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EPRI CS-4252
Volume 8
Project 1874-1
Final Report
November 1989

Dissimilar-Weld Failure Analysis and Development Program

Volume 8:

Design and Procedure Guide for Improved Welds

Prepared by
The Materials Properties Council, Inc.
New York, New York

REPORT SUMMARY

SUBJECTS	Fossil steam plant systems and performance / Fossil steam plant availability
TOPICS	Fossil fuel boilers Welded joints Service life Superheaters Nondestructive testing Failure analysis
AUDIENCE	Generation managers / R&D scientists

Dissimilar-Weld Failure Analysis and Development Program

Volume 8: Design and Procedure Guide for Improved Welds

Dissimilar metal weld (DMW) failure in superheater and reheater tubes is a major cause of forced boiler outages. Previous methods for repairing and replacing the damaged DMW sections are unsatisfactory and invariably lead to repeat failures at the same locations. This report provides improved design and welding procedures that can result in a much longer life for DMWs.

BACKGROUND DMWs in superheaters and reheaters of fossil-fuel-fired boilers experience stresses from system and pressure loading and from changes in operating temperature. Although all may contribute to failure in these welds, their relative importance is not known. These fusion welds, which join low-alloy steels to 300-series stainless steels, use either iron-based or nickel-based filler metals. Typically, they fail by low-ductility cracking in the low-alloy steel immediately adjacent to the weld fusion line.

OBJECTIVE To provide guidelines for improving the design and welding procedures for increasing the reliability and longevity of dissimilar metal welds.

APPROACH The research team obtained failed and sound DMW samples from numerous boilers and evaluated the operating conditions and metallurgical structures associated with the failures. On the basis of these evaluations, they learned that locating the DMWs in regions of lower stress and temperature in the boiler would significantly improve DMW life. The metallurgical evaluations led to the selection of improved filler metals and weld geometries, which were subsequently evaluated in accelerated laboratory tests. The research team utilized all the field observations and the results from the laboratory studies to draw up a set of guidelines that would lead to improved DMW performance.

RESULTS The investigation concluded that the use of nickel filler metals in combination with heat treatments that produced a band of well-distributed carbides (rather than a sharp interface of carbides) near the fusion line resulted in improved DMW life. Weld designs that resulted in a shallow weld angle and a wide weld cap resulted in even further improvements. Relocation of the DMWs to regions of lower stress and temperature in the boiler was found to provide an additional margin of safety.

EPRI PERSPECTIVE

The design and weld procedure improvements reported here can be readily implemented by utilities to achieve an order of magnitude improvement in DMW life. The DMW problem that has plagued the industry over two decades is finally amenable to a solution based on the promising results contained in this report.

This report is the last in an eight-volume series describing DMW failure analysis and development. The other volumes include volume 1, *Executive Summary;* volume 2, *Metallurgical Characteristics;* volume 3, *Accelerated Discriminatory Tests;* volume 4, *Utility Plant Results;* volume 5, *Evaluation of Acoustic Emission and Enhanced Radiography;* volume 6, *Weld Condition and Remaining Life Assessment Manual;* and volume 7, *Prediction of Damage in Service (PODIS)—Background Document.*

PROJECT

RP1874-1
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CS-4252, Volume 8
Research Project 1874-1

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ABSTRACT

As a result of the work performed under RP 1874-1, the factors influencing the performance of dissimilar metal welds (DMWs) in elevated temperature power plant boiler service have been defined. Details of the results are given in other volumes of this report series. In this volume, design and procedure guidelines for improving DMW performance are provided.

DMW life can be extended by:

1. Locating DMWs such that service conditions are conducive to long life; such locations may be identified by the use of the computerized analytical program PODIS, developed under RP 1874.
2. Using preferred weld filler metals.
3. Using specific weld configurations.

Details of each of these approaches are described herein.

CONTENTS

FIGURES

TABLES

UNITS

This report has been prepared using units in current use by personnel involved in boiler operation, maintenance and engineering. In all plants from which information was obtained to develop the life prediction technology, the data provided was in the system of units herein.

If plant data is available in SI units and it is deemed necessary to convert to U.S. Customary units (e.g., to use PODIS), the following conversions should be applied.

To Convert From	To	Multiply by
Temperature in °C	°F	$[T_c(9/5) + 32]$
Temperature change in °C	°F	9/5
Stress MPa	ksi	0.145
Force N	lbf	0.225
Length m	in.	39.370

Section 1
INTRODUCTION AND BACKGROUND

The characteristics of, and factors leading to, failures in dissimilar metal welds (DMWs) in elevated temperature service in utility power plant boilers are detailed in other volumes of this report series describing the results of EPRI RPI874[1].

As noted in these other volumes, the DMWs of interest are located in the final superheaters and reheaters of power plant boilers and join low-alloy steel (typically 2¼Cr-1 Mo) to 300-series austenitic stainless steel. They operate at steam-outlet temperatures generally ranging from 482°C to 592°C (900 to 1100°F), with internal pressures ranging from 3.5 to 26.2MPa (500 to 3800 psig). Typical tubing sizes range from 3.8 to 6.35 cm (1½ to 2½ in.) in diameter, with a 1.3-cm (½ in.) wall thickness for superheaters and a o.48-cm (3/16-in.) wall thickness for the reheaters. Common practice has been to make these welds by the shielded metal arc process, using either 300-series stainless steel or nickel-base filler metal, or by induction pressure welding. In recent time, factory made welds have been prepared using automatic gas tungsten- and gas metal-arc processes.

After periods of time in service ranging from as little as 2 to longer than 25 years, many of these DMWs crack and fail. Failure is defined as through-wall cracking which results in steam leakage. The overall intent of RP1874 was to determine the underlying causes of these failures, develop methods of predicting DMW performance, and to define palliative measures. Specifically, an objective of the program was to define methods for improving DMW performance through considerations of design, weld procedure, and weld consumables.

In pursuit of this latter objective, a broad range of research activities were undertaken. These included examination of numerous power plant welds, performance testing (using an accelerated test method developed under the program, specifically for this purpose) and the evaluation and development of alternative filler materials and weld designs. The results of all these studies are detailed in Volumes 4, 3 and 9[2] of the RP1874 report series, respectively.

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[1] EPRI CS-4252, Volumes 1-7

[2] To be released

As a result of these activities, a picture emerged of the influence of various factors on DMW performance. Accordingly, it was thought to be of value to potential users to draw together and summarize these conclusions in one document. That is the objective of this report volume.

It should be emphasized that this report does not contain the detailed technical results of the research program activities. For that information, other report volumes should be consulted. Instead, this document provides guidance on how to achieve improved DMW life after it outlines the technical basis for the relevant conclusions regarding design and fabrication issues.

Section 2
FACTORS INFLUENCING DMW BEHAVIOR

The principal conclusions of the RP1874 studies are that the major factors influencing DMW performance in boiler superheaters and reheaters service are:

1. The service conditions to which the DMW is subjected.
2. The filler material used for the DMW.
3. The geometry of the DMW.

Other factors such as postweld heat treatment, use of backing rings, and presence of weld defects can, in some circumstances, influence performance. However, within the usual limits, the effects from these factors are not of prime concern, i.e., they are second order factors.

In the following sections, each of the major factors influencing performance is discussed. These sections are followed by a brief review of the second-order factors and a final summary of how to achieve maximum DMW life when making new DMWs or repairing old ones.

In this context, it should be noted that it is fully recognized that each user of the report will need to consider the cost benefit of implementing any of the identified palliative measures since each situation will differ with regard to cost and value of the benefit of improved life and reliability. Accordingly, the report attempts to identify a range of improvement options to allow the user to select that combination most suitable to the objectives.

Section 3

DMW SERVICE CONDITIONS

A clear conclusion from RP1874 is that the performance of any DMW is governed by the service conditions to which it is exposed. Service conditions, in this context, include such factors as temperature, temperature cycling, pressure loads, deadweight loads, and secondary stresses due to constrained thermal expansion. (Since failures in DMWs result from circumferentially oriented cracking, the principal stresses of importance are those acting in the axial direction.) The influence of these factors has been fully quantified in the RP1874 developed analytical program, Prediction of Damage in Service (PODIS), as described in Volumes 6 and 7 of this report series. (How to develop the inputs required by PODIS and to recognize boiler conditions of concern for DMW performance are fully described in the Dissimilar Weld Condition and Remaining Life Assessment Manual for Fossil Fired Power Plants, which is Volume 6 of this report series. The best inputs require measurements and actual observations of the boiler situation.)

In PODIS the damage development at a DMW is tracked by numerically computing the cumulative effect of past (actual) and future (predicted) operating conditions at the DMW. Specifically, loadings are divided into one of three categories:

- Temperature cycling (which causes self stress at the weld due to the effects of differential thermal expansion of the metals joined).
- Primary loads (such as those due to pressure or deadweight).
- Secondary loads (such as those due to constrained thermal expansion of the tube assemblies).

The damage caused by each of these loadings is, to varying degrees, influenced by the temperature at the time of occurrence. Thus, the overall damage computation involves summarizing the cumulative results of each of the above loading types at each temperature of occurrence. (Practical procedures for performing these analyses are given in Volumes 6 and 7.) Obviously, such procedures and considerations go beyond the current ASME Code, Section I requirements.

A simple conclusion from this is that one effective way to maximize the life of a DMW is to ensure, through strategic location of the DMW, that its exposure conditions are such that a PODIS damage fraction of unity (or some preselected value less than unity as discussed below) will not accumulate during the required lifetime of the DMW. It is recommended that this approach be given serious consideration when designing new components featuring DMWs or when planning to replace and relocate DMWs in operating units.

In this context, it should be noted that a PODIS-calculated value of unity implies a best estimate of the actual damage to cause failure (i.e. when PODIS-calculated damage equals one, the probability of failure is 50 %). For many purposes, particularly those involving design or relocation of a DMW, it may be prudent to choose a more conservative limit. A basis for selection of appropriate values is given in Section 4 of the PODIS User's Manual (Appendix A of Volume 6). Typically, a limiting damage fraction of 0.3 might be employed where high reliability is desired. Unusual corrosion or erosion conditions should not be ignored.

The nature of the damaging components defined in PODIS make it possible to highlight those features of a boiler that most influence DMW life. These will be discussed under the subheadings of the three principal damage stresses: Self stress, primary loads, and secondary loads.

SELF STRESS

Self-stress loads arise from thermal cycling of the DMW. In general, thermal cycling results from plant operational characteristics. The most obvious cause of thermal cycling occurs from operating the power plant in a load following or two shifting mode or from frequent startup and shutdown. Damage from these sources increases as a function of the frequency of the events.

More subtle sources of thermal cycling have also been observed in power plants. In some plants the location of temperature peaks within the boiler changes substantially as plant power levels are changed. When this occurs, temperature swings at DMWs can be greater (and self stresses correspondingly greater) than might be expected from a simple observation of changes in bulk outlet steam temperature.

Another form of temperature cycling that has been observed is relatively rapid (having a periodicity of several minutes) and occurs during nominal steady-state operation. Sources of this condition vary and may result from automatic control systems. These, also, can be a source of self-stress damage.

In general, it is prudent to use the most durable available DMWs when cyclic service is expected. When cycling occurs due to automatic control systems, minimization of these effects will enhance DMW life.

PRIMARY STRESS

The primary stresses on a DMW due to internal pressure and design deadweight loads are, by design, below ASME Code, Section I, allowables and are modest relative to material capability at design temperature. Additional deadweight loads can develop on DMWs in service as a result of the failure of tube support systems. For maximum DMW life, it is desirable to locate DMWs in positions such that support failures of this type Will not impose significant additional deadweight loads. Here, review of the Weld Condition and Remaining Life Assessment Manual in Volume 6 will be instructive.

The ability of the materials to carry the deadweight stresses (including those imposed by design) is highly dependent upon the metal temperatures. Even the axial stresses produced in an internally pressured tube in which the hoop stresses meet ASME Code allowable values will cause significant damage if temperatures are above design. Such above-design temperature conditions are quite commonly encountered in fossil power plant superheaters and reheaters. The high temperature is usually confined to a local section of the system and is counterbalanced by below-design temperatures elsewhere. However, in the region of above-design temperature, severe and rapid damage will occur. To the extent that such temperature maldistributions are understood, DMW life will be greatly enhanced by choosing locations unlikely to be influenced by the hot spots. An example of the influence of temperature on DMW life under simple loading conditions is given in Figure 3-1.

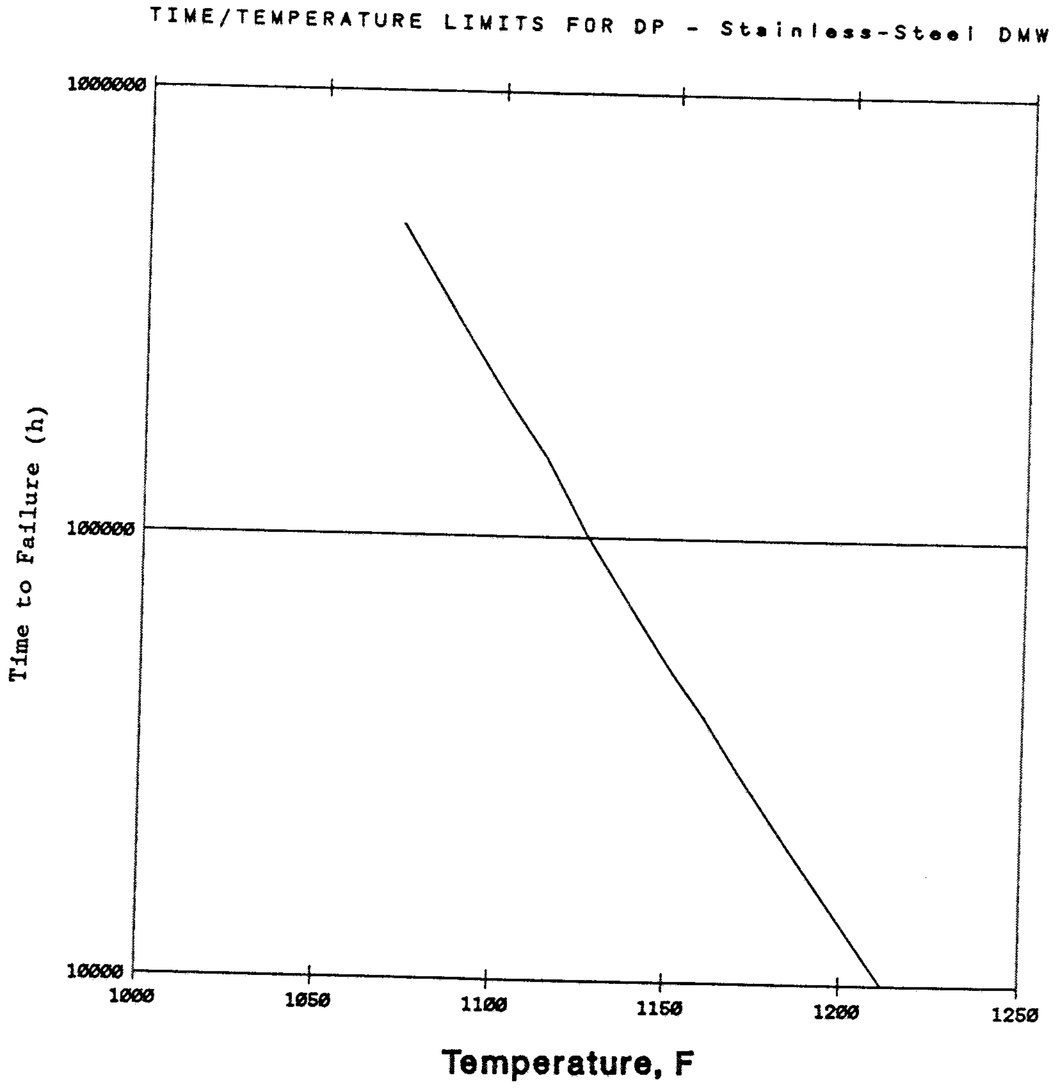
SECONDARY STRESS

Secondary stress typically results from constrained thermal expansion. It has been widely observed during the course of RP1874 that local secondary stresses can be an important factor in DMW failure. Many failures have been observed in DMWs located close to fixed points in such a manner that constrained expansion loads are maximum in the region of the DMW. For example, DMW failures occurred in the penthouse region of one unit only in locations within 0.3 m (1 ft) of the roof where the tubes were fixed. Adjacent tubes with DMWs located approximately

1.2m (4 ft) from the roof were unfailed and showed no signs of cracking. This difference in performance was due to the difference in magnitude of the bending moment (secondary system stress) developed when the tubes were heated.

Proximity to intertube supports and dependence on proper support functions are important in determining DMW loads. Accordingly, a basic guideline for DMW location includes positioning the DMW as far from fixed supports as feasible. Good location also includes positioning the DMW so that, if support failure or lockup occurs, loads on DMWs will not be excessive.

In a manner analogous to primary loads, damage from secondary stresses increases with increasing temperature. Locating DMWs away from hot spots will therefore extend life. Secondary loads are also regenerated as a result of thermal cycling. This is an additional reason to ensure that the most durable available DMWs are employed when cycle service is anticipated.



Primary Axial Stress = 2 ksi

Figure 3-1. Predicted Effect of Temperature on DMW Life Under the Actual Stresses Resulting from Pressure Containment Under Limits of the ASME B&PV Code, Section 1

Section 4
WELD FILLER METAL

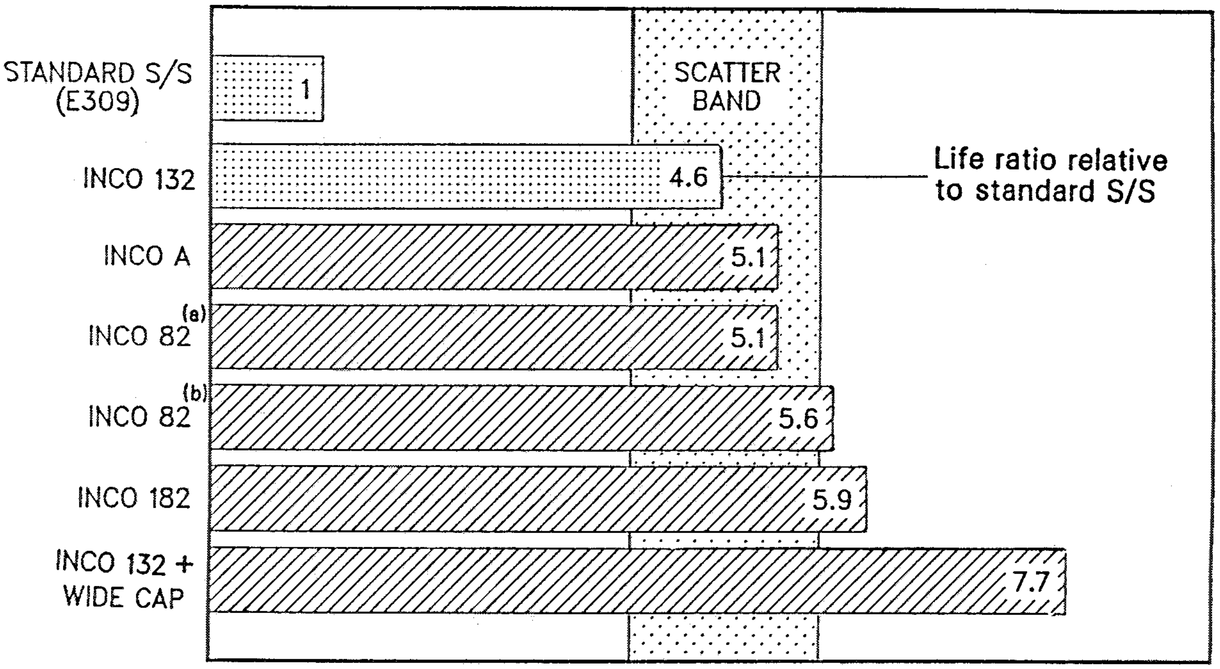
The work of RP1874 has also shown that filler metal selection can have a major influence on DMW performance. In almost all operating circumstances, DMWs made with commercially available nickel-base filler metal significantly outperform DMWs made with 300-series stainless steel filler metal. Both experimental and service observations indicate that the use of nickel fillers can improve life by a factor between 3 and 5 in specific circumstanceS One reason for this is that the expansion coefficient of nickel fillers is generally intermediate between that of the 300-series stainless steel and the low-alloy steel being joined. Thus, the self-stress component of damage is far less when nickel fillers are used (Table 4-1). From a life and performance standpoint, experience thus far has sown that it is better to make a DMW with the usual commercially available nickel-base fillers rather than 300-series stainless steel filler. (However, see the paragraph below.) Service experience also indicates that considerable life improvement occurs when a DMW made with stainless steel filler is repaired using nickel-base filler even when part of the original stainless steel filler is left in place.

However, the work of RP1874 has also demonstrated that commercial nickel-base filler metals have limitations in the context of elevated temperature DMW service. Specifically, most of the more commonly used nickel-base fillers, such as Inco 132, Inco 182 (SMA electrodes), and Inco 82 (GTA wire), tend to form a planar array of carbides at the fusion line with the low-alloy steel. Once this planar array of carbides (designated Type I carbides) has formed, the available evidence shows that the load-carrying capacity of a nickel-base filler DMW is greatly reduced. Some data indicate that, once an array of carbides above a certain size has formed, the rupture strength of the nickel-base filler DMW is degraded to values similar to or below that of the 300-series stainless filler DMW (Figure 4-1). The carbides form in relatively short times at high temperatures (above 1100°F).

The kinetics of formation of this carbide array have been determined (Figure 4-2). The results suggest that the performance improvement of nickel DMWs over stainless DMWs is due in major part to the time taken to grow a degrading array of Type I carbides in the nickel filler DMWs. (These relative behaviors of nickel

Table 4-1

RELATIVE PERFORMANCE OF DMWs WITH DIFFERENT COMMERCIAL FILLER METALS AND GEOMETRIES UNDER ACCELERATED DISCRIMINATORY TESTING[c]



(a) High heat input
(b) Low heat input
(c) For details of this test see Vol. 3 of this report series

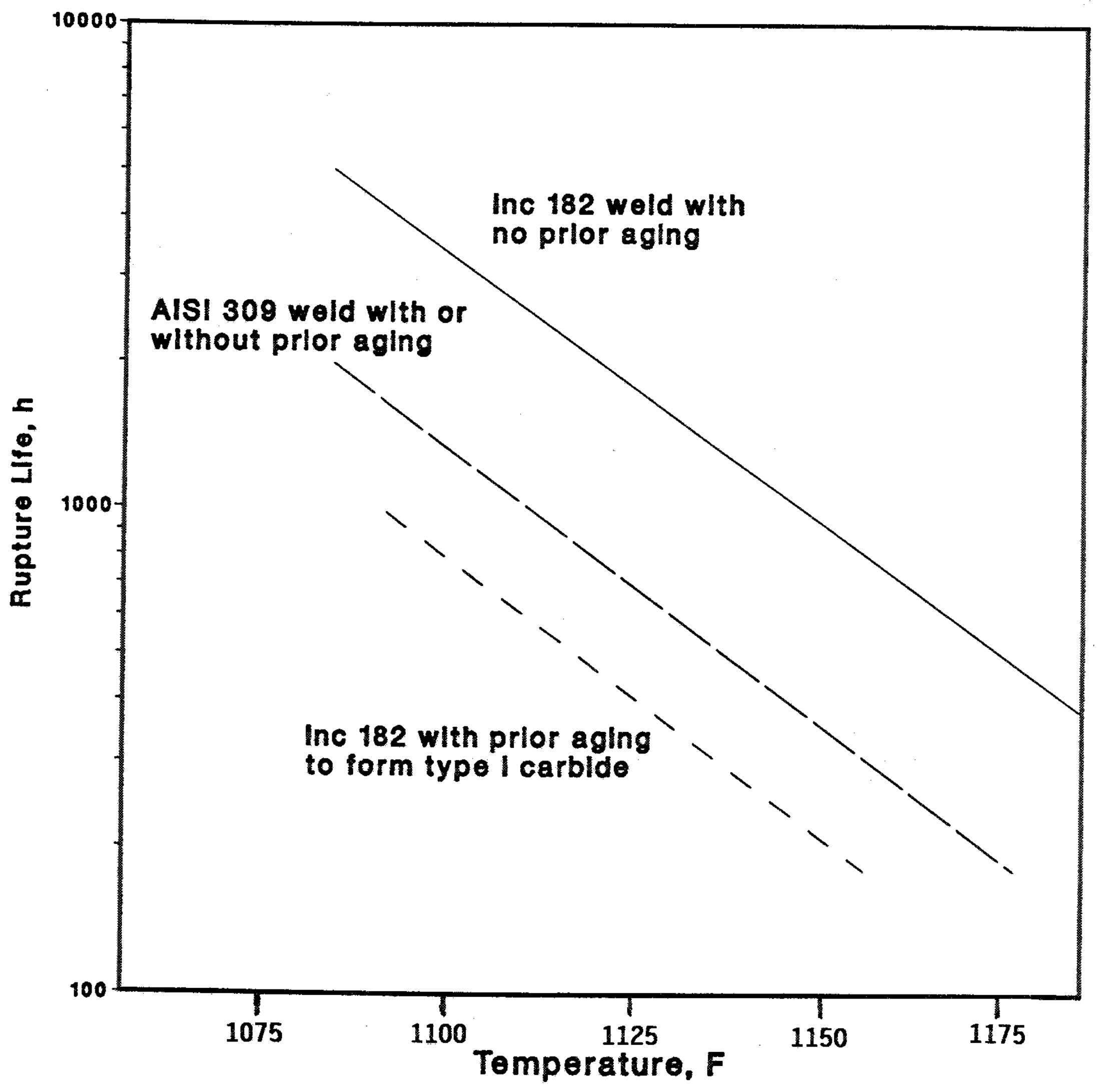


Figure 4-1. Stress Rupture Behavior of Cross-Weld Stress Rupture Specimens Removed from Dissimilar Welds Between 2-1/4 Cr-1 Mo and 300-Series Stainless Steel Tested in Either the As-Weld Condition or After Preaging (or Service Exposure)

and stainless DMWs are modeled in PODIS with due account being taken of the influence of Type I carbide formation on nickel-filler weld strength.)

This limitation of commercial nickel fillers was the reason for the exploration, under RP1874, of alternative filler materials. The results of this work are described in full detail in Volume 9 of this report series, which will be released following conclusion of the final phase of testing under EPRI contract. A summary of the key results is given in Table 4-2. What these data show are:

- There is little to choose between the Inco 132, Inco 182 (SMA electrodes), and Inco 82 (GTA wire) as far as DMW performance is concerned. All three have shown life improvement over stainless, but all three develop undesirable Type I carbides and produce interfacial failures.

- A potential limitation of Inco 182 is the tendency of some heats to harden excessively with time at operating temperature. The consequences of this were not explored in this program, but should be considered.

- Although Inco A also develops Type carbides and tends to produce interfacial failures, DMWs made with this electrode showed some tendency to longer life than the others.

- Inco 61, Hastelloy W, and Inco 92LC all exhibit marked age hardening. While the consequences of this for service were not explored, such hardening behavior should be viewed with caution as possibly indicative of long term embrittlement.

- Filler alloys that form very hard martensitic or bainitic products as deposited (e.g., 9Cr-1Mo modified) are viewed as of limited use unless postweld heat treatment is feasible and economic.

- The optimum alloy appears to be a developmental nickel-base composition (designated HFS6) studied under RP1874. This electrode exhibited good welding characteristics, desirable physical properties, and did not form Type I carbide. Overall, the alloy performed well in laboratory and field trials. The alloy did show a tendency (common in nickel-base filler metals) to form microfissures. While this does not limit the usefulness of the filler for superheater/reheater tube DMWs, it does suggest that additional optimization is desirable before the alloy is used for more general applications.

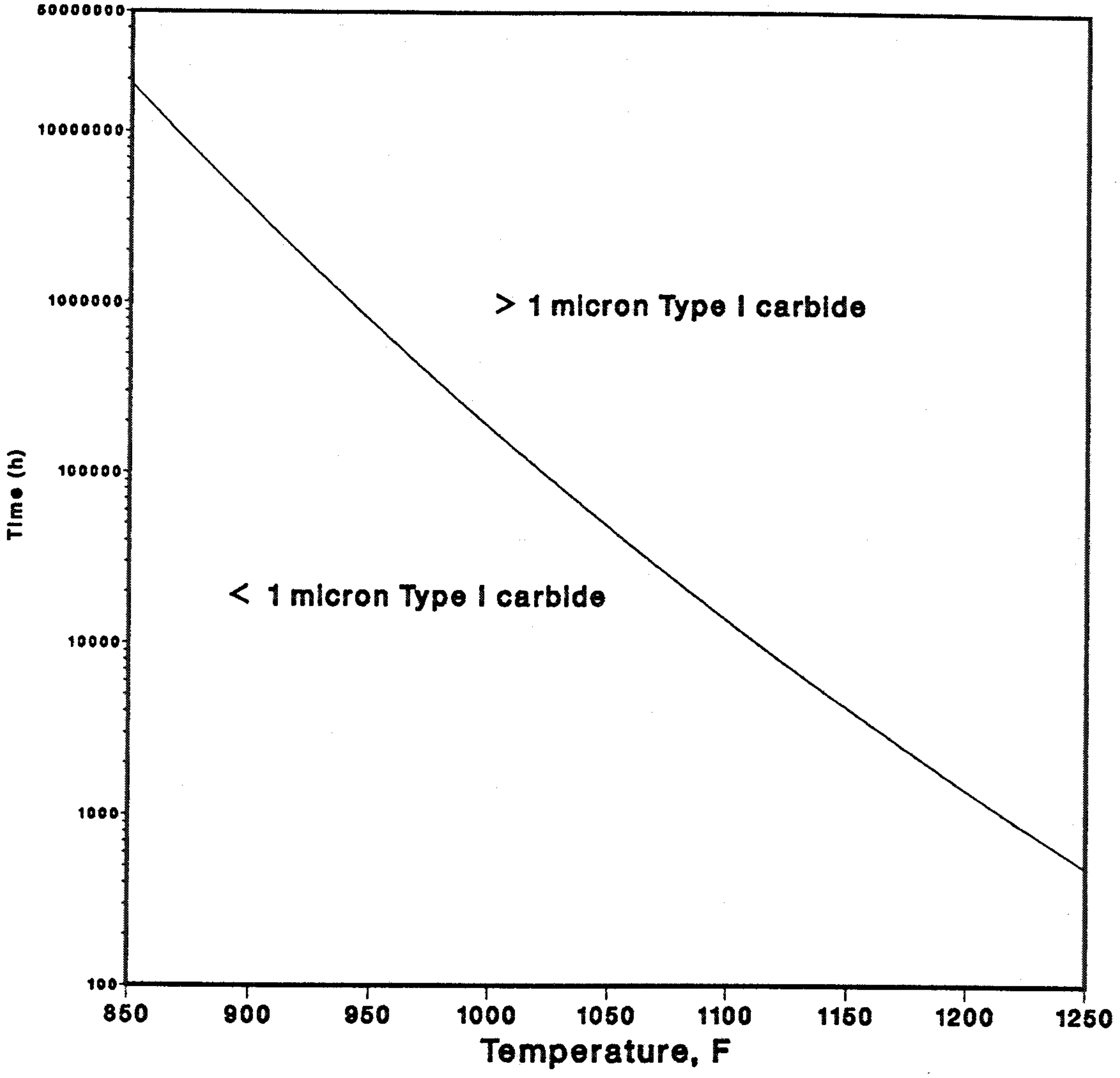


Figure 4-2. Time/Temperature Relationships to Form Degrading (Approximately 1 μm) Type I Carbides at the Interface Between Typical Nickel-Base Filler (Inco 132) and 2-1/4 Cr-1 Mo Steel

Table 4-2

SUMMARY OF KEY PERFORMANCE CHARACTERISTICS OF DMWs (2 1/4 Cr - 1 Mo/ 300-SERIES STAINLESS STEEL) MADE WITH VARIOUS FILLER METALS

Filler	Expansion Difference with 2 1/4Cr-1Mo (RT-1000°F)	Tendency to Form Type 1 Interfacial Carbides	Needs PWHT?	Thermal Stability	DMW Performance Observations	Conclusions Relative to DMW Use
<u>Commercial Alloys</u>:						
E309	27% greater	None	No	Fairly stable.	Gives poorest performance.	Use only in least arduous applications.
Inco 92	5% greater	Slight	No	Marked age hardening.	Shows little tendency to interfacial failure.	Use limited by age hardening.
Inco 132	7% greater	Marked	No	Fairly stable.	Significantly better than E309 (like factor of 3 - 5x) but shows interfacial failure.	Better than E309 in most cases, widely used.
Inco 182	10% greater	Marked	No	Considerable age hardening.	Significantly better than E309 (factor of 3 - 5x) but shows interfacial failure.	Better than E309 in most cases, widely used.
Inco 82	3% greater	Marked	No	Fairly stable.	Significantly better than E309 (factor of 3 - 5x) but shows interfacial failure.	Better than E309 in most cases, widely used where TIG welding employed.
Inco A	3% greater	Marked	No	Fairly stable.	Significantly better than E309, lasts longer than most nickel welds but shows interfacial failure tendancy.	Some indications that this is the best of the commercial nickel fillers.
Inco 61	3% higher	Slight	No	Marked age hardening.	Shows interfacial failure.	Little used, aged hardening is a concern.

Table 4-2 (Continued)

Filler	Expansion Difference with 2 1/4Cr-1Mo (RT-1000°F)	Tendency to Form Type 1 Interfacial Carbides	Needs PWHT?	Thermal Stability	DMW Performance Observations	Conclusions Relative to DMW Use
Hast W	9% lower	Slight	No	Very marked age hardening.	Shows interfacial failure.	Little used, aged hardening is a concern.
MTS4	18% lower	None	Yes	Thermally softens	No tendency to interfacial failure.	May have value where PWHT possible.
E410/ E410 NiMo	19% lower	None	Yes	Thermally softens	No tendency to interfacial failure.	May have value where PWHT possible.
9Cr-1Mo	14% lower	None	Yes	Thermally softens	No tendency to interfacial failure.	May have value where PWHT possible.
Experimental Alloy:						
HFS6	7% greater	None	No	Excellent	No tendency to interfacial: shows best life.	Microfissuring tendency needs control before widespread use possible.

Section 5
WELD CONFIGURATION

Both service experience and experimental studies have shown that the use of a weld with a shallow angle and/or a wide capping pass on the low-alloy steel side of the DMW leads to significant life improvements. In the case of DMWs made with stainless steel filler, the use of a 60 degree angle on the low-alloy steel side (Figure 5-1) increased life by 60% compared to a standard weld preparation. Similarly, the use of a wide capping pass (also shown in Figure 5-1) increased life by a factor of 50%. In fact, comparing the life of a standard E309 filler weld, Inco 182 weld with a wide capping pass, shows that the latter lasts 7.7 times longer than the former under standard accelerated discriminatory test conditions. Of course a shallow angle naturally also increases the width of the capping pass. Conversely, narrow welds typically have a short interface and narrow cap and relatively shorter life. An angle approaching normal to the tube axis (designated 0 degree angle in Figure 5-1) produced shorter lives, compared to a DMWs of standard weld preparation.

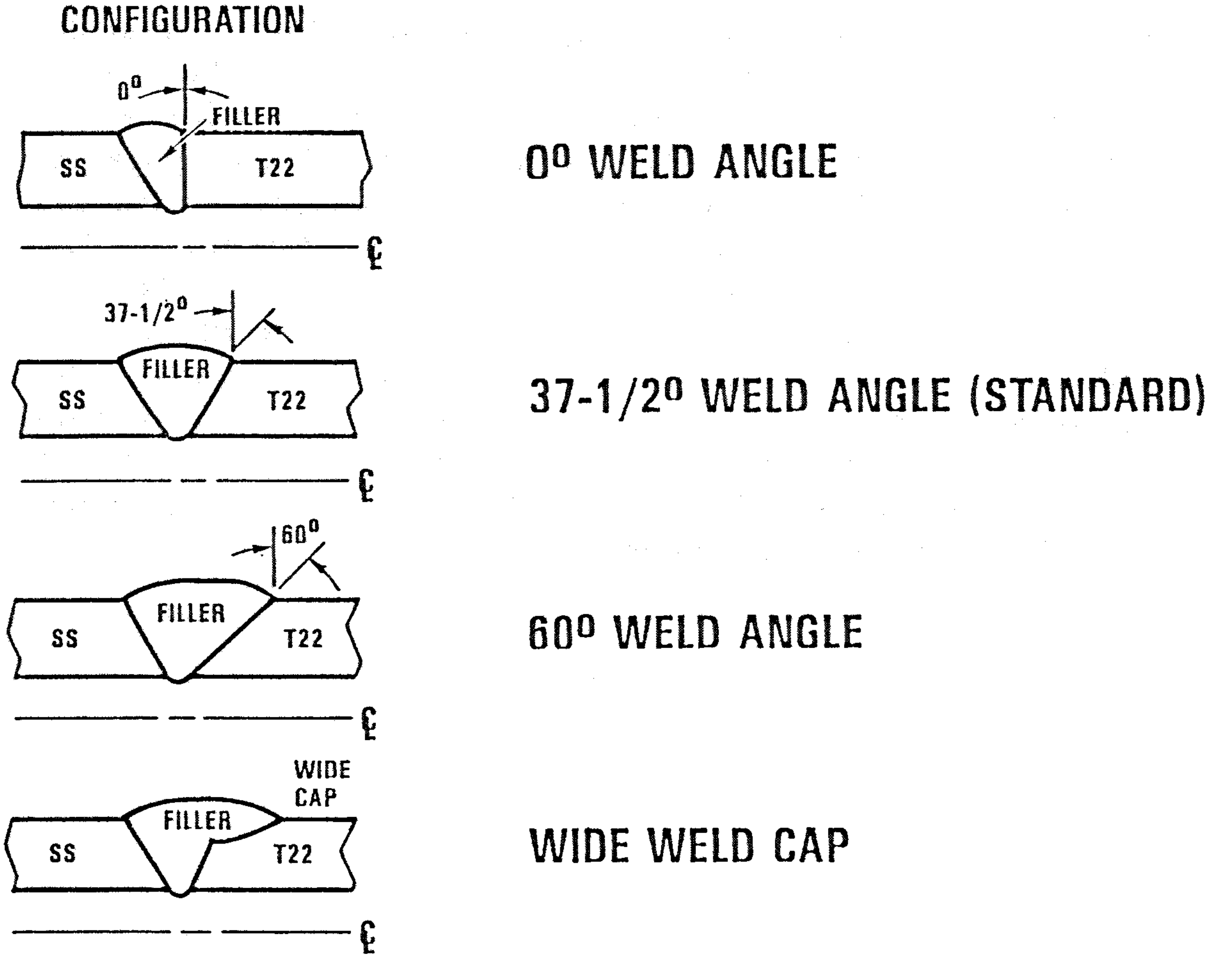


Figure 5-1. Weld Geometries Evaluated in RP1874

Section 6
REPAIR

Based on the work that has been performed, methods of repair in the field that can be used which are relatively simple yet provide a high degree of confidence for an extended life cycle are:

1. <u>Dutchmen</u>
   The dissimilar weld between two short lengths of tubing is prepared in the ideal shop environment, and a nondestructive test such as liquid penetrant and for radiography is performed. The assembled joint can then be installed at the site where like materials can be welded. This method of repair would be most useful when it is known that welds in the boiler require complete replacement and cannot be repaired in situ.

2. <u>Repair in Situ</u>
   During the life of the plant it will be determined either using one of the methods established during this contract or another that dissimilar metal welds are approaching an unacceptable level of failure rate. In these instances it could be recommended that these welds be ground out to a level where approximately 1/16 in. of weld metal remains in the root.

   The grind out should be such that it will provide a relatively large included angle which will result in a wide capping pass and a long weld interface similar to the recommendation made earlier in this report. The grind-out weld joint should be performed using one of the recommended high nickel filler metals. This type of repair would be applicable to welds previously made with either stainless steel or nickel-base electrodes.

Section 7
OTHER FACTORS

As previously noted, most other weld features exercised a lesser (second-order) influence on DMW performance. Within that context, the observed effects were as follows:

POSTWELD HEAT TREATMENT

In general, the effects of postweld heat treatments of the type normally commercially applied are small but detrimental to DMW performance. PWHT will cause severe decarburization on the 2¼Cr-1Mo side of the weld if excessive temperatures and time are employed. Such treatments should be avoided. Figure 7-1 shows the permissible time/temperature relationships for PWHT to avoid formation of unacceptable decarburization in DMWs made with stainless steel filler metal. In superheater and reheater construction, some manufacturers employ a stress-relieving heat treatment after platen fabrication. Since decarburization was not seen in DMWs returned from service and examined here, the relationships in Figure 7-1 are assumed to be unviolated.

DMWs made with nickel-base filler metals can withstand long times at 732°C (1350°F) without developing gross decarburization. However, care should be taken to avoid postweld heat treatments that encourage Type I carbide formations. Such carbide formation requires long times (thousands of hours) at normal service temperatures but can develop in 120 h at 1250°F. The latter treatment is highly unlikely to occur during component fabrication, since PWHTs do not normally extend for this length of time. However, it is sometimes necessary to employ very prolonged PWHT during the manufacture of complex vessels, when an accumulated exposure of 120 h is conceivable. When DMWs are present in such vessels, this condition should be avoided in manufacture.

WELDING PRACTICE

Welding defects, although present in DMWs examined, were not found to be a principal cause of DMW failures. The extent to which normal welding defects played a role in early DMW failures (i.e. , experienced during startup or short-time service) was not determined. Lack of fusion or other large defects at the ferritic alloy interface in DMWs should result in increased stress from

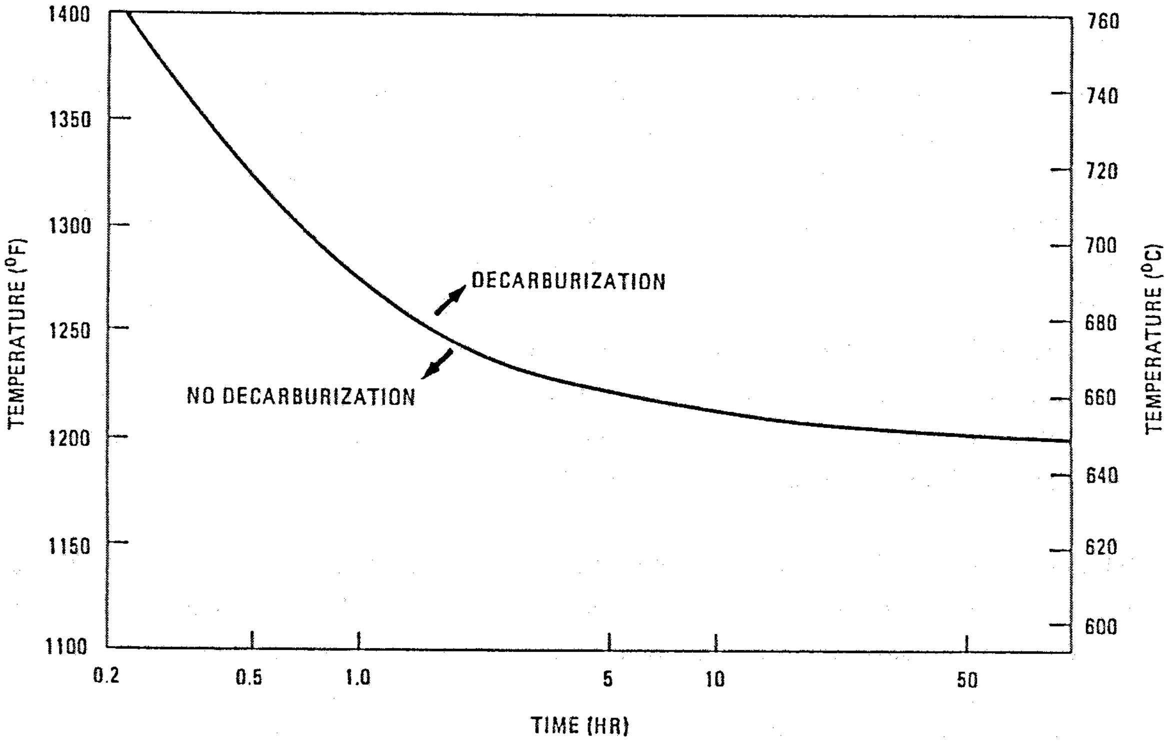


Figure 7-1. Permissible Time/Temperature Conditions for PWHT of DMWs Joining 2-1/4 Cr-1 Mo to 300-Series Stainless Steel Filler Metal

loss of load-bearing cross section and stress concentration and this condition should be avoided.

Other sources of stress concentration in the region of potential failure should be avoided. For example, a transition in the tube wall thickness should be made with a transition piece or by upsetting the stainless steel tube. Abrupt wall thickness changes at the DMW intensify local stresses and are undesirable. Similarly excessively high weld reinforcement may increase the stress concentration and should be avoided.

Section 8

CONCLUSIONS

As noted previously, the extent to which it is beneficial to adopt any of the palliative measures summarized in this document will depend upon the individual utility circumstances and the cost benefits of any actions taken. The principal options available to a utility experiencing or anticipating DMW failures are:

1. To analyze the weld service conditions using PODIS and use the results of this analysis to define design and operational options, such as relocating welds or modifying plant operating conditions to reduce future damage accumulation rates. (The methodology described in Volume 6 of this series can be used to carry out the analysis).
2. To utilize for repair or replacement purposes alternative filler metals offering improved performance. These include both commercial and developmental filler materials.
3. To utilize alternative weld preparation geometries that improve life.

Depending upon the severity of the problem and the perceived degree of true reliability required, combinations of the above options can be beneficially employed.

Exercise of these options will have a major influence on DMW performance. In addition, care should be exercised in DMW production to avoid the application of damaging postweld heat treatments and to ensure that welds entering service have the benefit of minimal defects and unnecessary geometric features that increase local stress intensities.

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