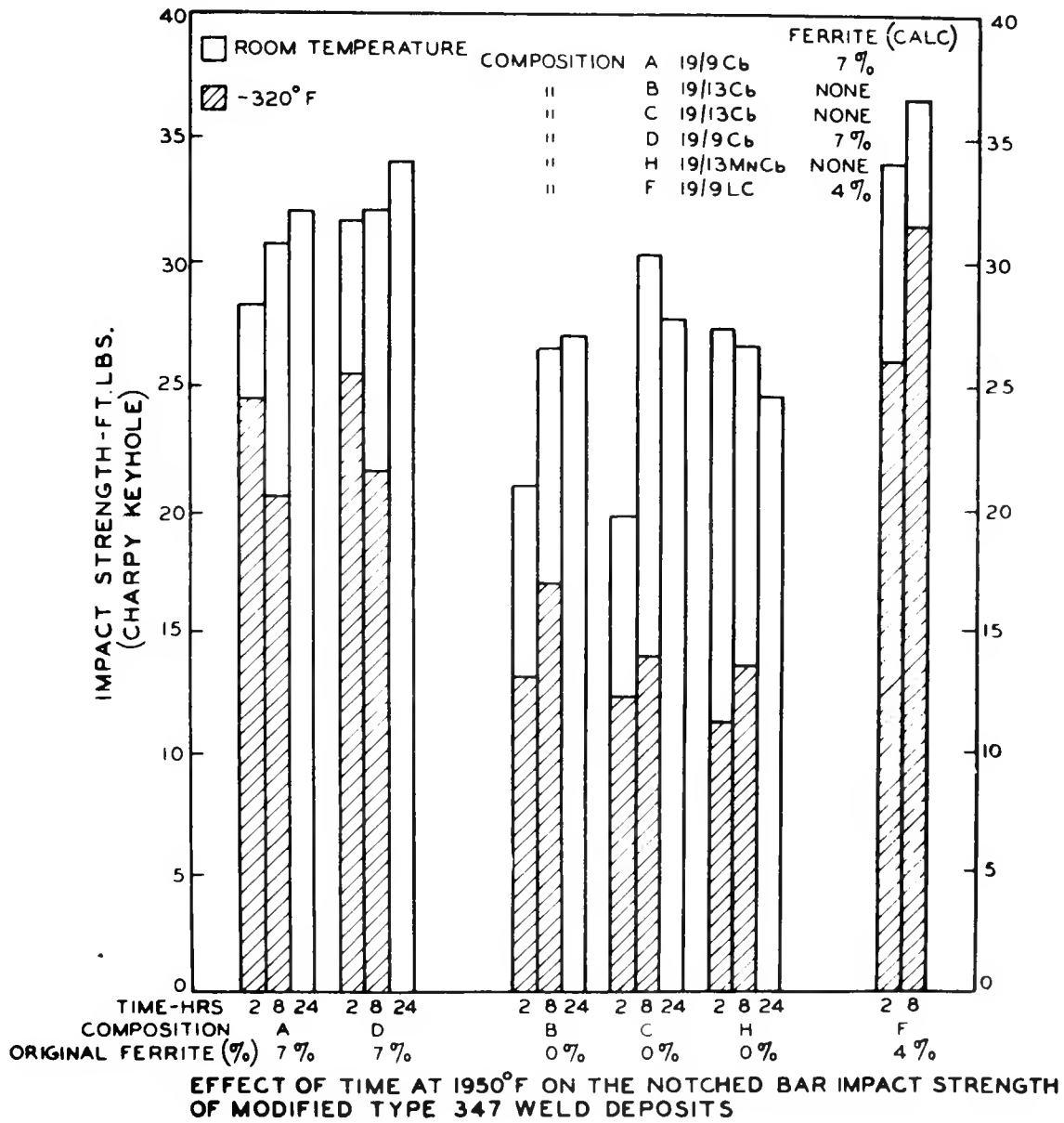
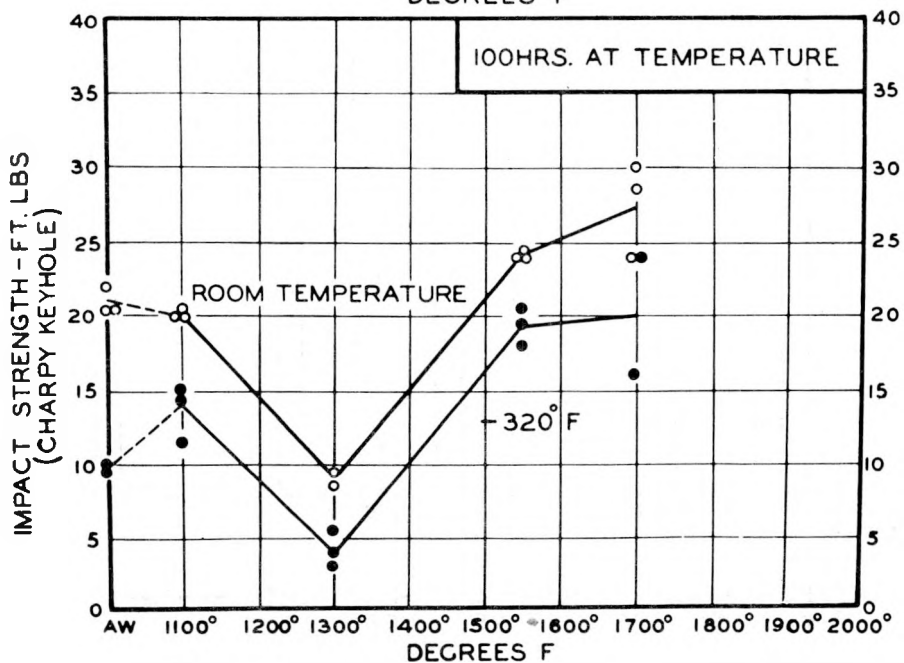
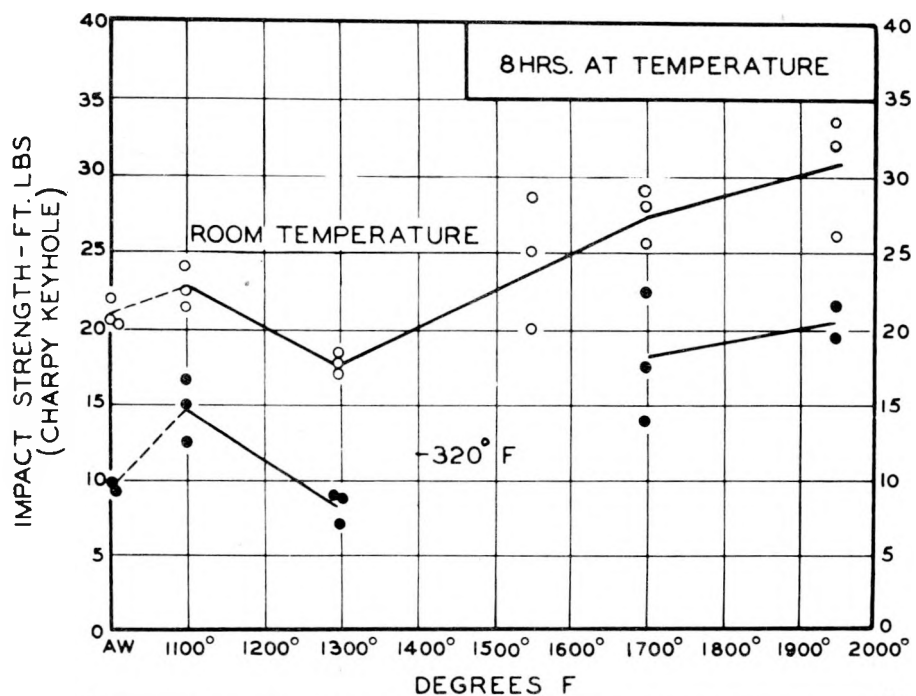


Figure 73



EFFECT OF 8 AND 100HR. HEAT TREATMENTS ON THE NOTCHED BAR IMPACT STRENGTH OF COMPOSITION "A" (19/9cb) WELD DEPOSITS

Figure 74

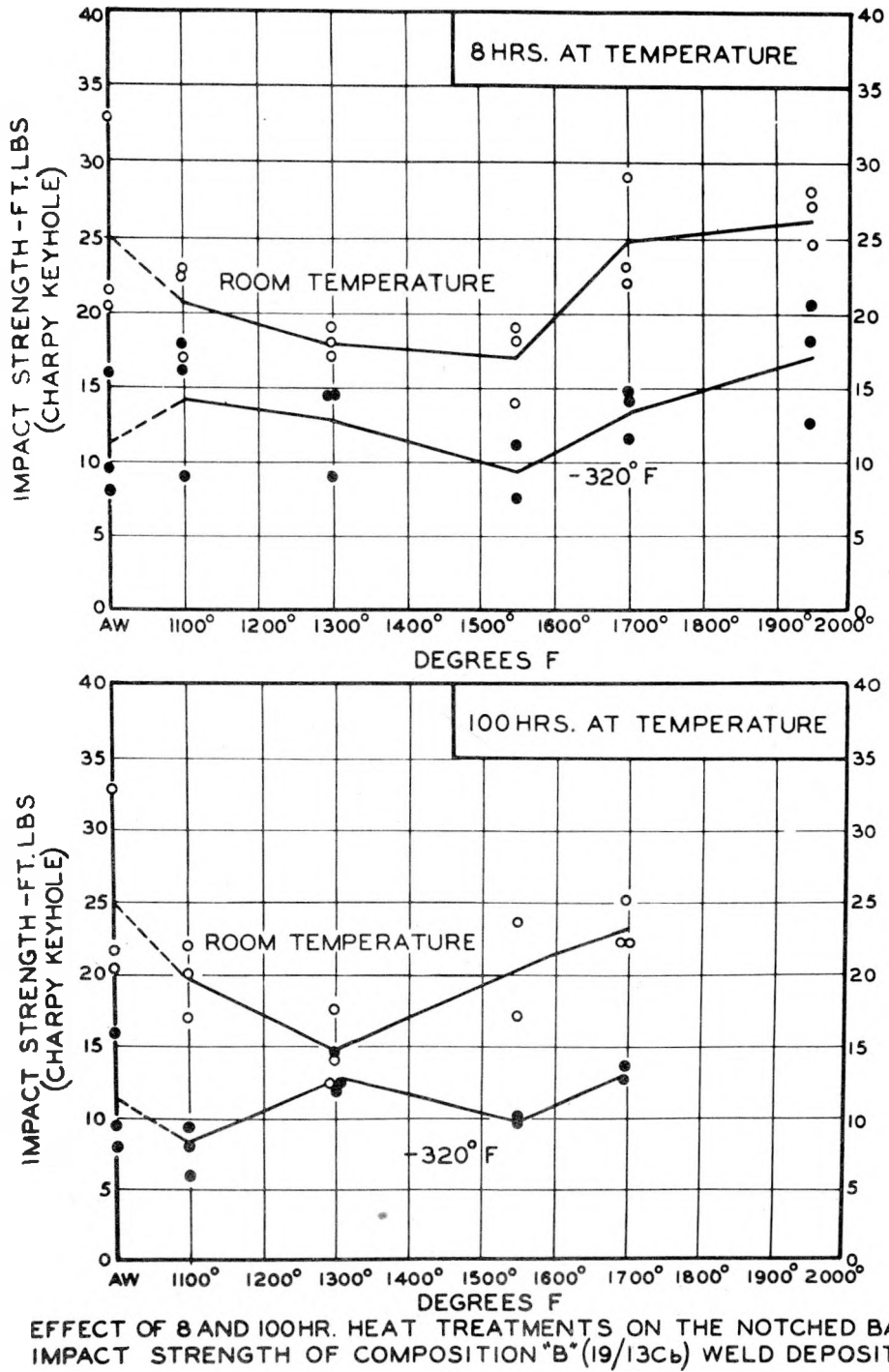
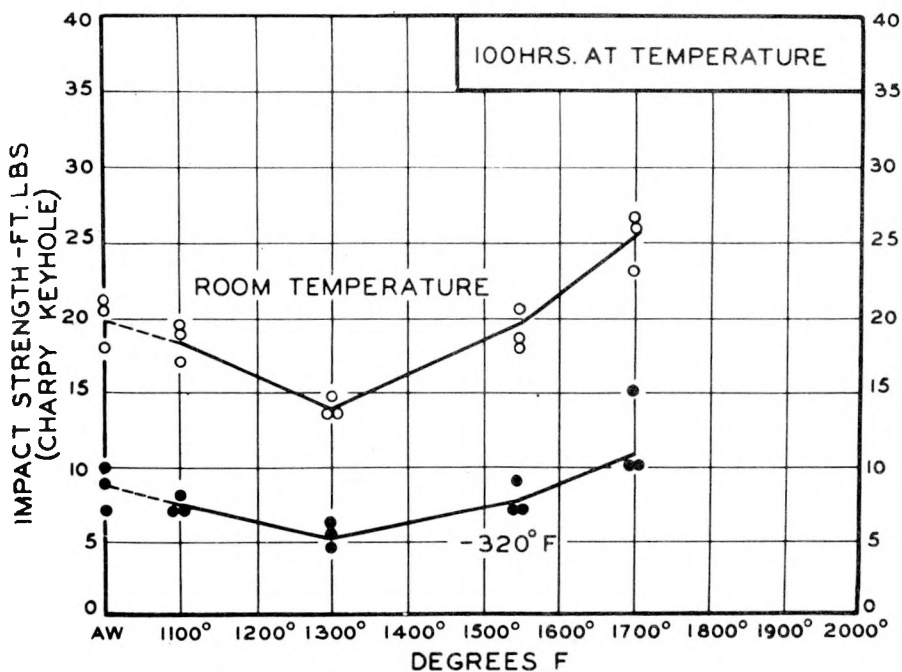
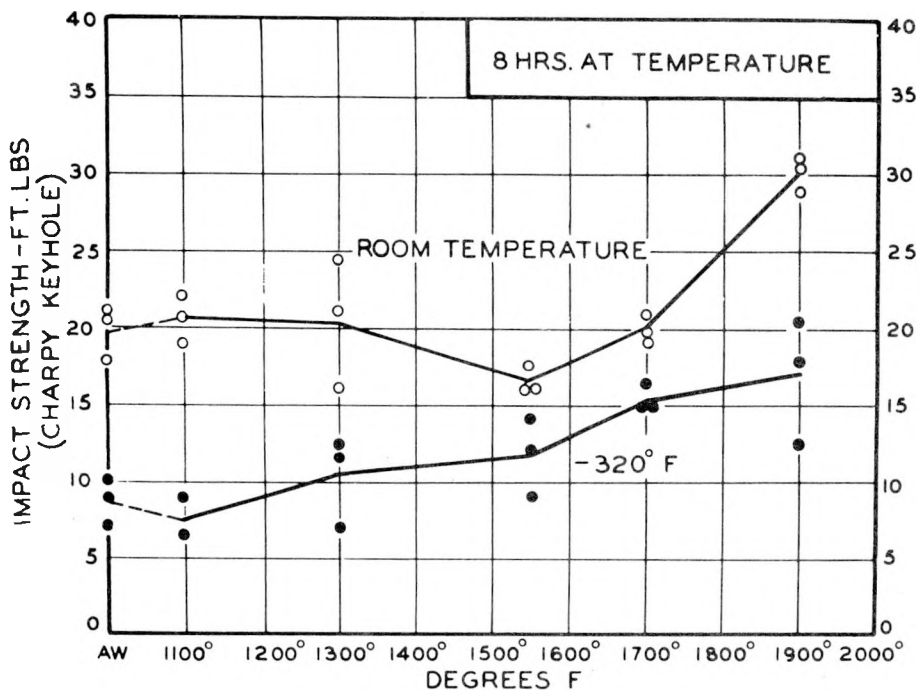
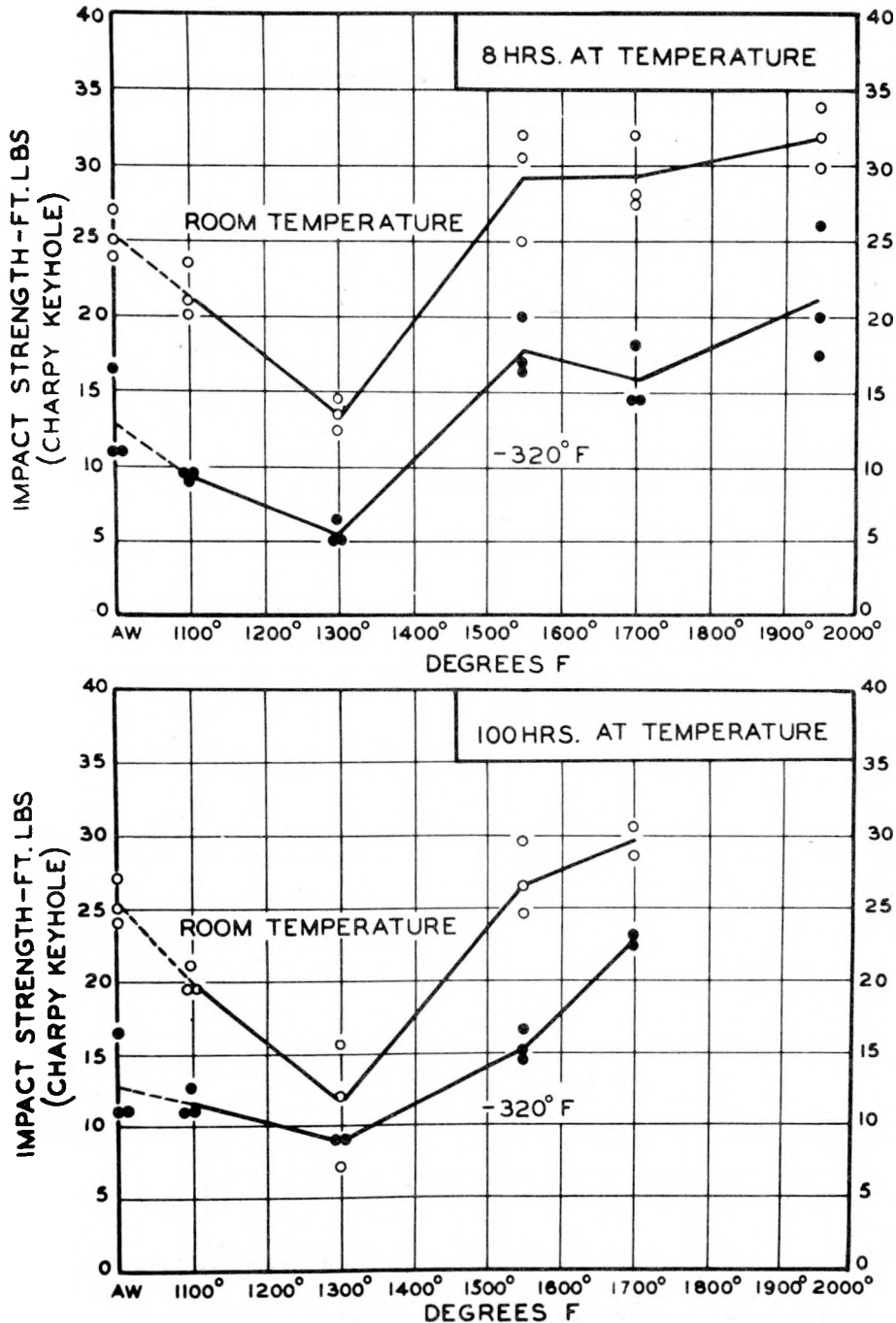


Figure 75



EFFECT OF 8 AND 100 HR. HEAT TREATMENTS OF THE NOTCHED BAR IMPACT STRENGTH OF COMPOSITION °C (19/13Cb) WELD DEPOSITS

Figure 76



EFFECT OF 8 AND 100HR. HEAT TREATMENTS ON THE NOTCHED BAR IMPACT STRENGTH OF COMPOSITION 'D' (19/9Cb) WELD DEPOSITS

Figure 77

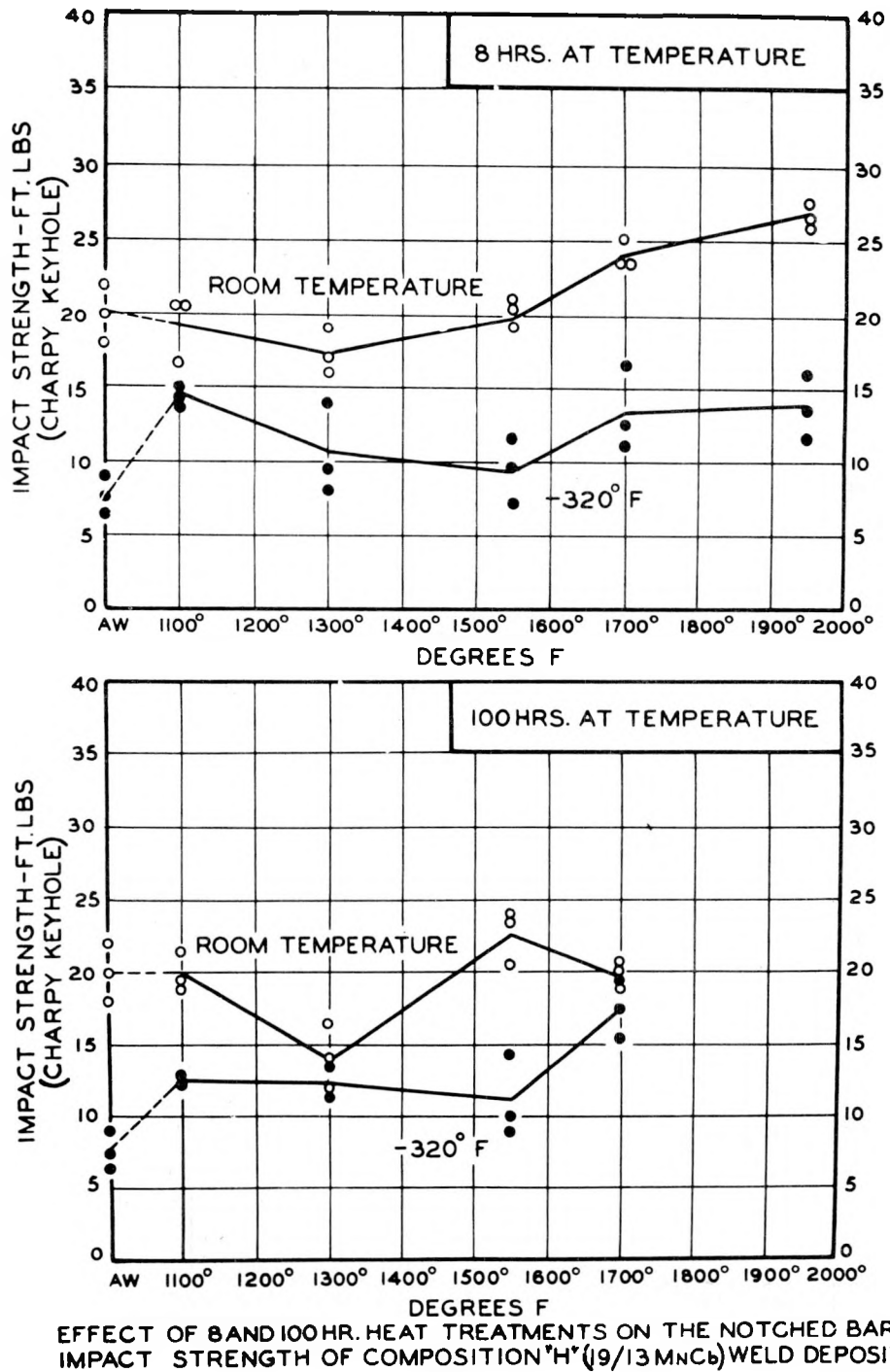
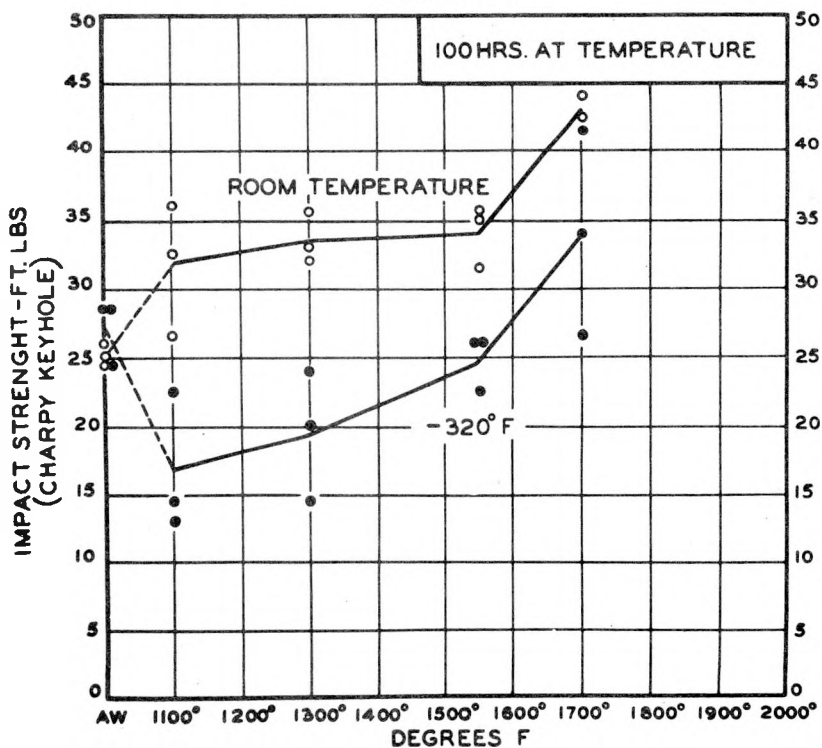
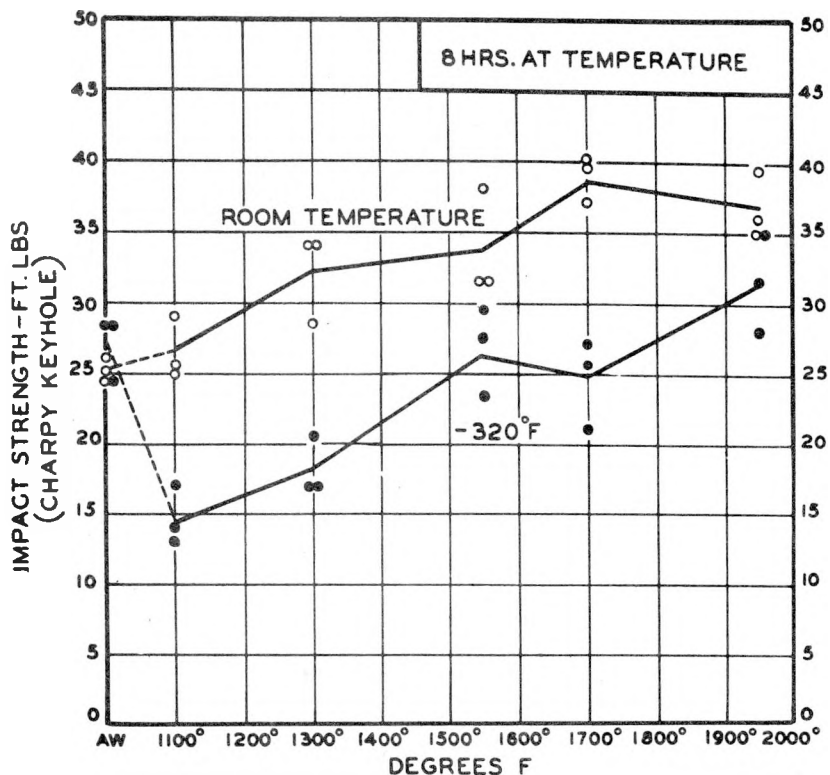
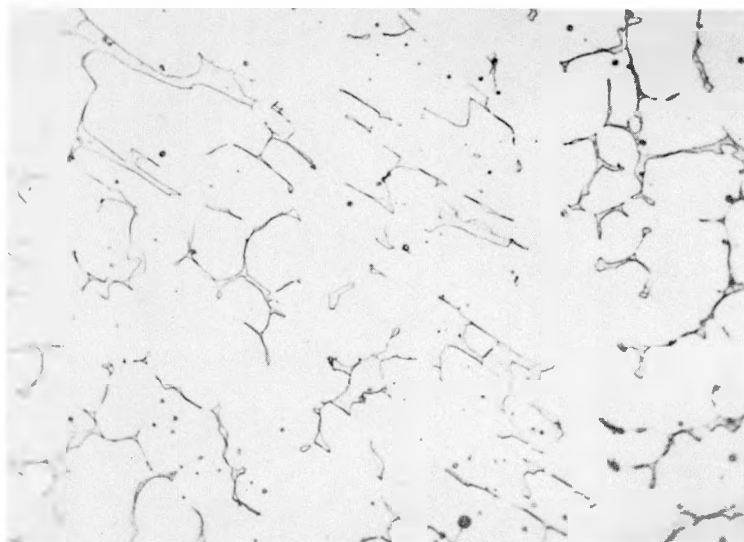


Figure 78



EFFECT OF 8 AND 100HR. HEAT TREATMENTS ON THE NOTCHED BAR IMPACT STRENGTH OF COMPOSITION 'F'(19/10LC) WELD DEPOSITS

Figure 79



P3861

Kalling's Reagent

1000X

Figure 80. As welded microstructure of Composition A deposit. Ferrite is observed in a matrix of austenite.

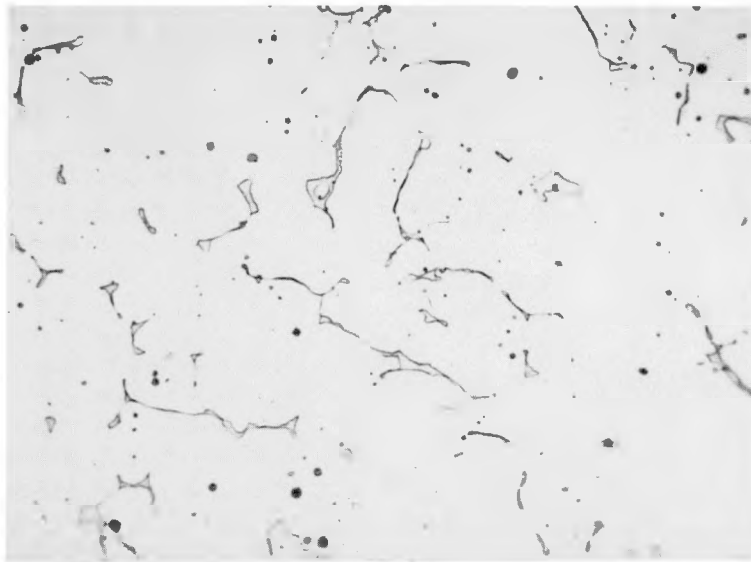


P3863

Oxalic Acid Electrolytic

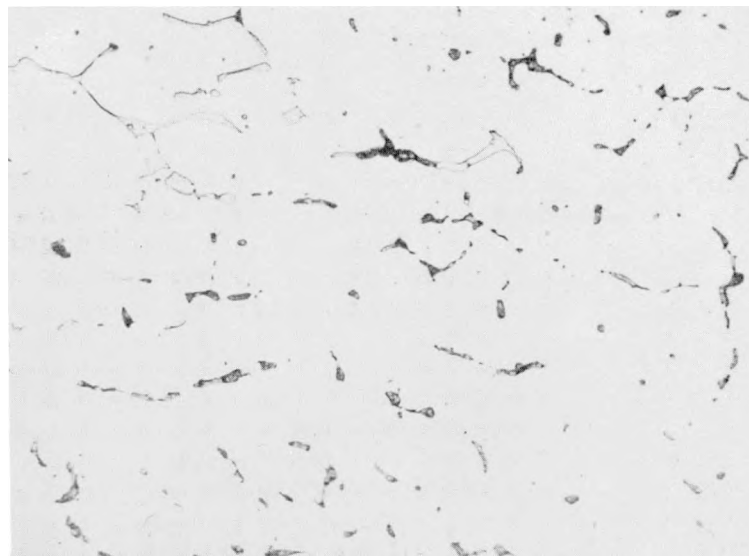
1000X

Figure 81. As welded microstructure of Composition H deposit. An eutectic-like grain boundary constituent is observed in a matrix of austenite.



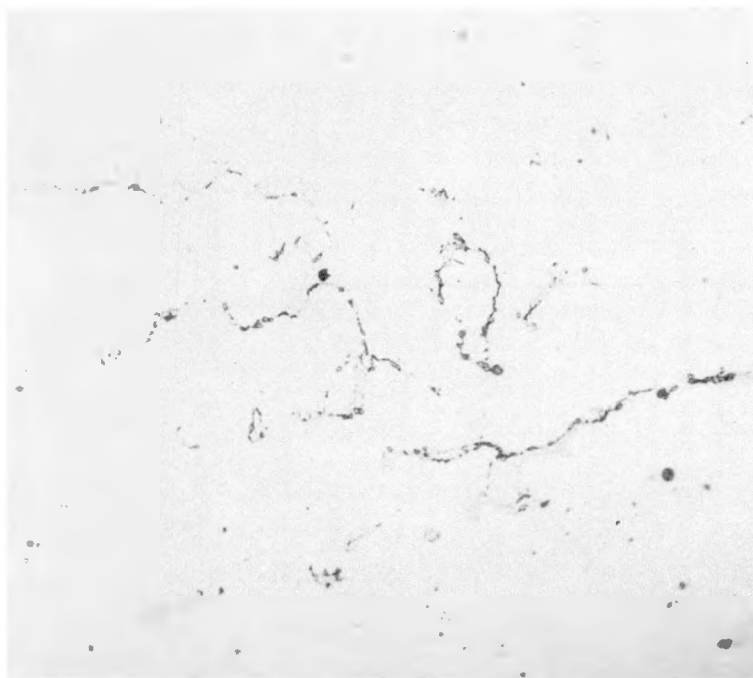
P3862 Kalling's Reagent 1000X

Figure 82. As-welded microstructure of Composition F low carbon weld deposit. Ferrite is observed in an austenitic matrix.



P3867 Kalling's - Mod. Murakami's 1000X

Figure 83. Microstructure of Composition A weld deposit after heat treatment of 1300°F for 100 hours. Ferrite (light) and sigma (dark) are observed in an austenite matrix.



P3865

Mod. Murakami's

1000X

Figure 84. Microstructure of Composition H weld deposit after heat treatment of 1300°F for 100 hrs. Grain boundary constituent believed to be sigma and/or carbides in an austenite matrix.

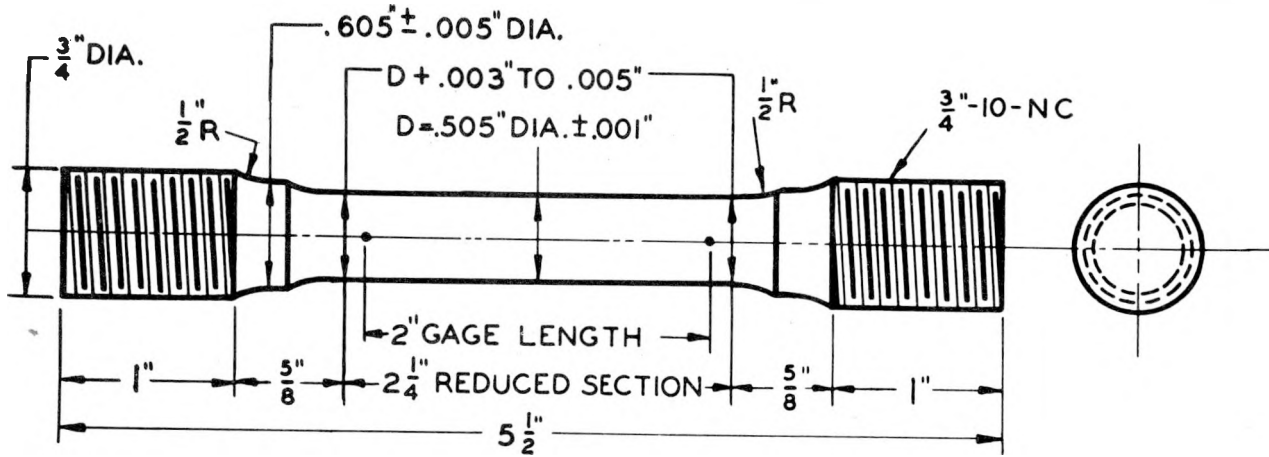


Figure 85. Test specimen employed in high-temperature tensile and stress-rupture test programs.

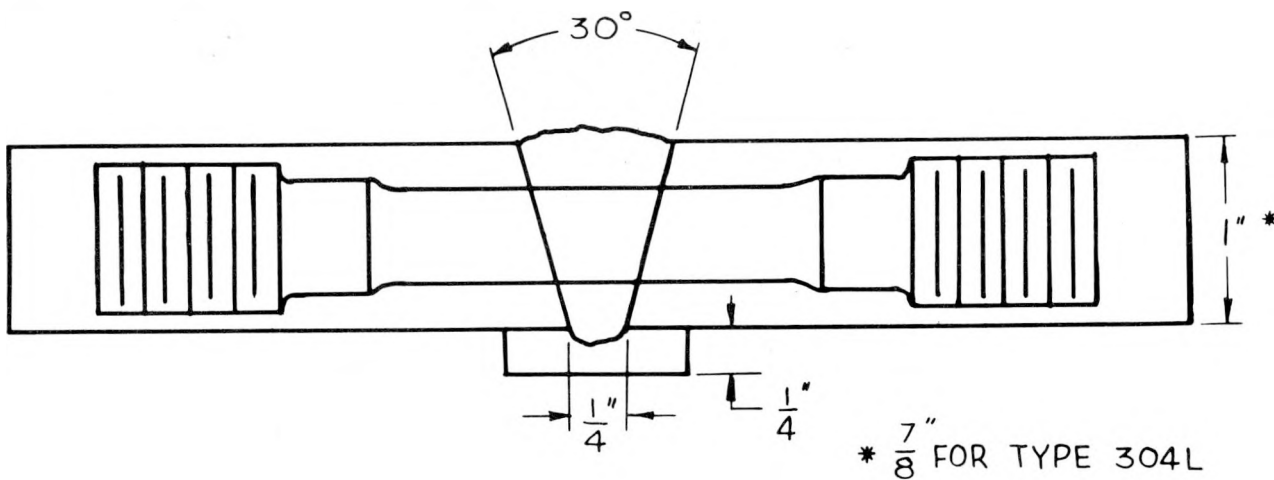


Figure 86. Design of transverse stress-rupture specimen.

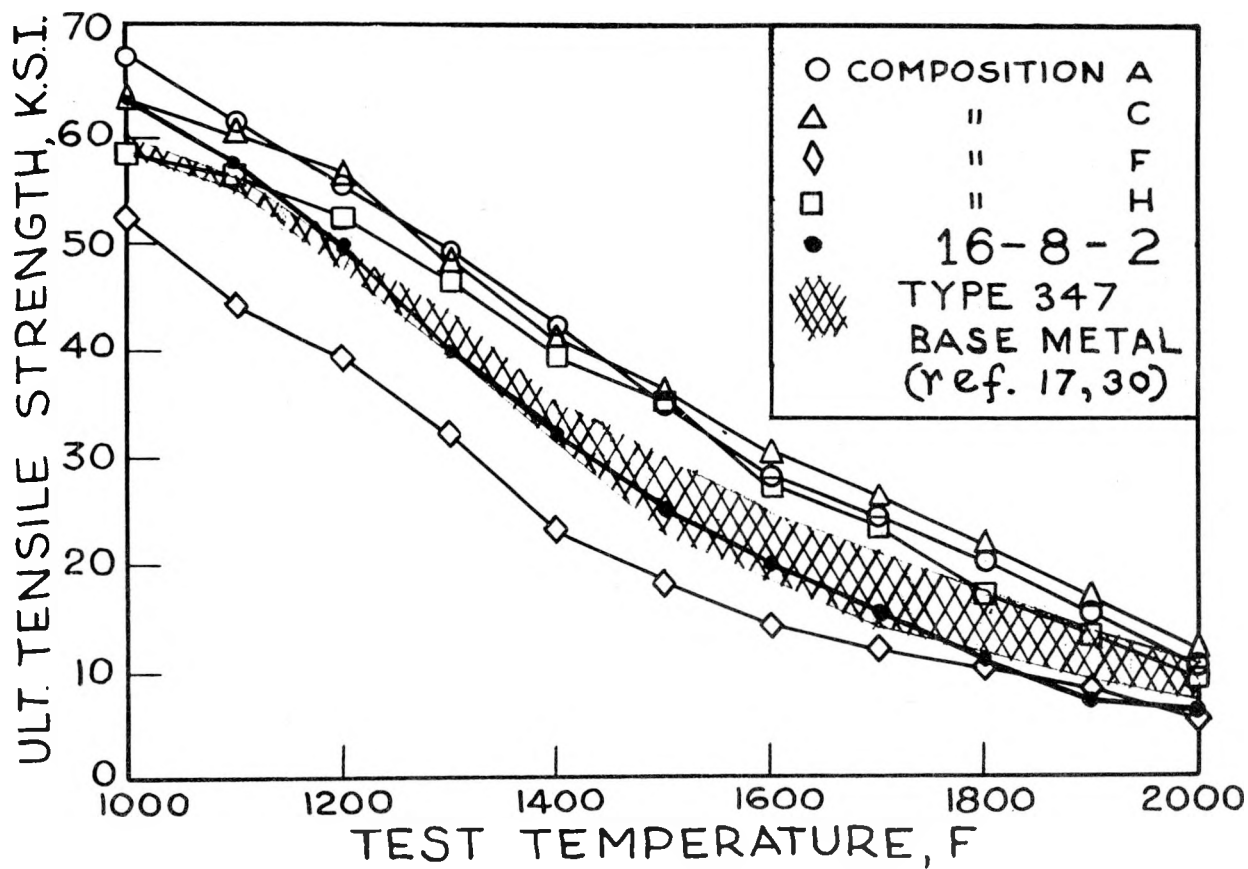


Figure 87. Elevated-temperature strength of various weld metals and Type 347 base material.

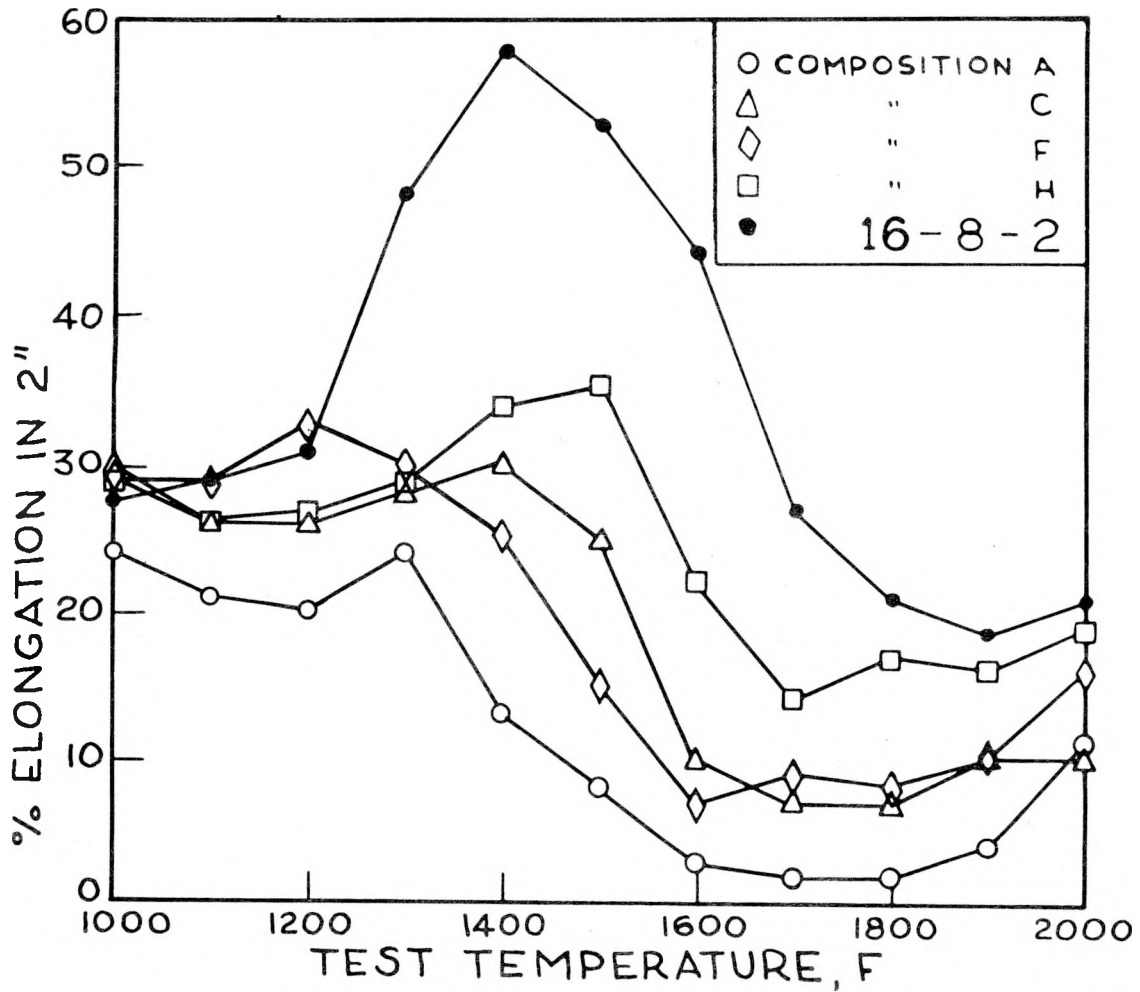


Figure 88. Variation of percent elongation with test temperature.

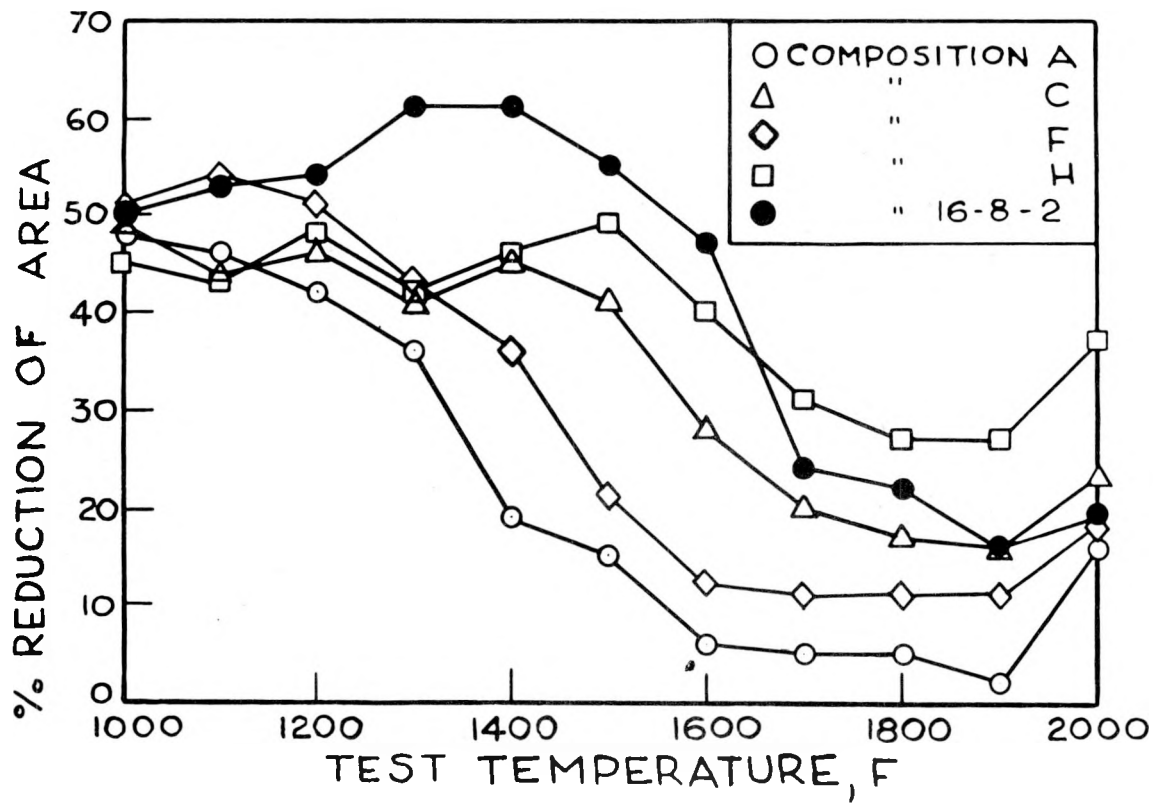


Figure 89. Variation of percent reduction of area with test temperature.

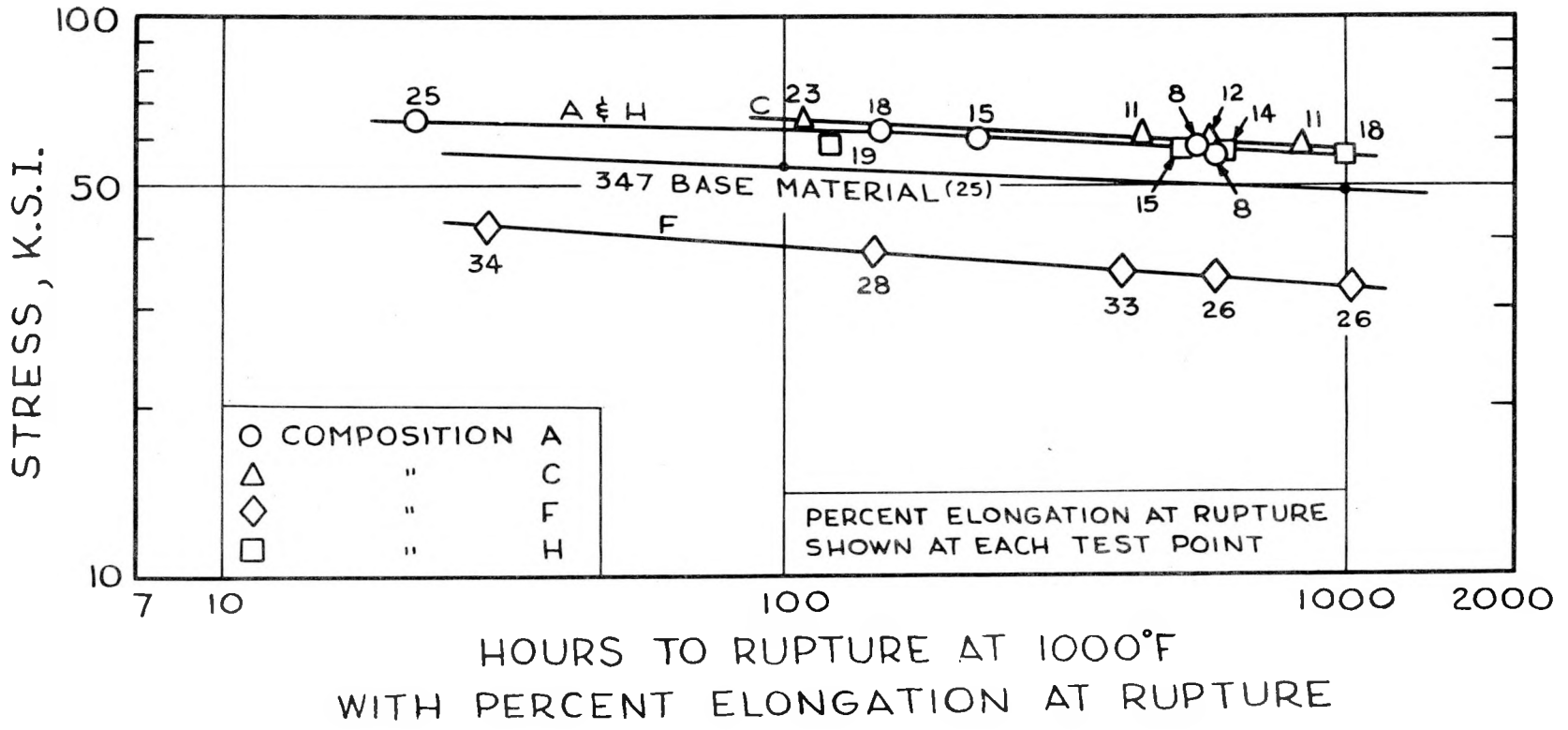


Figure 90. Stress-rupture curves for as-welded all-weld-metal specimens at 1000°F.

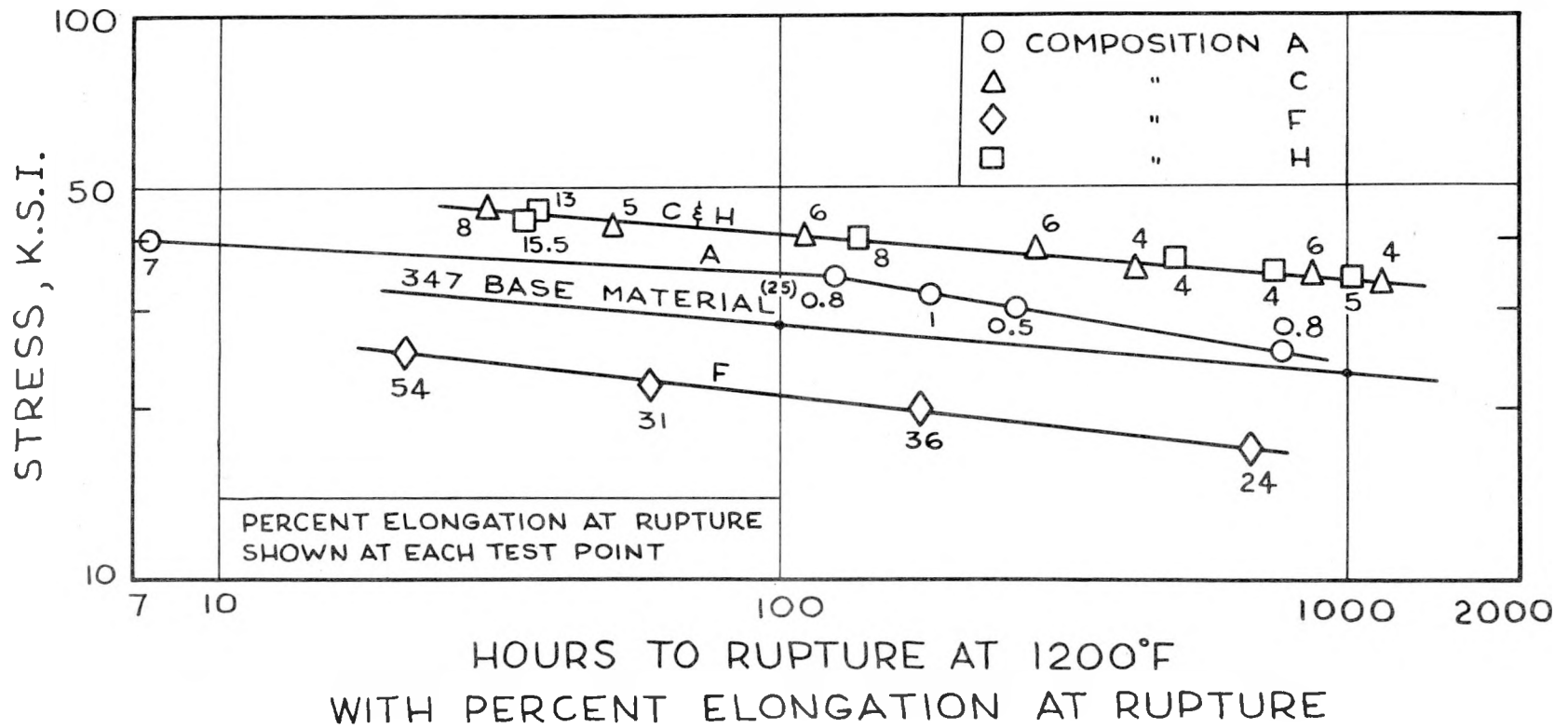


Figure 91. Stress-rupture curves for as-welded all-weld-metal specimens at 1200°F.

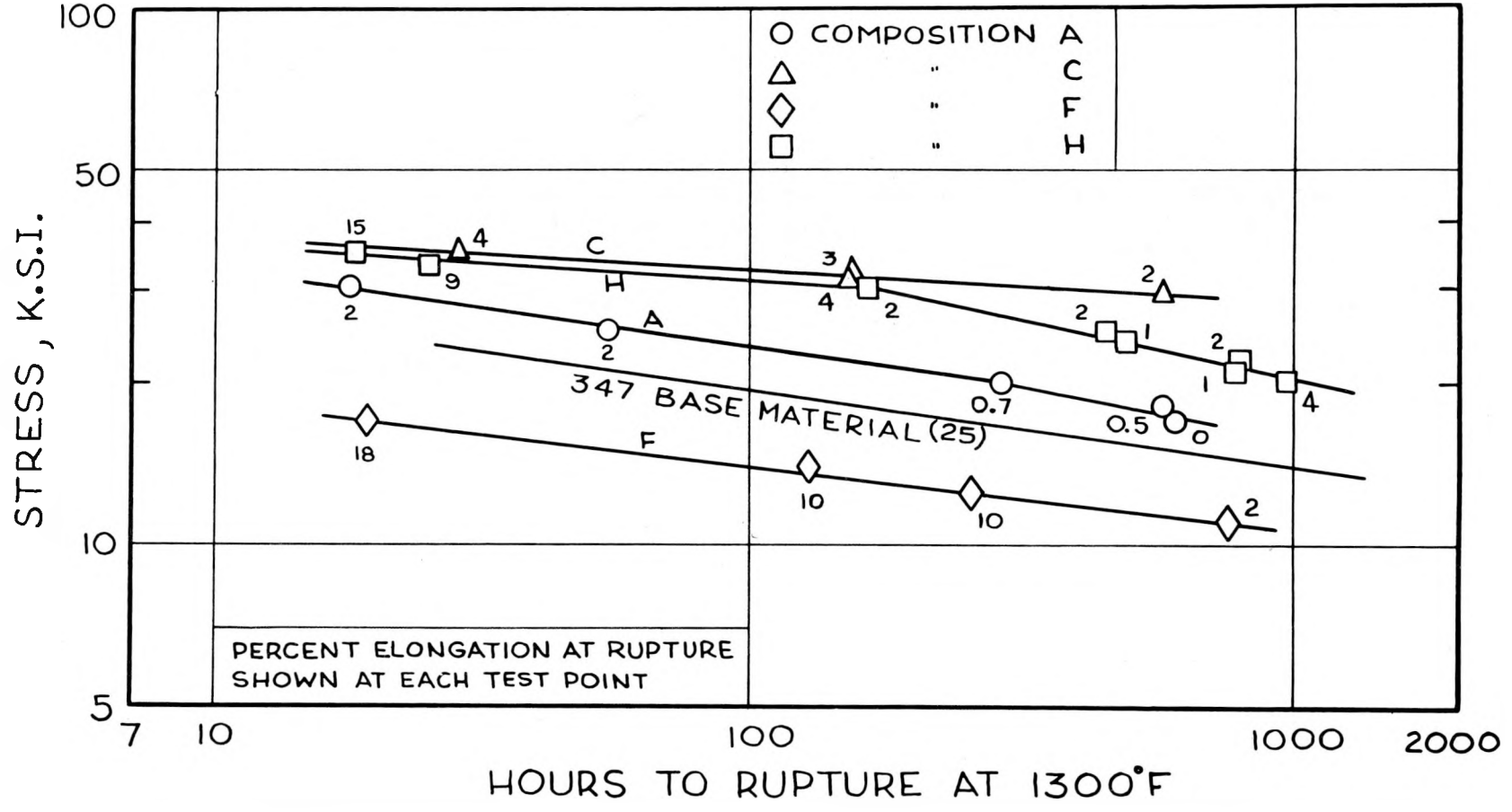


Figure 92. Stress-rupture curves for as-welded all-weld-metal specimens at 1300°F.

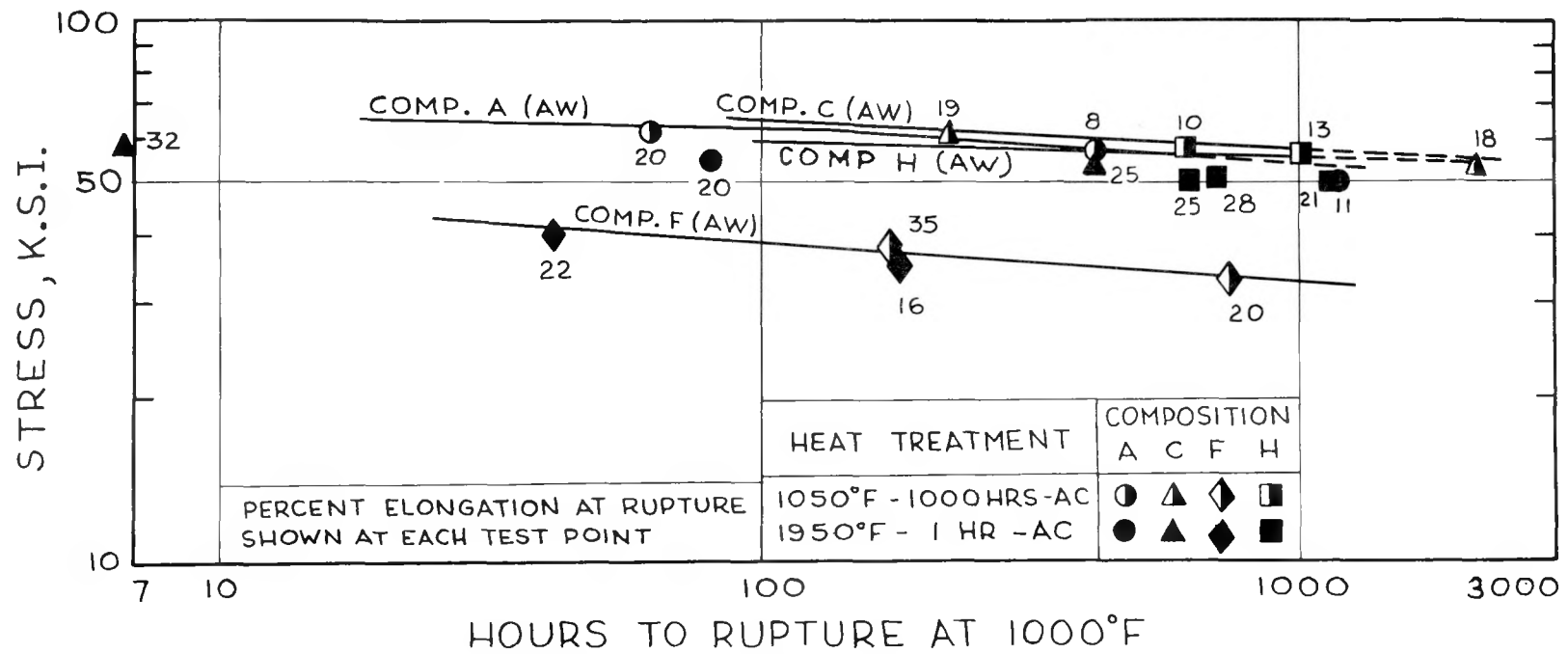


Figure 93. Stress-rupture points for heat-treated all-weld-metal specimens plotted for comparison with the curves which represent the results of tests which were conducted in the as-welded condition at 1000°F.

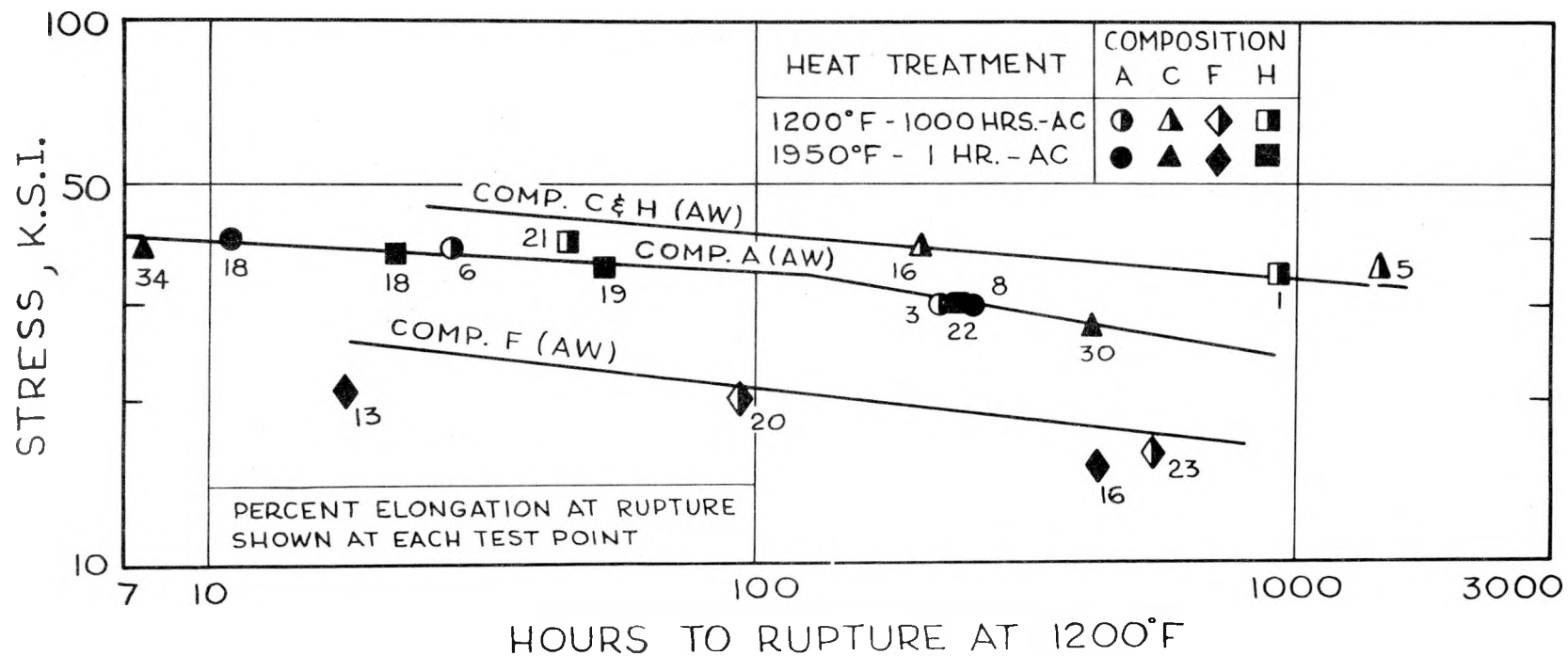


Figure 94. Stress-rupture points for heat-treated all-weld-metal specimens plotted for comparison with the curves which represent the results of tests which were conducted in the as-welded condition at 1200°F.

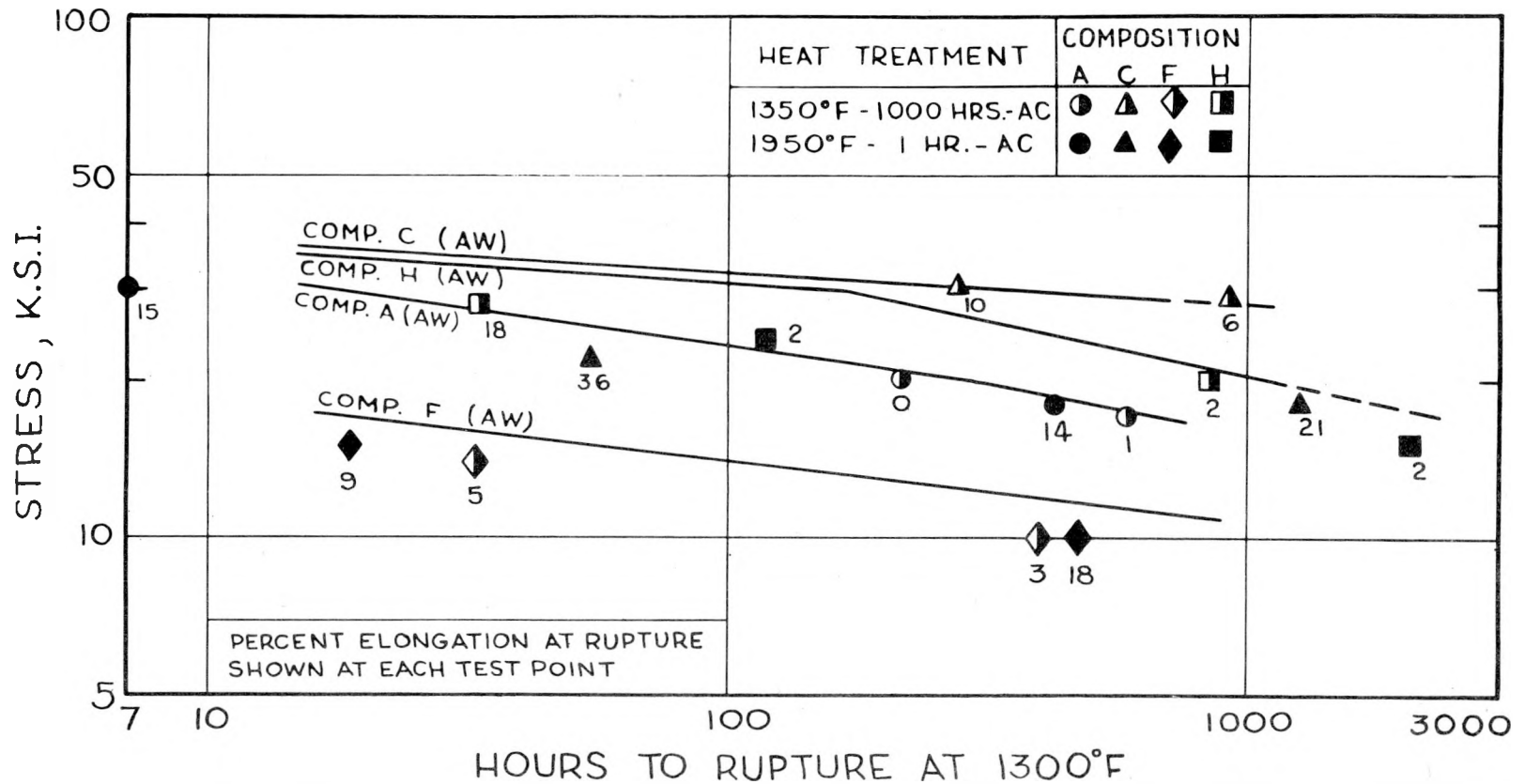


Figure 95. Stress-rupture points for heat-treated all-weld-metal specimens plotted for comparison with the curves which represent the results of tests which were conducted in the as-welded condition at 1300°F.

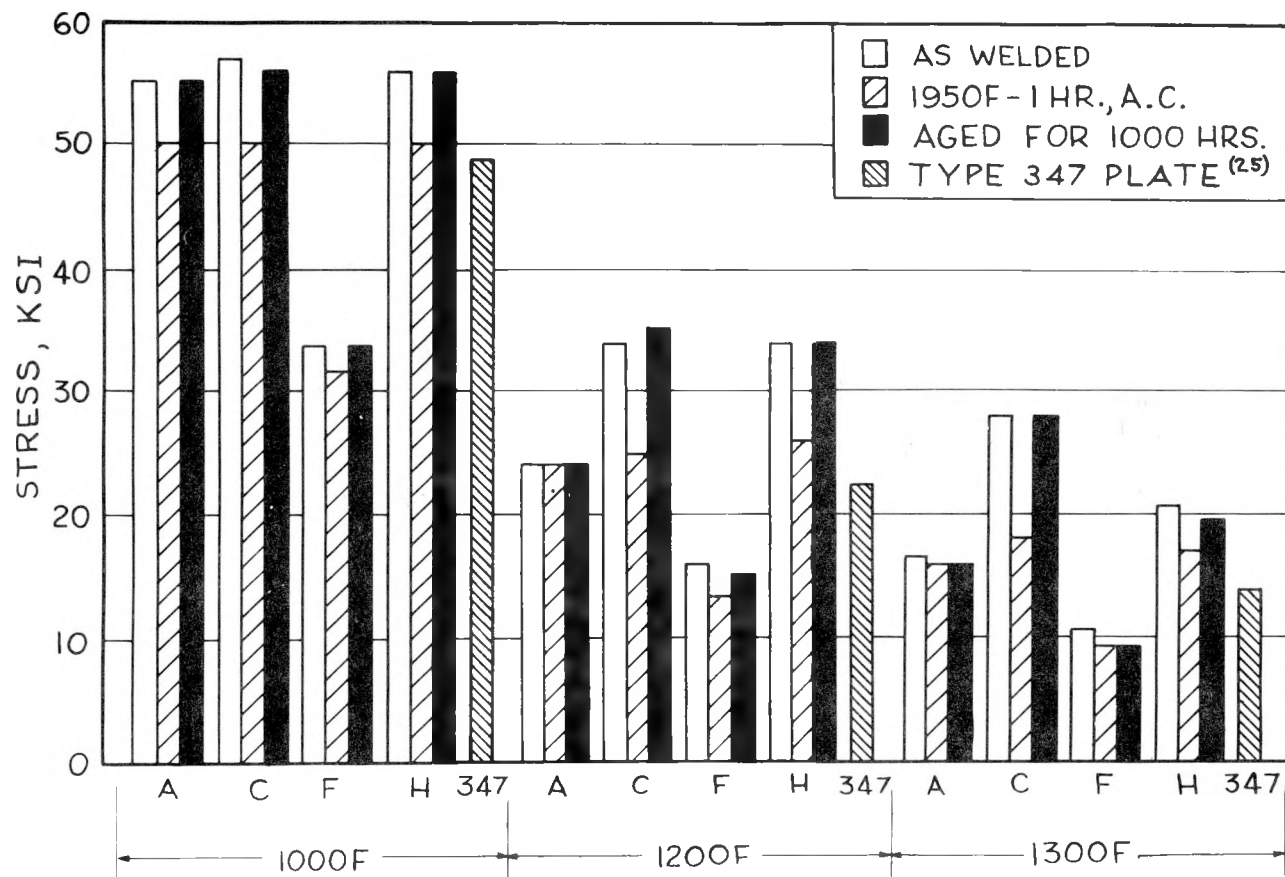


Figure 96. Stress for rupture in 1000 hr. at 1000, 1200 and 1300°F.

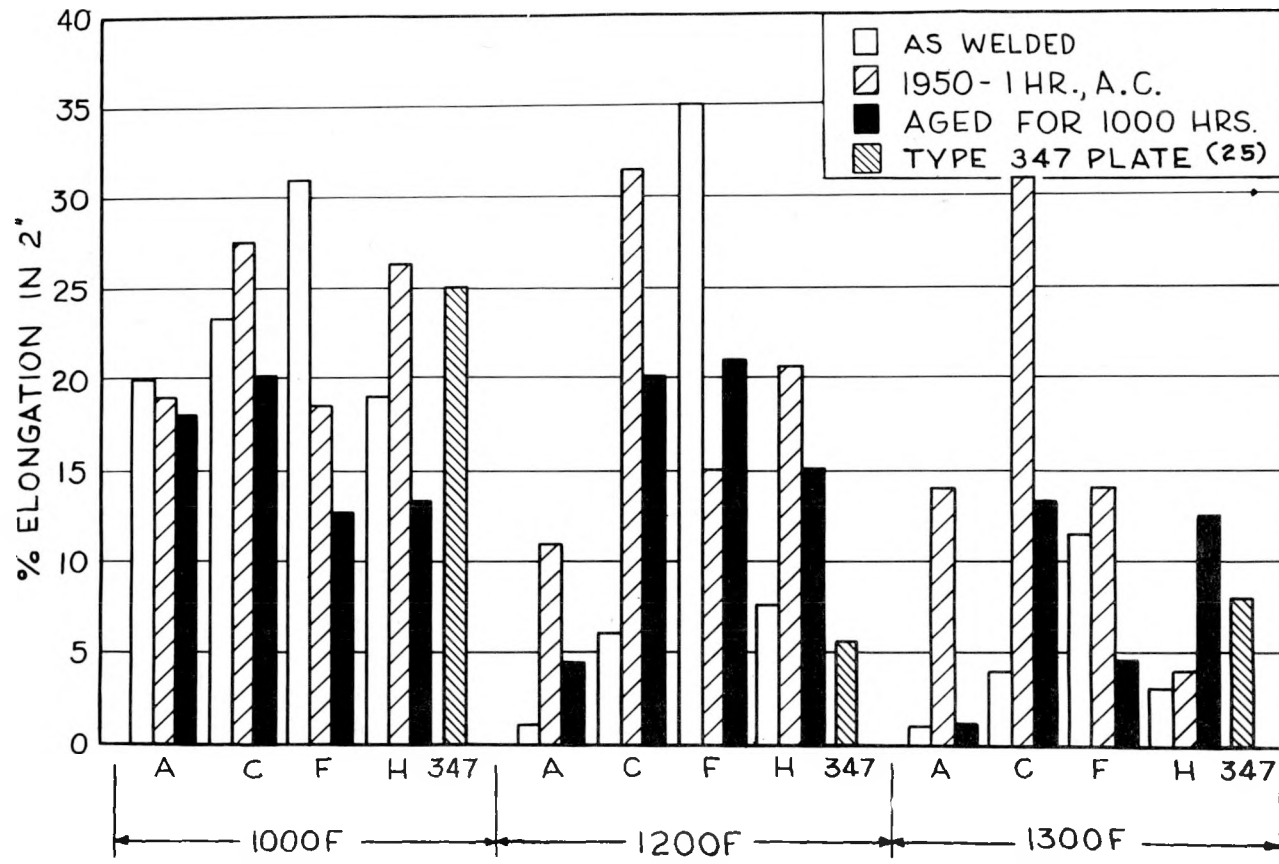


Figure 97. Approximate percent elongation for a 100-hr. stress-rupture life.

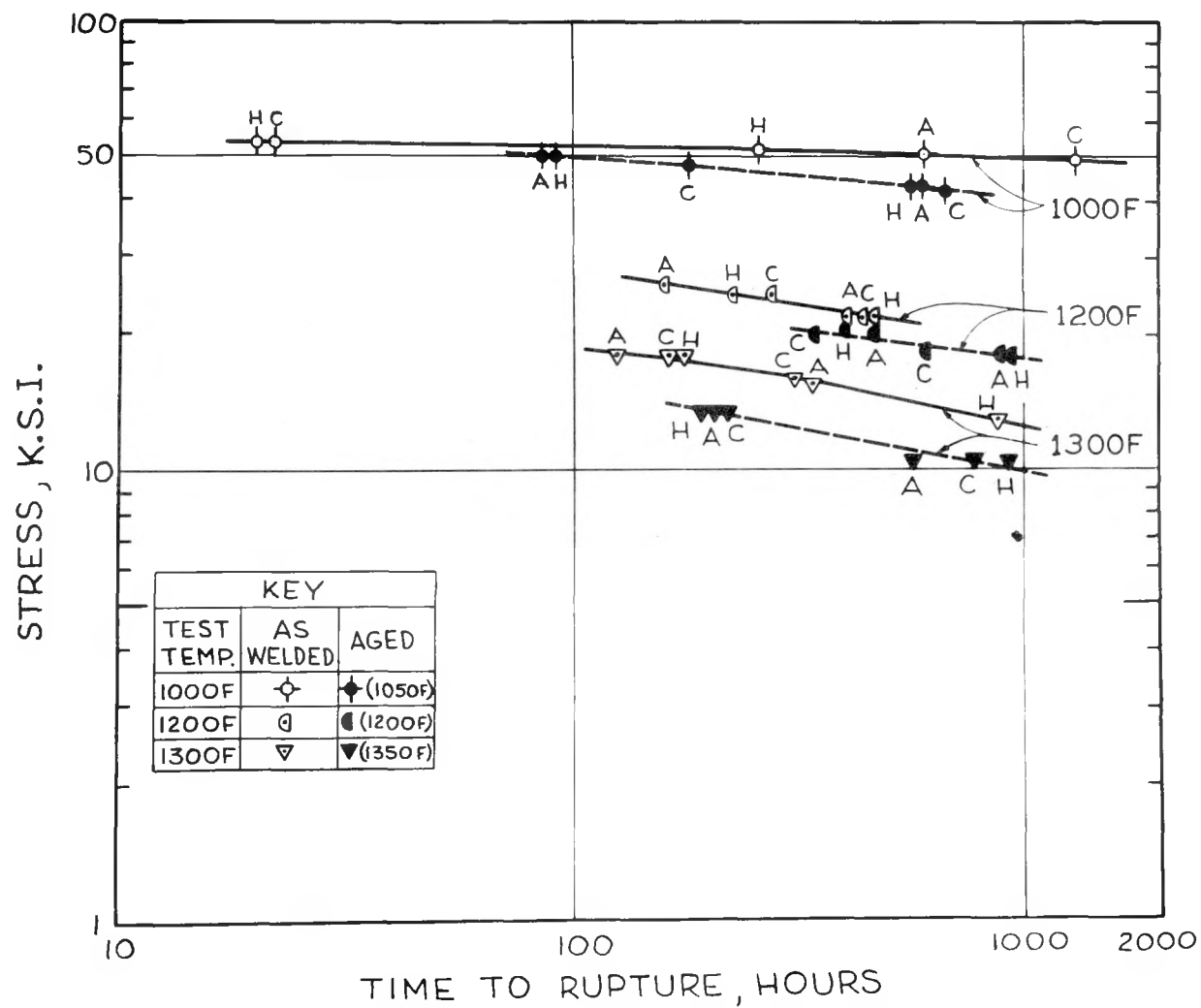


Figure 98. The effect of 10,000 hours of aging on the stress-rupture strength of transverse specimens. All failures in the as-welded and aged conditions were located in the Type 347 base material.

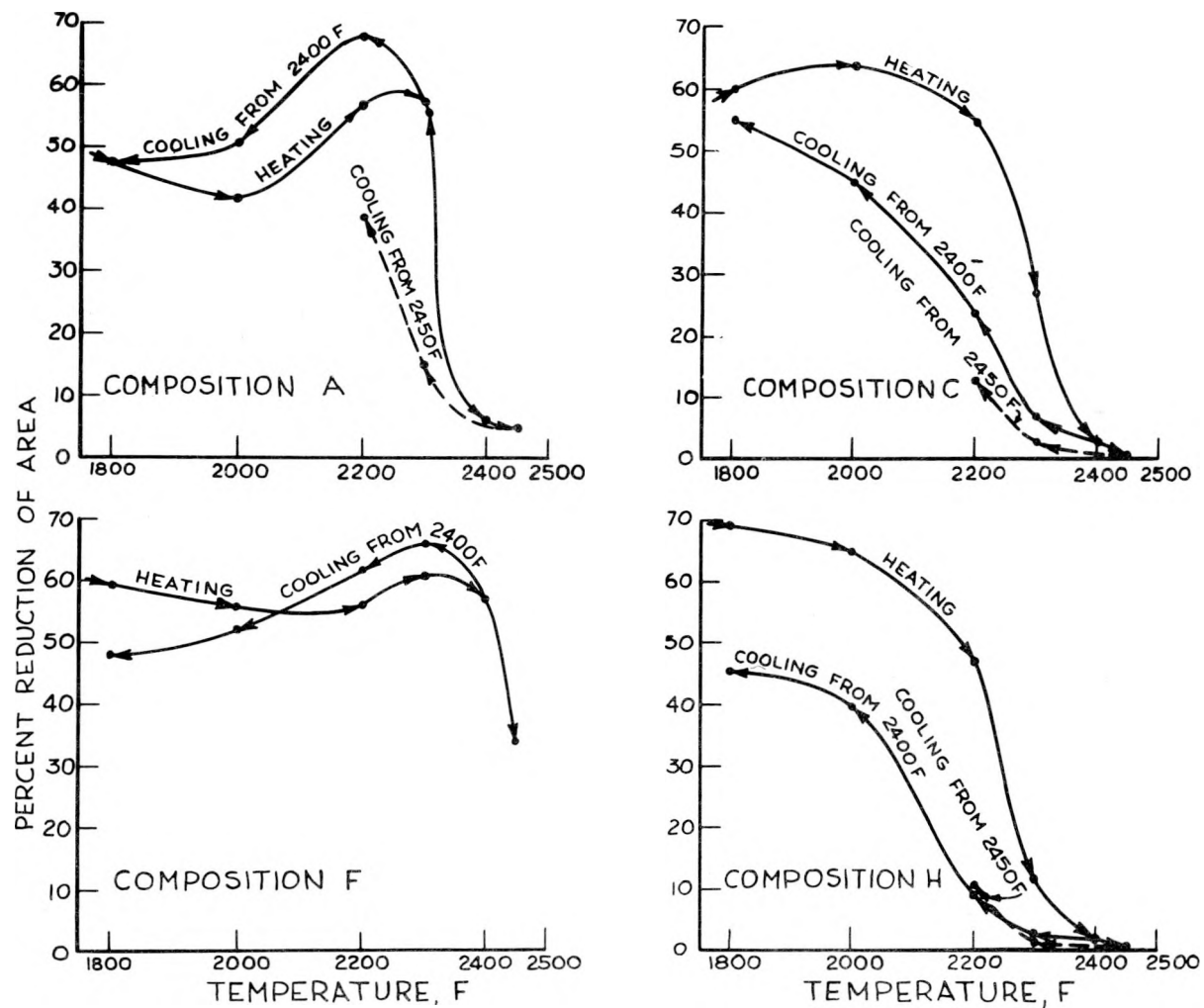


Figure 99. RPI hot-ductility test results comparing the reduction of area obtained when tested on heating the specimen or on cooling the specimen from the indicated temperature.

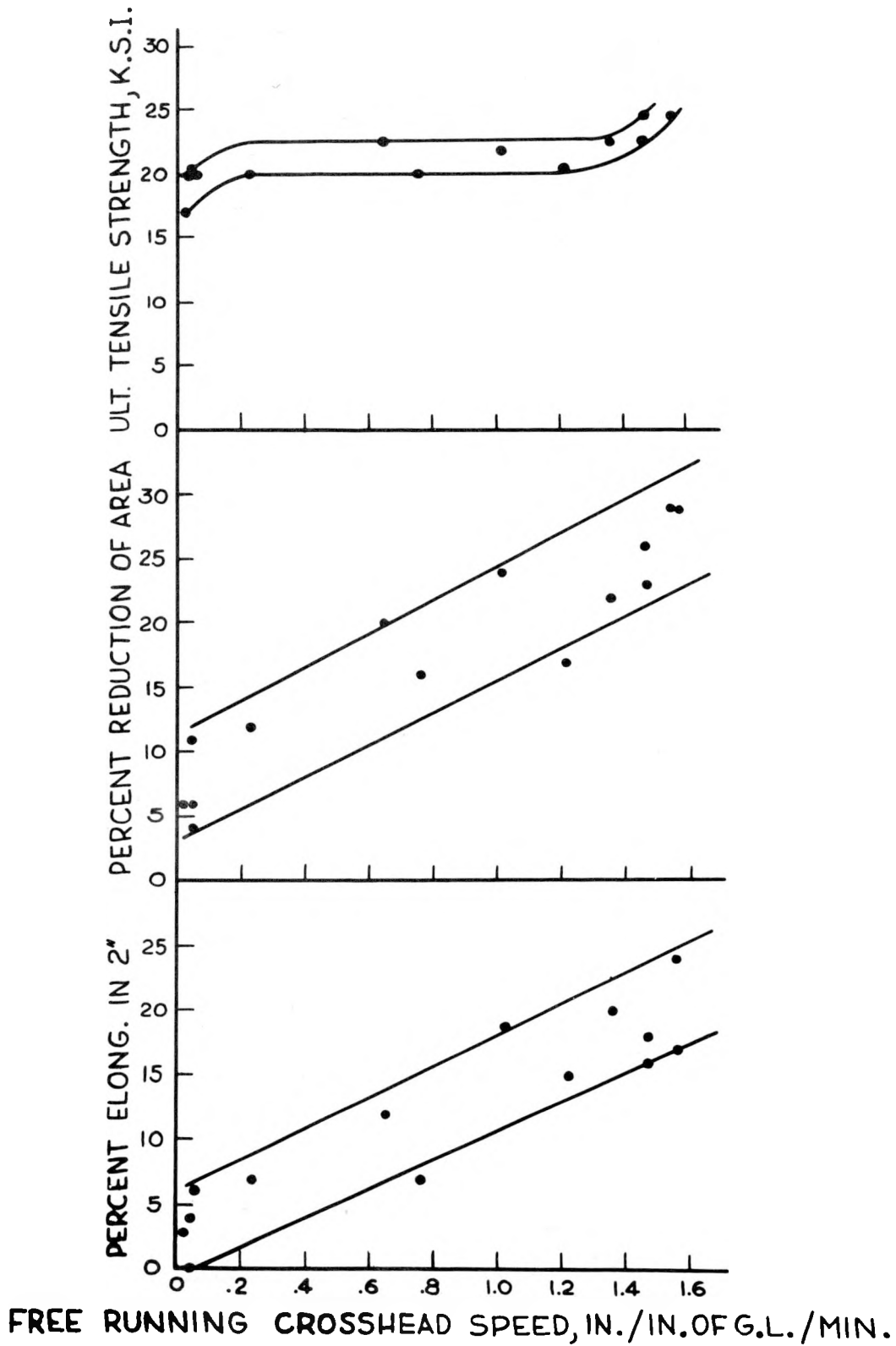
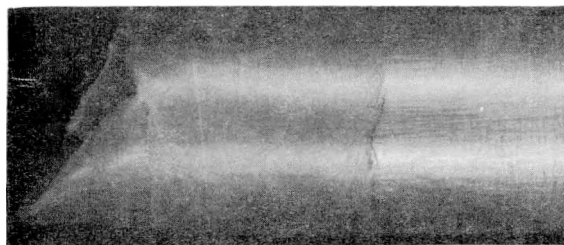


Figure 100. Strength and ductility versus tensile-testing speed for composition A weld metal tested at 1800°F.



1:1 HCL Specimen A2T. X2

Figure 101. Macro-photograph illustrating mode of fracture of transverse stress-rupture specimen which was composed of Type 347 plate and standard Type 347 weld metal containing 7% ferrite and tested in the as-welded condition. Rupture life was 612 hrs. at 1000°F. Notice the crack in the heat-affected zone of the base material on the opposite side from fracture.

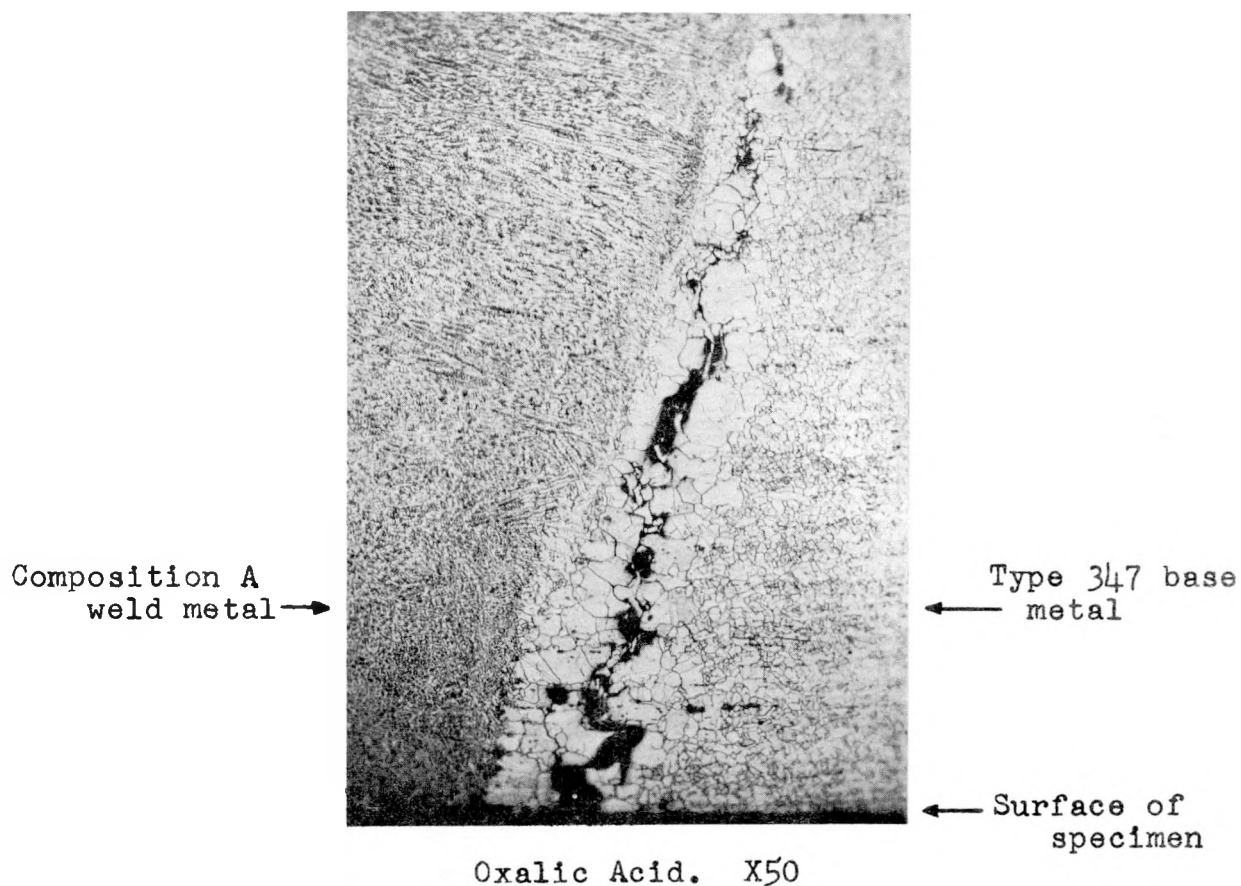


Figure 102. Photomicrograph illustrating intergranular stress-rupture cracking in the coarse-grained heat-affected zone of the Type 347 base material. Section taken in cracked area of Specimen A2T on opposite side from fracture.

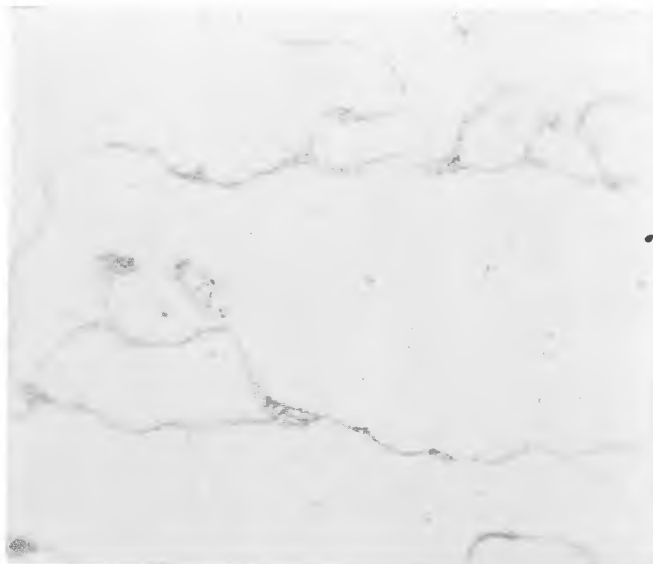
Direction of \updownarrow tensile force.



Marble's Reagent.

Specimen DZ6

Figure 103. Photomicrograph of RPI hot-ductility bar of high-manganese Type 347 weld metal illustrating the intergranular nature of failure and the continuous intergranular precipitate. This specimen was tested at 2300°F on cooling from 2400°F. X50



Oxalic acid.

Specimen DZ6

Figure 104. Appearance of eutectic-like intergranular precipitate at high magnification. X1000.

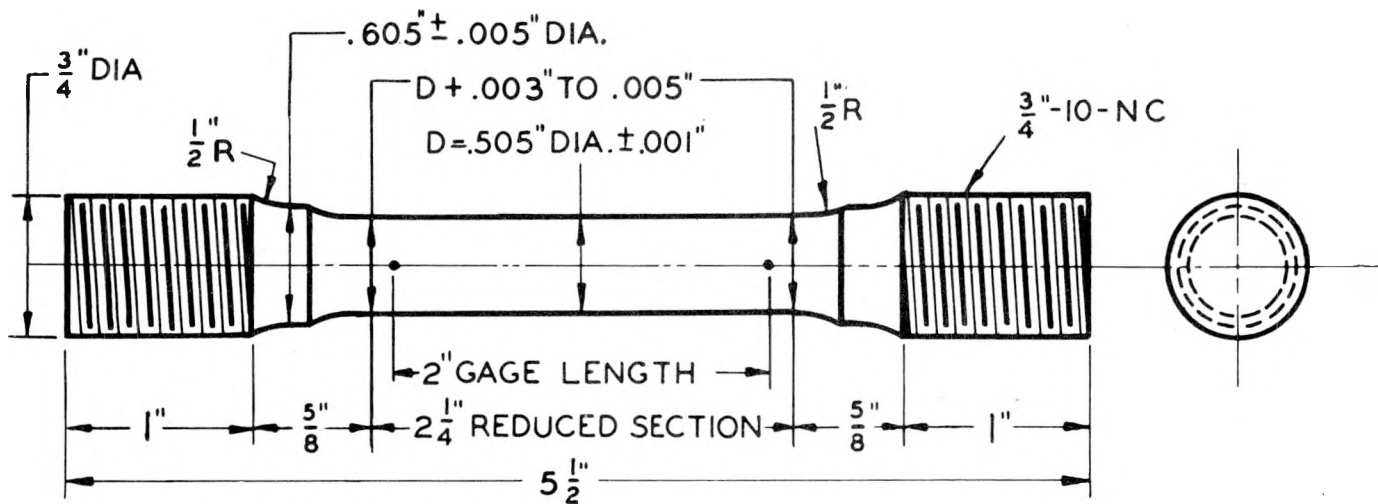


Figure 105. Stress-rupture test specimen.

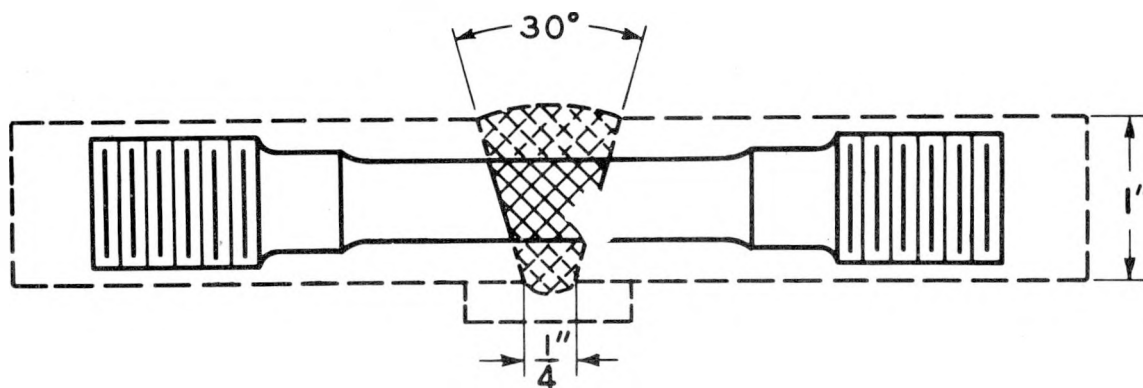


Figure 106. Design of transverse stress-rupture specimen.

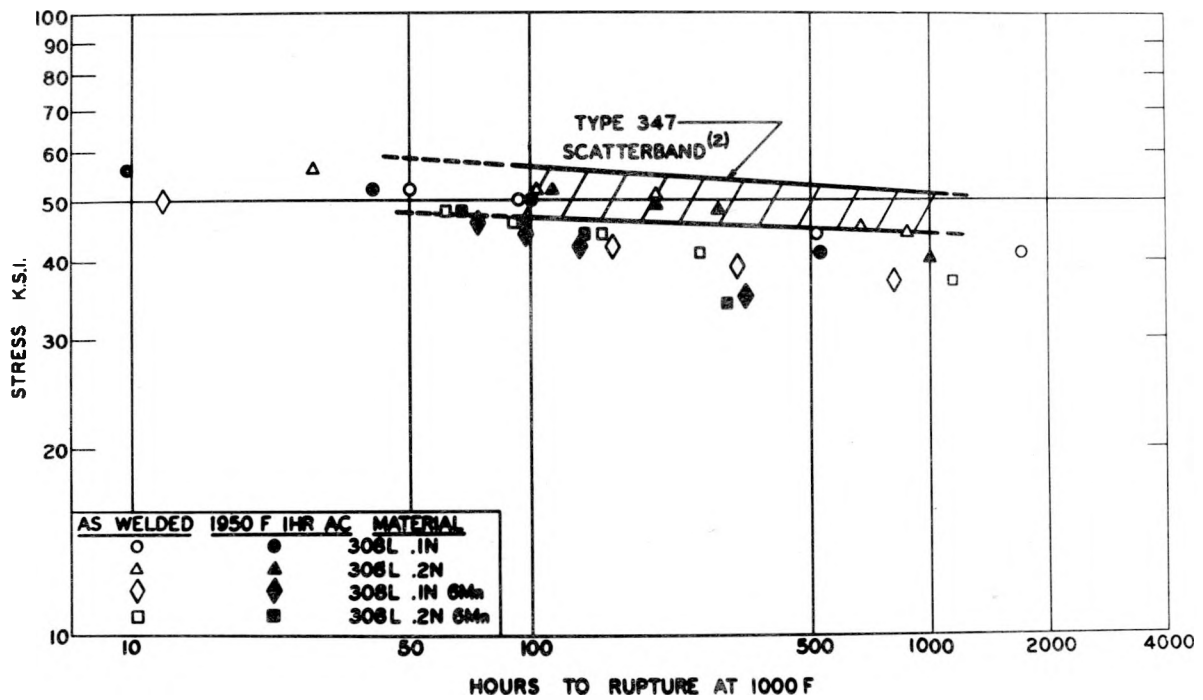


Figure 107. Stress-rupture data for all-weld-metal specimens which were tested at 1000F in the as-welded and annealed conditions. The Type 347 base material scatterband is presented for comparative purposes.

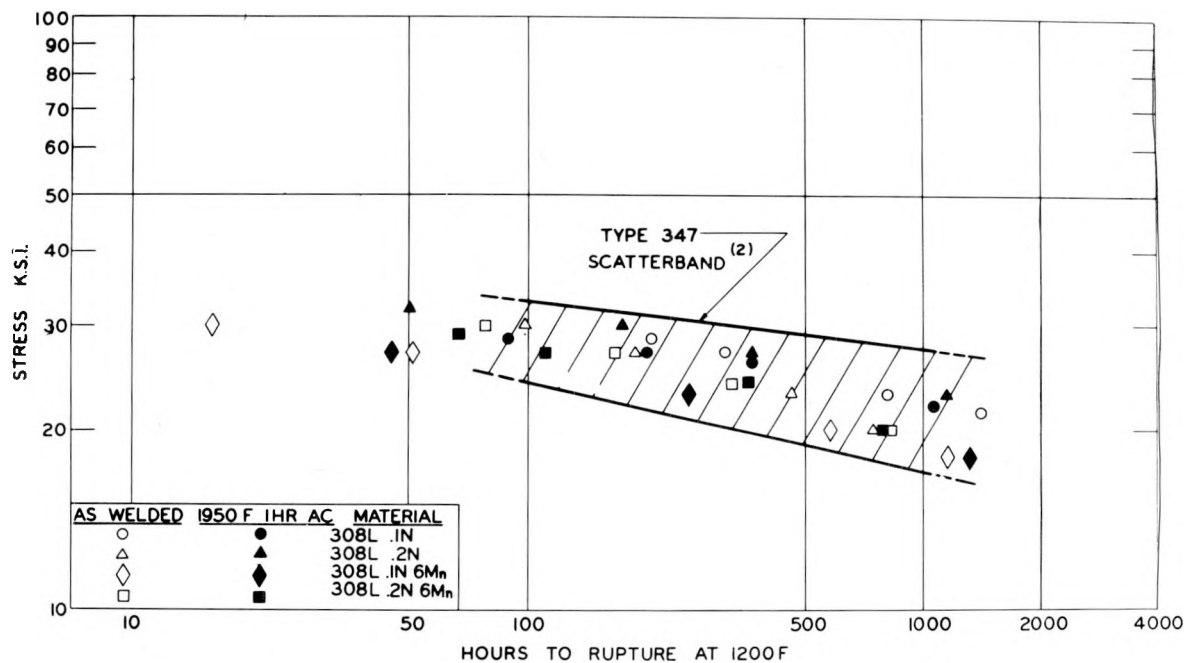


Figure 108. Stress-rupture data for all-weld-metal specimens which were tested at 1200F in the as-welded and annealed conditions. The Type 347 base material scatterband is presented for comparative purposes.

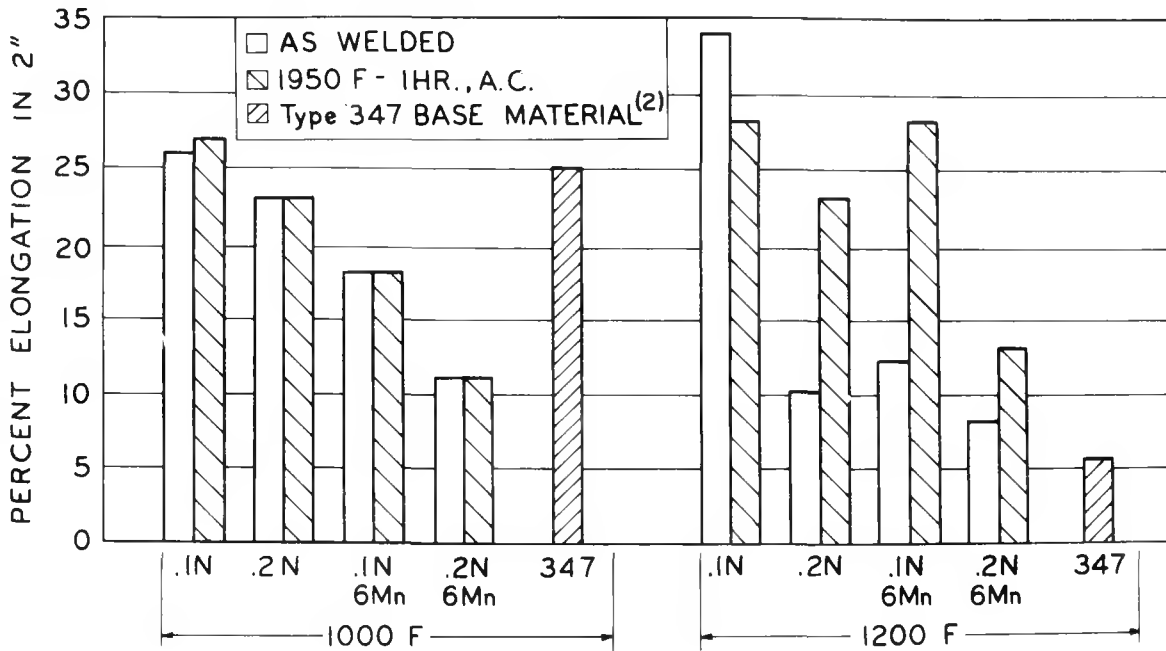


Figure 109. Approximate percent elongation for 100-hour stress-rupture life for all-weld-metal specimens and Type 347 base material.

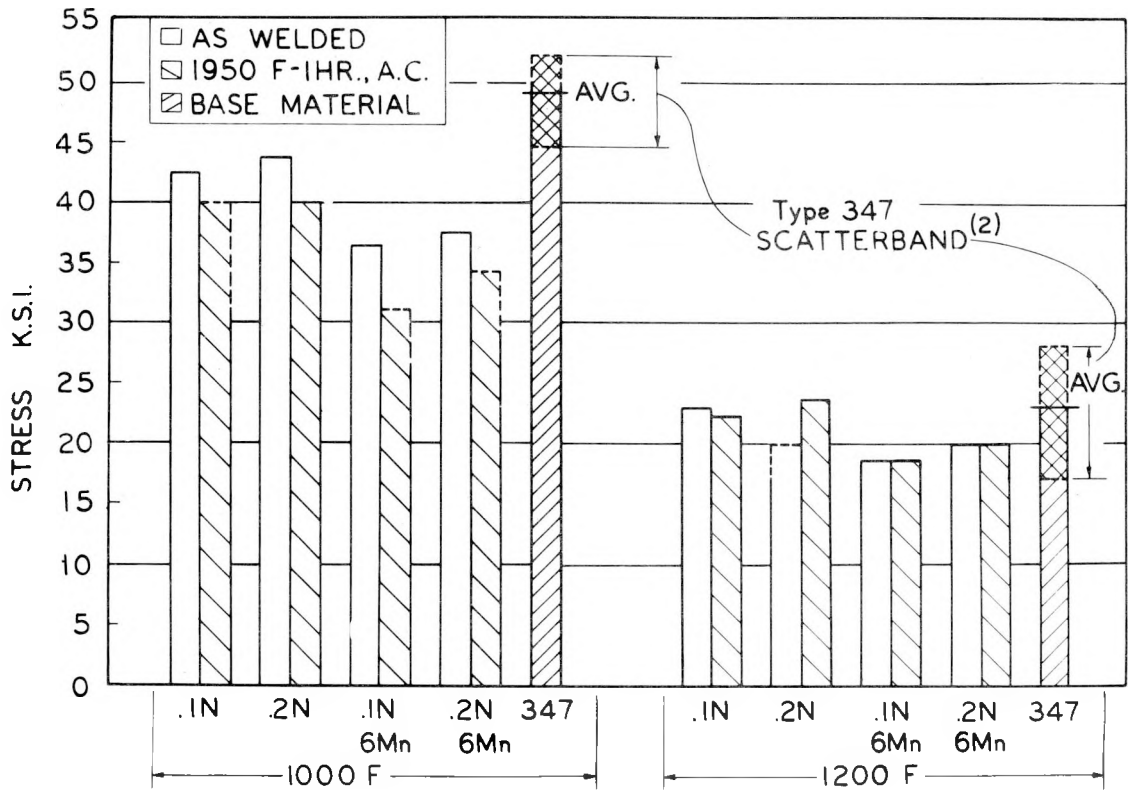


Figure 110. Stress for rupture in 1000 hours for all-weld-metal specimens and Type 347 base material.

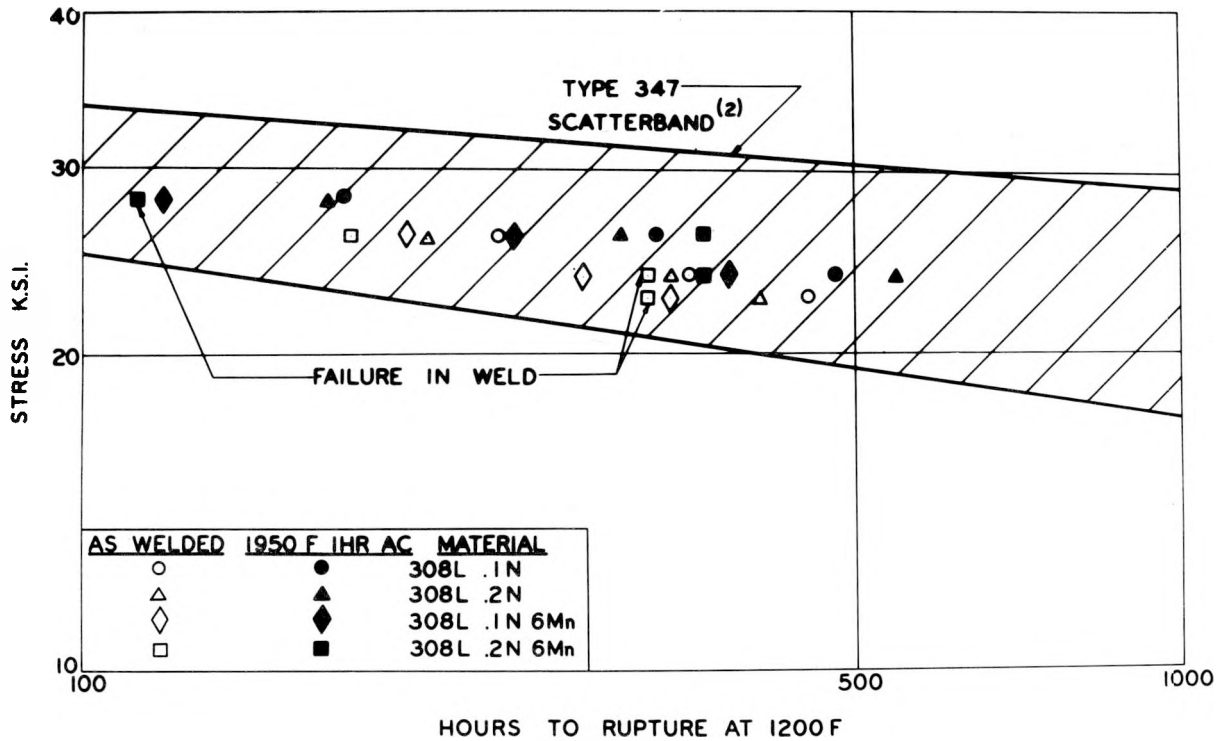


Figure 111. Stress-rupture data for transverse test in Type 347 base material. All but three specimens failed in the base material.



Kalling's Reagent

PRIOR TO TESTING
As-Welded Condition
Ferrite: 3-5%



Marble's Reagent

AFTER STRESS RUPTURE TESTING
at 1200F and 21.5 ksi for 1405 Hours
Ferrite: 1-3%

308L 0.1N WELD METAL
(Specimen No. S51)



Kalling's Reagent

PRIOR TO TESTING
As-Welded Condition
Ferrite: 7-9%



Marble's Reagent

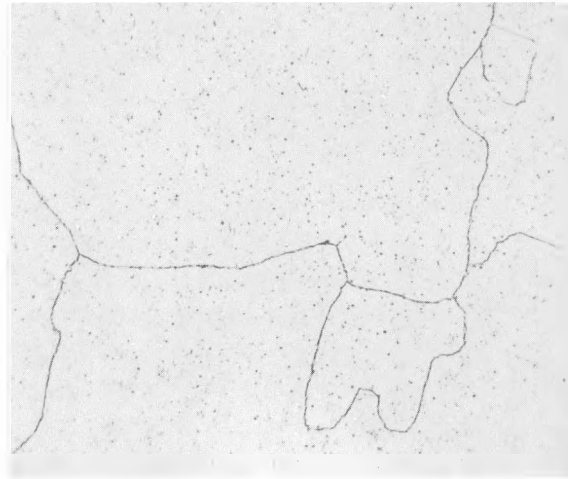
AFTER STRESS RUPTURE TESTING
at 1200F and 20.1 ksi for 746 Hours
Ferrite: 1-3%

308L 0.2N WELD METAL
(Specimen No. S53)

Figure 112. Typical partially ferritic microstructures before and after stress rupture testing. 250X



Kalling's Reagent
PRIOR TO TESTING
As-Welded Condition
Ferrite: <1%

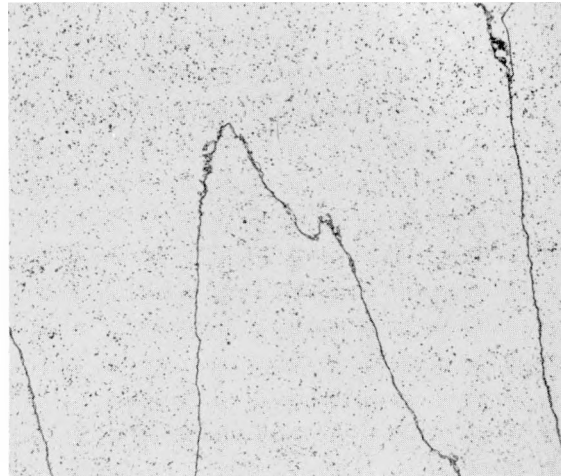


Marble's Reagent
AFTER STRESS RUPTURE TESTING
at 1200F and 18.0 ksi for 1152 Hours
Ferrite: <1%

308L 0.1N 6Mn WELD METAL
(Specimen No. S85)



Kalling's Reagent
PRIOR TO TESTING
As-Welded Condition
Ferrite: <1%



Marble's Reagent
AFTER STRESS RUPTURE TESTING
at 1200F and 20.0 ksi for 823 Hours
Ferrite: <1%

308L 0.2N 6Mn WELD METAL
(Specimen No. S59)

Figure 113. Typical austenitic microstructures before and after stress rupture testing. 250X

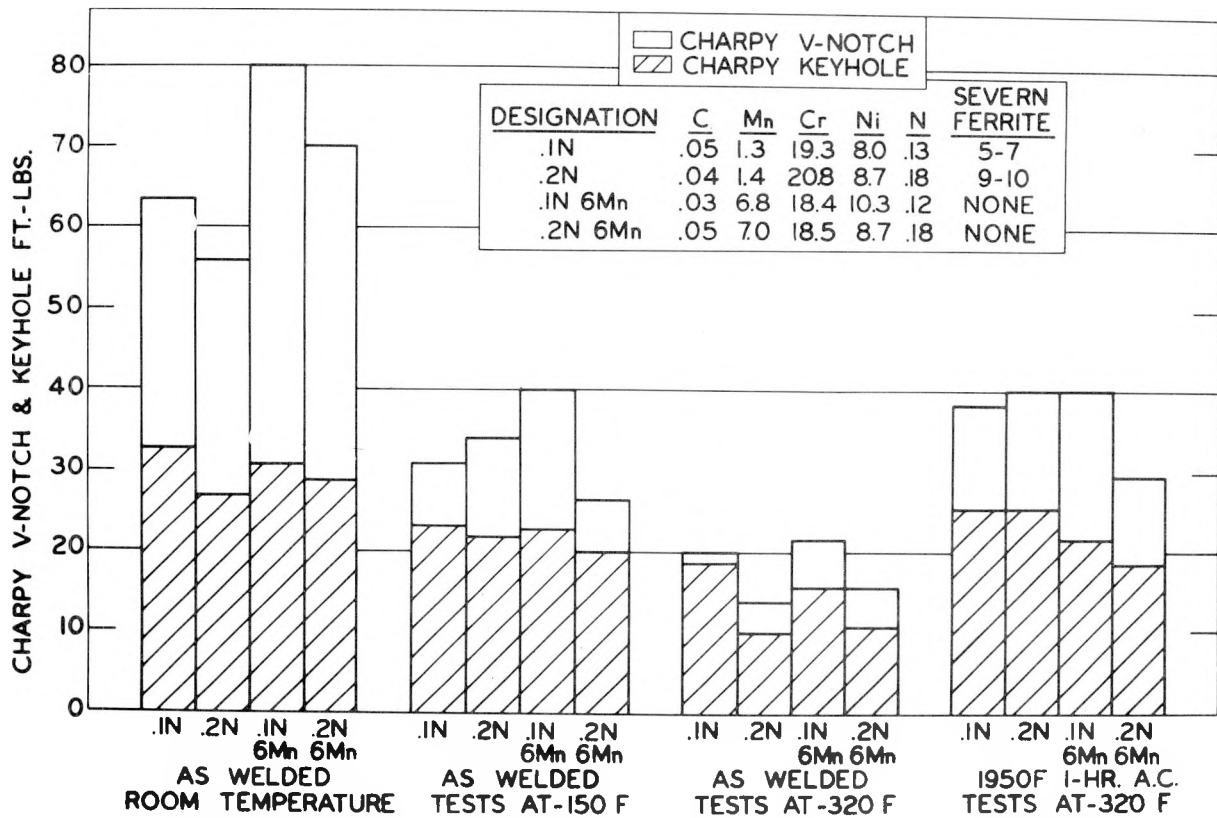


Figure 114. Charpy impact properties of high-nitrogen 18-8 weld metals at room temperature, -150F, and -320F.