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MASTER

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Mr. S. G. Harbison, Director
Nuclear Energy Division
U S Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

AT03-76SF70030

Dear Mr. Harbison:

Subject: DOE Contract No. DE-AM-3-76SF00893, Task 30, Work Package No. AG 10 20 42, LMFBR Steam Generator Systems Development Program, Work Package Task No. SG029, Steam Generator Materials Qualification

"Recommended Test Conditions for Transition Joint Life Test Articles"

Transmitted herewith,for your information and use, is a document entitled "Recommended Test Conditions for Transition Joint Life Test Articles," by T. M. Yang, W. Palmer, and K. Lewis of GE-ARSD. This document describes the basis for the establishment of the test conditions to be used in the conduct of the life testing which is scheduled to begin at ETEC in the near future.

Mr. R. A. Meyer or Dr. C. N. Spalaris may be contacted with any questions regarding this matter.

Very truly yours,

W V Leeburn

W. V. Leeburn, Manager
Steam Generator Projects

WVL:yl

Attachment

DISCLAIMER

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RECOMMENDED TEST CONDITIONS

FOR

TRANSITION JOINT LIFE TEST ARTICLES

By

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April 1979

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I. INTRODUCTION

Transition Joint Life Test (TJLT) is a series of high temperature creep-fatigue tests of welded pipe transition joints. The joints are made from ferritic steel (2 1/4 Cr-1Mo) to austenistic steel (SS316) pipes of 18 inch (45.7 cm) outside diameter with or without an intermediate pipe section of Alloy 800H. ERNiCr-3 is the weld metal between 2 1/4 Cr-1Mo and Alloy 800H or between 2 1/4 Cr-1Mo and SS316, and weld metal 16-8-2 is used between Alloy 800H and SS316. All welds are with a nominal 0.5 inch (1.27 cm) root and a 30° inclusion angle. This weld geometry is selected such as to minimize the thermal stresses within practical fabrication requirements.[1]

Among the major objectives of TJLT are[2]: (1) Evaluate structural integrity of the tri-metallic transition joint design; (2) Induce cracks in the test articles; (3) Evaluate the service life of the tri-metallic design and compare it to the service life of the bi-metallic design. To achieve definite conclusions to these objectives, failure of the tri-metallic joint is necessary. Failure is defined as crack propagation to 5% of the wall thickness, and is expected to occur near the weld interfaces.

Stress analysis together with the ASME B & PV Code concept of damage evaluation[3] are used to determine the loads required to produce cracking at the tri-metallic joint. Since material test data of creep-fatigue failure show large variation of failure time (or cycle) under similar loading conditions, the "average" strength properties (stress-to-rupture and fatigue cycles) are used for failure assessment. The nominal test time is one year, which includes transient cycles as well as creep hold periods.

Inelastic analysis method is used to define the test loading conditions to meet the test objectives within the available facility time (one year nominal). The stress and strain calculation follows the procedures recommended by RDT standard F9-5T. The evaluation to determine material damage follows the concept of [3]. When the total damage to any of the materials due to test loadings reaches a specific value which varies with the material and the mode of damage accumulation, the material is considered as failed. The present report summarizes the recommended test conditions to achieve the goals of the testing program.

II. CURRENTLY RECOMMENDED TEST CONDITIONS

There are three test articles for the TJLT. The test facility, Transient Test Facility at Energy Technology and Engineering Center, consists of three test structures with two pipe loops that can supply large quantities of cold nitrogen for down transient tests. All three test stands are equipped for high temperature test and for application of external axial loads. Two of the test articles are to undergo combined fatigue and creep tests and the third article will be a long term hold time test with no fast transients.

The main criteria for the determination of loading conditions for both test articles 1 and 2 is to produce one or more cracks within a year test time.

For high temperature transition joint evaluation, Reference [3] postulates two modes of material damage. The creep damage is evaluated by the cummulative fraction of time at a stress compared to the time-to-rupture at that same stress. The fatigue damage is evaluated by the summation of the fractions of cycles at a strain range compared to the cycles to failure at that same strain range. The summation of these two damage fraction is the total damage to the metal, as shown in the following equations

$$D = \sum_i \frac{t_i}{T_{Di}} + \sum_j \frac{n_j}{N_j}$$

where D = total damage

t_i = time at stress level σ_i

n_j = number of cycles at strain range ε_i

T_{Di} = time of stress-to-rupture at stress level σ_i

N_j = cycles to failure at strain range ε_i

The total damage, D, that can be tolerated before failure occurs varies with the material type and with the amount of creep damage and fatigue damage. The tolerable D for various metals used in the current analysis is shown in Figure 1. Because of the spread in these evaluation properties of the materials, large uncertainty on the failure time exists. The prediction is, therefore, based on the average properties with lower and upper bounds, based on test data spreads, attached for reference purpose. The lower bound failure time (the probable shortest time the test article would fail) for TA1 and TA2 is predicted in the order of several months, while the upper bound failure time will be much longer than the one year nominal test time. Since TA1 and TA2 are to be tested at high temperature to accelerate failure and there exists uncertainty on the failure evaluation method, it was felt that TA3 should be tested at a temperature close to CRBRP temperature to evaluate the possible plant service condition. At this temperature and without a severe down transient, TA3 (2 1/4 Cr-1Mo to Alloy 800 welded joint) is not expected to fail within one year.

A series of analysis indicates that the creep fatigue damage will be increased if the fast thermal transient is applied before creep hold period. This is due to the fact that the fast thermal transient is severe enough to cause plastic response of the tube wall metal. This plastic response sets up a high residual stress in the metal, which causes high creep damage during the high temperature hold period according to the concept of damage evaluation in [3].

The recommended test loading conditions for the three articles are summarized in Table 1. The load application sequence is qualitatively depicted in Figure 2. Figures 3, 4 and 5 show the estimated failure time of articles 1, 2, and 3 respectively. Note the possible variation in failure time as indicated by the spread between lower bound and upper bound estimates.

TABLE 1. RECOMMENDED TEST CONDITIONS FOR TJLT ARTICLES

Test Article No.	Creep Hold			Thermal Transient		
	Axial Load	Temperature	Duration of Each Cycle	Rate+	To Temperature	No. of Cycles
1	400,000 lbs.	$T_H = 1100°F$	$t_H = 66$ hrs.	$\dot{T}_1 = -10°F/sec$ $\dot{T}_2 = -4°F/sec$	T_1 800°F T_2 550°F	120
2	700,000 lbs.	$T_H = 1075°F$	$t_H = 66$ hrs.	$\dot{T}_1 = -10°F/sec$ $\dot{T}_2 = -4°F/sec$	$T_1 = 800°F$ T_2 550°F	120
3*	700,000 lbs	$T_H = 950°F$	long	--	--	--

* No normal creep/fatigue failure at Alloy 800H to 2 1/4 Cr-1Mo weld joint expected

\+ Measured at the I.D. of 2 1/4 Cr-1Mo at the most upstream 2 1/4 Cr-1Mo to Alloy 800H joint

III. LIMITATIONS

The foregoing test conditions are obtained with a procedure with the following major inputs: (1) state of the art creep and plasticity analysis as recommended in RDT Standard F9-5T;[4] (2) ASME damage evaluation concept per Code Case N-47 (1592); and (3) available material properties as of September 1978.[5] Uncertainties in (2) and (3) can be large and affect the prediction. Each of these is explained below.

The single material property that has the most influence on these predictions is the stress-to-rupture property.[6] The creep relaxation damage is the dominant cause of failure per the ASME code concept of evaluation. The predicted failure time is therefore, directly related to the stress-to-rupture values. ORNL test data have shown that, under similar test conditions, the time to rupture by creep can vary by ten fold or more. In a test where actual failure is a major objective, this large variation undoubtly prevents a precise prediction of failure time.

The ASME concept of high temperature structural damage is based on a combination of creep damage and fatigue damage. The creep damage originated from the observation that a structural member in the creep temperature region under load will creep and eventually rupture. In this mode of failure, large strain and reduction of cross-sectional area usually occur. However, in most real structures, large stress usually occurs locally and the constraints from neighboring materials generally prevent the occurance of large strain. In this situation, the stress history of the structure is a stress relaxation state if thermal stress is significant, or when the structure is held in constant strain. This type of structure response is quite different from a pure creep type of response. Whether the structure failure modes are similar to a creep failure is not certain due to lack of test confirmation.

REFERENCES

1. Yang, T. M., "A Summary of the Effects of Material Combinations and Weld Joint Geometries on the Elastic Stress in a Dissimilar Metal Pipe Joint," GE Report NEDM 14109, May, 1976.

2. G.E. Specification No. 23A2222, May, 1977.

3. ASME Boiler and Pressure Vessel Code Case 1592-9, January, 1977.

4. RDT F9-5T, "Guidelines and Procedures for Design of Nuclear System Components at Elevated Temperature," Westinghouse Electric Corporation, September, 1974. Supplemented by "Constitutive Equation Recommendations for 2 1/4 Cr-1Mo Steel," Oak Ridge National Laboratory, January 15, 1975.

5. Yang, T.M. and Palmer, W., "Material Properties for Inelastic Analysis of TJLT Articles, Rev. 1," Attachment to GE memo YL-600-78119, August, 1978.

6. Lewis, K. and Palmer, W., "Parametric Study of 2 1/4 Cr-1Mo to Alloy 800 Welded Joint of Transition Joint Life Test Articles," Attachment to GE memo YL-600-78150, September, 1978.

7. Yang, T.M., "Inelastic (Plastic and Creep) Analysis of a Dissimilar Metal Welded Pipe Joint," GEFR-00249 (DR), September, 1977.

APPENDIX: Outline of Inelastic Analysis of TJLT Articles

Inelastic analyses of the TJLT articles leading to the determination of the recommended test conditions were primarily performed on the 2 1/4 Cr-1 Mo to Alloy 800H joint. This is based on the knowledge that in a transition joint, such as a TJLT article, which is subjected to high temperature service under external mechanical load and severe thermal transients, 2 1/4 Cr-1 Mo will sustain the highest creep-fatigue damage per ASME Code suggested rules.

A set of test conditions was determined by the elastic method in the ASME Code Case N-47. The major parameters of this set of conditions are: Article 1 - hold temperature 1050°F, axial load 200,000 lbs., down transient 2°F/sec.; Article 2 - hold temperature 950°F, axial load 400,000 lbs., down transient 2°F/sec.; Article 3 - hold temperature 1050°F, axial load 200,000 lbs., no fast transient. This set of test conditions was later found to be inadequate to cause failure to the test articles based on the inelastic method. Several trial conditions, each with successively larger loads, higher temperature, and more severe transient, were analyzed. Simultaneously,material property data, especially the stress-to-rupture data of 2 1/4 Cr-1Mo steel, were generated from the TJLT heat of materials.

The results from this series of inelastic analyses, together with the TJLT material properties, indicate failure may be achieved with the currently recommended test conditions. However, the uncertainty associated with the stress-to-rupture data is large. Hence, it is deemed necessary to include the probable lower and upper bounds in the evaluation.

The failure time on Alloy 800H to 2 1/4 Cr-1 Mo joint and on 2 1/4 Cr-1 Mo to SS316 joint is largely an extrapolated evaluation based on analytical results on the 2 1/4 Cr-1 Mo to Alloy 800H joint. A limited amount of analysis was carried out for the 2 1/4 Cr-1 Mo to SS316 joint to assist on the extrapolation.

More details on the analysis of the 2 1/4 Cr-1 Mo to Alloy 800H joint will be available in a forthcoming report on this subject. The general methodology of these inelastic analyses is similar to that used in a previous inelastic analysis for comparison of analytical results with ORNL TTT-3 ratchetting test measurements.[7] Good agreements are obtained in the TTT-3 comparison which renders confidence to the inelastic analysis procedures used.

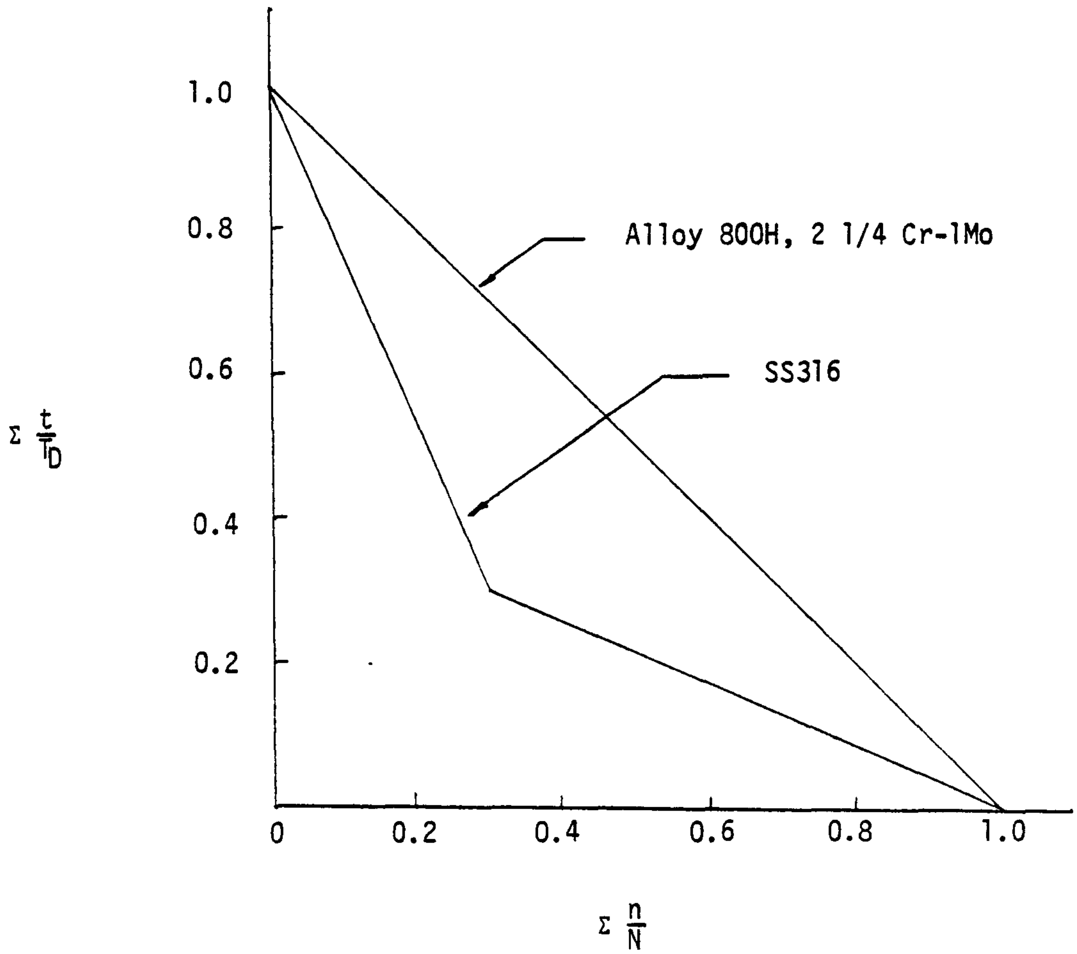


Fig. 1 Creep-fatigue Damage Envelope

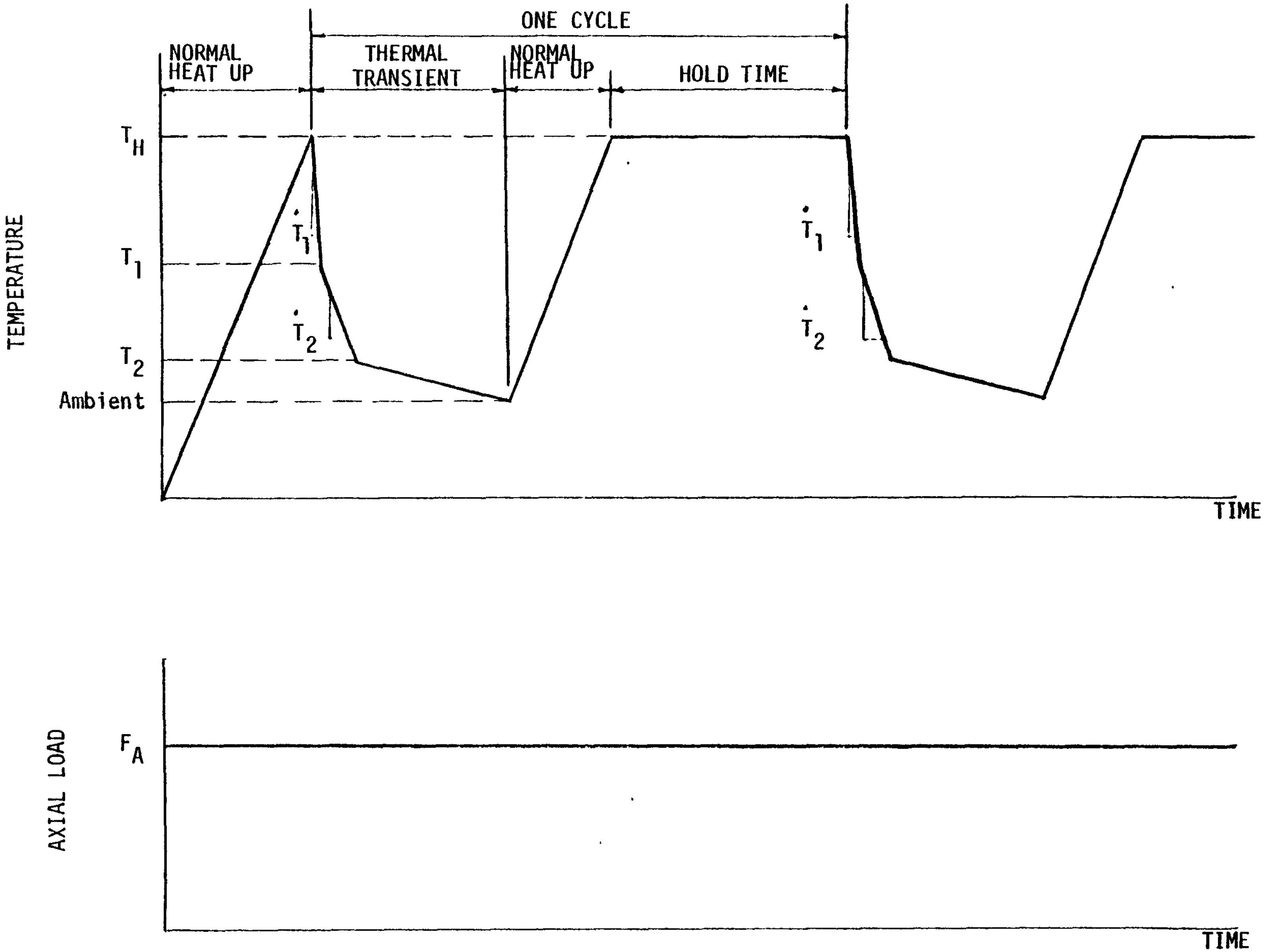
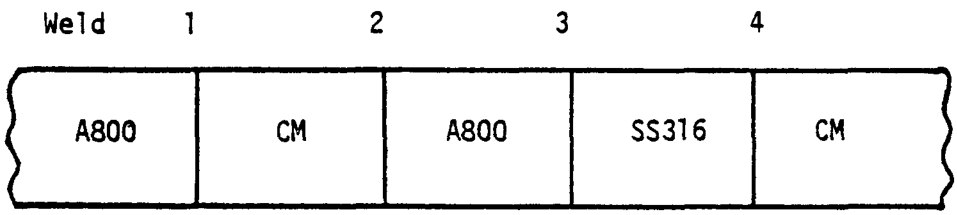


Fig. 2 Time Sequence of Load Application

Test Article 1 Configuration



Test Conditions: 1100°F Hold Temperature, -10°F/S transient to 800°F and -4°F/S to 550°F, 400,000 lbs Axial Load

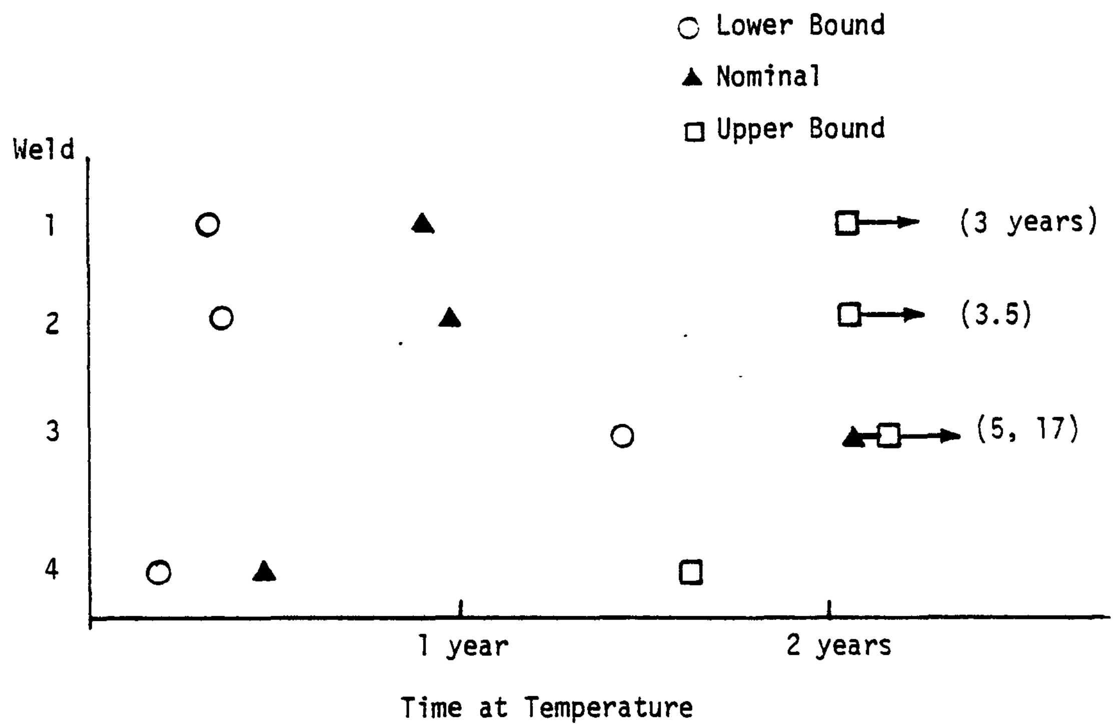
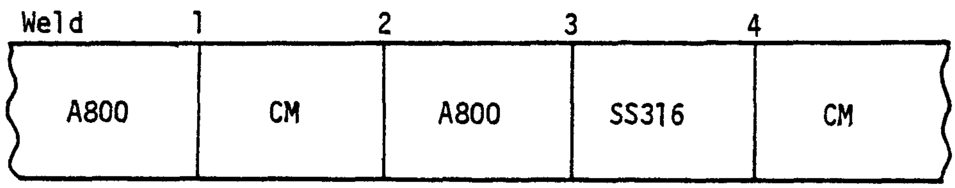


Fig. 3 Predicted Failure Time of Welds

Test Article 2



Test Conditions: 1075°F Hold Temperature; -10°F/S Transient to 800°F and -4°F/S to 550°F; 700,000 lbs Axial Load

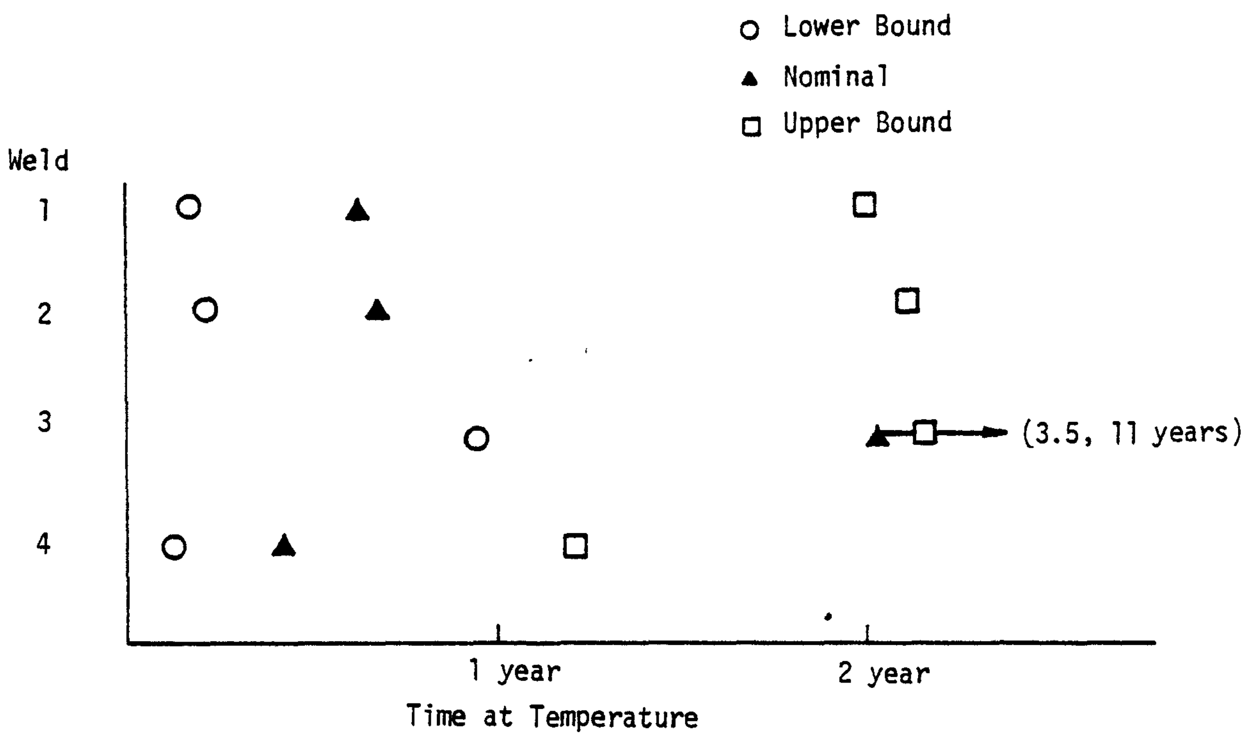
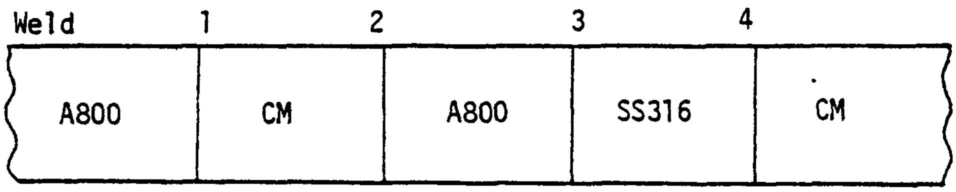


Fig. 4 Predicted Failure Time of Welds

Test Article 3



Test Conditions: 950°F Hold Temperature; 700,000 lbs Axial Load

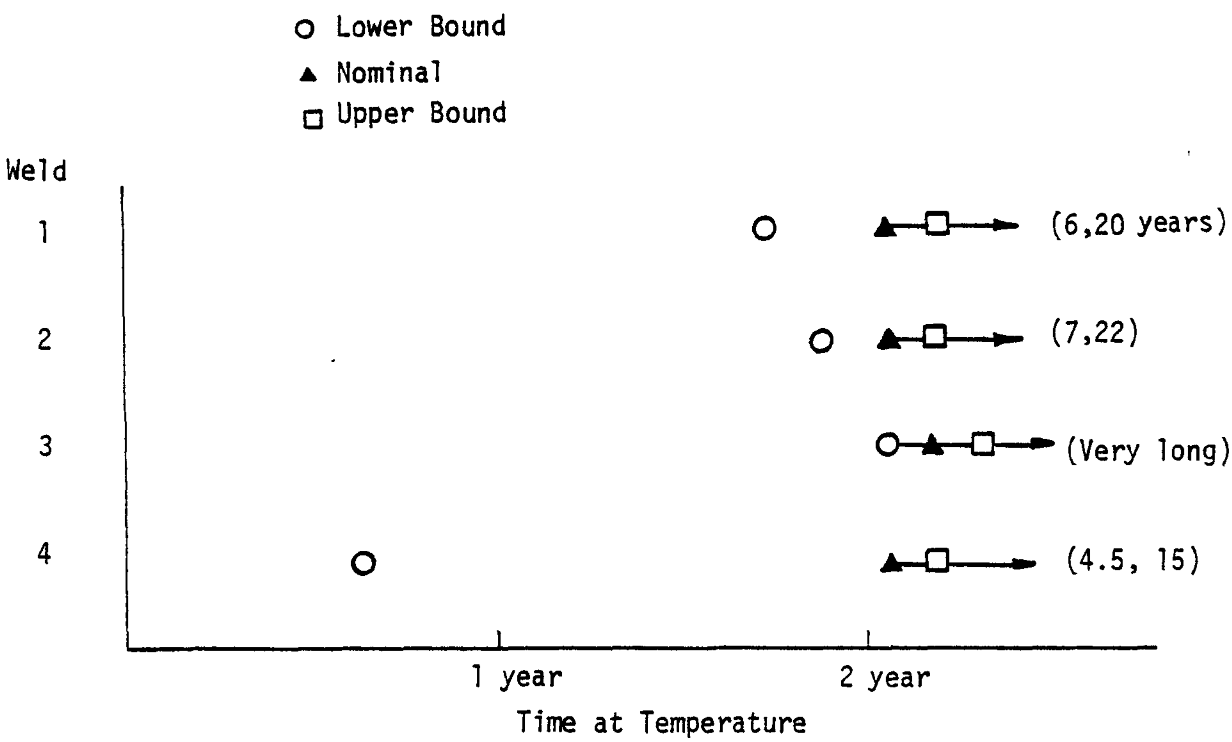


Fig. 5 Predicted Failure Time of Welds