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APPLICATION OF STRAINRANGE PARTITIONING TO THE PREDICTION OF CREEP-FATIGUE LIVES OF AISI TYPES 304 AND 316 STAINLESS STEEL

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ABSTRACT

As a demonstration of the predictive capabilities of the method of Strainrange Partitioning, published high-temperature, low cycle, creep-fatique test results on AISI Types 304 and 316 stainless steel were analyzed and calculated cyclic lives compared with observed lives. Predicted lives agreed with observed lives within factors of two for 76 percent, factors of three for 93 percent, and factors of four for 98 percent of the laboratory tests analyzed. Agreement between observed and predicted lives is judged satisfactory considering that the data are associated with a number of variables (two alloys, several heats and heat treatments, a range of temperatures, different testing techniques, etc.) that are not directly accounted for in the calculations.

NOMENCLATURE

E	modulus of elasticity
K	NOBS/NPRE
NOBS	observed number of cycles to failure
NPRE	predicted number of cycles to failure
n	number of data points
N	pure PP life, cycles to failure
N	pure PC life, cycles to failure
N	pure CP life, cycles to failure
N	pure CC life, cycles to failure
SE	standard error of estimate
$\Delta\varepsilon_{in}$	inelastic strainrange
$\Delta\varepsilon_{pp}$	PP component of inelastic strainrange
$\Delta\varepsilon_{pc}$	PC component of inelastic strainrange
$\Delta\varepsilon_{cp}$	CP component of inelastic strainrange
$\Delta\varepsilon_{cc}$	CC component of inelastic strainrange
$\delta\sigma$	amount of stress relaxation during strain hold-time

TEST TYPE

BCCR	balanced cyclic creep rupture
BHSC	balanced hold strain cycle
CCCP	compressive cyclic creep rupture (low temperature plasticity)
CCCR	compressive cyclic creep rupture
CHSC	compressive hold strain cycle
HRSC	high rate strain cycle
TCCP	tensile cyclic creep rupture (low temperature plasticity)

TCCR	tensile cyclic creep rupture
THSC	tensile hold strain cycle
UHSC	unbalanced hold strain cycle

INTRODUCTION

Strainrange Partitioning is a method for characterizing and predicting the high-temperature, low-cycle fatigue behavior of metallic materials. Initial studies(1-3)* have demonstrated the viability of the method for characterizing laboratory creep-fatigue data for tests involving completely reversed strain cycles. Characterization is expressed in terms of the four generic strainrange versus life relations that are the cornerstones of the method. For a given heat of certain materials, (for example, AISI Type 316 stainless steel and 2 1/4Cr - 1Mo steel, Ref. 2) the life relations have been shown to represent laboratory fatigue lives generally within factors of two on cyclic life for a range of test temperatures and strainranges of practical interest. The characterization capabilities of the method are now well documented, but the predictive capabilities require additional verification.

The purpose of this report is to demonstrate the method's predictive capabilities. This is accomplished by analyzing, in accordance with previously published procedures for applying Strainrange Partitioning, a large quantity of strain hold-time and stress hold-time creep-fatigue data for AISI Types 304 and 316 stainless steel published by investigators from five independent laboratories. The predictions are based on the use

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* numbers in parentheses designate references at end of text.

of the interaction damage rule(3) and the life relations for AISI Type 316 stainless steel established from previous tests(4) conducted at a single isothermal temperature of 705 deg C (1300 deg F).

REVIEW

It is appropriate to review briefly those aspects of Strainrange Partitioning pertinent to the analyses presented in this paper. A complete background of the method can be found in a recent summary paper (5) and in the initial papers on the subject (1-3).

The basic premise of the method of Strainrange Partitioning is that creep-fatigue life is controlled primarily by the ability of a material to absorb cyclic inelastic strain. Two inelastic strain components are recognized by the method; "creep", associated with thermally-activated, time-dependent deformation, and "plasticity", associated with time-independent deformation. Coupling the two types of strain with the two directions of axial straining results in the four basic strainranges known as the partitioned strainranges:

$\Delta\varepsilon_{pp}$ = completely reversed plasticity

$\Delta\varepsilon_{pc}$ = tensile plasticity with compressive creep

$\Delta\varepsilon_{cp}$ = tensile creep with compressive plasticity

$\Delta\varepsilon_{cc}$ = completely reversed creep

Each strainrange can be expressed as a function of cyclic life by a relation similar to the Manson-Coffin equation. The relations usually differ from one another, but may be coincident in some cases for some materials. They are established by conducting completely reversed strain-cycling fatigue tests.

Once all four strainrange-life relations have been established for a material by following recommended procedures(5), they may be used as the basis for predicting the cyclic lives of specimens made of that material. Conceivably, any high temperature cycle involving completely reversed strains can be analyzed and the corresponding cyclic life calculated. The interaction damage rule is used to account for the damage due to each of the strainranges present in such cycles.

DATA SOURCES

Published high-temperature, low-cycle, creep-fatigue test data on AISI Types 304 and 316 stainless steel have been analyzed. The creep-fatigue data for which life predictions have been made cover a range of test temperatures , 316 to 816 deg C(600 to 1500 deg F) ,and hold times (both stress-hold and strain-hold), and have come from a number of sources: Manson, Halford, and Hirschberg (1); Halford, Hirschberg, and Manson (2); Halford (4); Brinkman and Korth (6), (7); Weeks, Diercks, and Cheng (8); Conway, Stentz, and Berling (9); Jaske, Mindlin, and Perrin (10).

ANALYSIS

Partitioning of Strainranges

Partitioning of the inelastic strainranges of the hysteresis loops of all the test results contained in this paper follows procedures outlined in Ref. (1). The partitioned test results are given in Tables 1 thru 6. All of the high-temperature, creep-fatigue tests are for completely-reversed strain cycles and involve either a stress hold-time or a strain hold-time.

Partitioning of the creep strain in the stress hold-time tests is a straight-forward procedure of simply considering as creep strain all of the inelastic strain accumulated as a function of time under the applied constant stress; the remainder of the inelastic strain is taken to be plastic strain. The method of partitioning the strain hold-time tests is given in Appendix A.

In partitioning the inelastic strainranges of the data used in this report, all the time-independent strain was regarded as ''plasticity'', and all time-dependent strain was regarded as ''creep'' as recommended and successfully used in the original papers (1-3) on Strainrange Partitioning. Recent studies (11) indicate that more accurate life prediction are possible with a more sophisticated interpretation of creep strain. However, it was not possible to take advantage of this new development since the literature data that are analyzed in this paper were generated and reported prior to the above study.

Establishment of Life Relations

The predictions are based on the partitioned strainrange-life relations established from tests performed at the NASA-Lewis Research Center on annealled AISI Type 316 stainless steel at a single isothermal temperature of 705 deg C (1300 deg F). These test results are listed in Table 1.

The life relations for AISI Type 316 stainless steel shown in Figs. 1a-d are expressed as power law equations relating inelastic strainrange and cyclic life . The best values for the two constants in each life relation (exponent and intercept) were determined by performing a linear least squares curve fit on the plotted data points. The inelastic strainrange is the independent variable and is assumed to be known without error. The power functions are linearized by taking logarithms of strainrange and life.

The correlation coefficient and standard error of estimate were also determined (Appendix B) for each strainrange-life relation.

Life Prediction

The cyclic lives are predicted for all of the tests for which data are listed in Tables 2 thru 6 using, as a basis, the interaction damage rule and the partitioned strainrange-life relations shown in Figs. 1a-d. In making the life predictions, no special consideration was given to the fact that the data came from a number of sources involving several different heats of material, a number of isothermal (and some non-isothermal) testing temperatures from as low as 315 deg C (600 deg F) to as high as 816 deg C (1500 deg F), or that diametral and axial strain control was employed in obtaining the data. Both stress-hold time and strain-hold time tests were involved.

Despite the number of variables associated with the manner in which the data were obtained by the various investigators, the strainrange-life relations used for the life predictions were obtained from tests on only one heat of the alloy AISI Type 316 stainless steel evaluated at a single isothermal test temperature of 705 deg C (1300 deg F).

The method of analysis was programmed for a digital computer, and automatic computer microfilm plots of the output were made using CINEMATIC (12).

COMPARISON OF PREDICTED AND OBSERVED LIVES

Previous experience with Strainrange Partitioning (Ref. 2, for example) has shown that cyclic lives can generally be calculated to within factors of two when dealing with a given heat of material tested at a single laboratory employing a given set of testing techniques. Factors of two in life, therefore, represent a background variation that might be expected of this method when dealing with a single set of data. When additional variables are involved, such as different heats and heat treatments of material, different materials, different laboratories employing different testing techniques, etc., greater variations between predicted and observed lives should be expected.

For example, suppose that two different heats of a material had life relations that were displaced in life by factors of two because of, say, differences in their ductilities. Using the life relations from one material to predict the observed cyclic lives of the other could thus result in a potential total variation of a factor of four.

The results of the present life prediction calculations are shown in Figs. 2a and b where observed life is plotted versus predicted life for AISI Types 304 and 316 stainless steel respectively. It should be noted that the AISI Type 316 stainless steel data used originally to determine the four life relations employed in the predictions are <u>not</u> included in this figure. The central 45 degree lines representing exact agreement between observed and predicted lives are bracketed by sets of lines which indicate factors of variation between predicted and observed lives.

Close scrutiny of the results plotted in Figs. 2a and b reveals apparent differences in the creep-fatigue behavior of these two technologically important stainless steels. For a given predicted life (i.e., given inelastic strainrange and degree of partitioning), the 304 alloy exhibited generally greater creep-fatigue lives than the 316 alloy. If this observation is a true reflection of the inherent high-temperature behavior of these two alloys, one would expect the partitioned strainrange-life relations for AISI Type 304 stainless steel to be located somewhat above those for AISI Type 316 stainless steel. However, the ASME Code Case 1592(13) does not at the moment distinguish between these two alloys in regard to their creep-fatigue behavior. We have therefore superimposed the results from Figs. 2a and b and have plotted them in Fig. 3. Inset in Fig. 3 is a brief table summarizing the percentage of data points falling within the indicated factors.

To encompass 98 percent of all the data, it is necessary to accept factors of four on life. Despite this seemingly large factor, the ability of the method of Strainrange Partitioning to predict the cyclic lives of the data contained in this report must be judged as satisfactory considering the numerous variables involved. None of the variables listed below were directly accounted for in making the life predictions. The life relations used in all of the predictions were based on only 25 test results determined for only one heat of AISI Type 316 stainless steel at a single isothermal temperature of 705 deg C (1300 deg F).

a) data obtained at five independent laboratories
b) two different alloys
c) several heats of material and heat treatments
d) temperatures covering a wide range
e) isothermal and non-isothermal tests
f) stress and strain hold-time cycles.

SUMMARY OF RESULTS

Using the method of Strainrange Partitioning, the four inelastic strainrange-life relations were obtained from a least squares curve fit of 25 uniaxial isothermal test data points for AISI Type 316 stainless steel obtained at 705 deg C (1300 deg F). High-temperature, low-cycle, creep-fatigue life predictions were then made and compared to life data obtained from other laboratory strain-cycling tests conducted on specimens of AISI Types 304 and 316 stainless steel. A variety of test conditions were covered including a temperature range from 316 deg C to 816 deg C (600 deg F to 1500 deg F), several different heats of material, heat treatments, and several testing techniques. Had the partitioned strainrange-life relations been known for the different testing techniques, test temperatures, and heats of material of interest, greater accuracy in the life predictions could likely have been achieved. However, this information was not available. Consequently, life relations for a single condition were used. Predicted lives agreed with observed lives within factors of two for 76 percent, factors of three for 93 percent, and factors of four for 98 percent of the laboratory tests analyzed.

This study illustrates that the method of Strainrange Partitioning has the ability to both characterize and predict the creep-fatigue behavior of a material, or class of materials, in a simple, straight-forward manner based on the results from a relatively small number of isothermal laboratory tests.

Lewis Research Center,

National Aeronautics and Space Administration,

Cleveland, Ohio, March 5, 1975.

APPENDIX A

PARTITIONING of STRAIN HOLD-TIME TESTS

The amount of time-dependent strain induced in a cycle that is associated with a hold period at constant total strain can be determined directly from a knowledge of the modulus of elasticity and the amount of stress that is relaxed during the hold time.

This is illustrated with the aid of Fig. A-1. Here a stress-strain hysteresis loop, abcdea ,is shown for the case of a tensile strain hold. The inelastic strainrange is given by be. In the tensile half of the cycle, the component of inelastic strain bc' is defined to be time-independent plastic strain since the straining rate in going from point b to c is presumed to be high enough to preclude creep effects. The strain rate was greater than 0.004/sec for all of the test results analyzed in this paper. At point c the total tensile strain is held constant and the stress relaxes an amount $\delta\sigma$ with time from point c to point d. The amount of time-dependent strain under these circumstances is simply equal to the amount of the relaxed stress divided by the modulus of elasticity. The calculated quantity is the amount of elastic strain that has been converted to creep strain during the relaxation process.

To better appreciate this, one could consider a different stress-strain path through which the specimen could be subjected to still arrive at point d.

At point c, assume that the stress had been held constant and the specimen was allowed to creep under constant stress to point d'. Immediately upon reaching d', the specimen could be unloaded elastically to point d. Under these alternate circumstances, the creep strain is readily identified as the amount _d', which is exactly equal in magnitude to the elastic strain change produced by decreasing the stress from its value at c or d' to its value at d. The loop is completed by straining rapidly from point d back to point a. The inelastic strain during compressive deformation is equal to eb and is time-independent plasticity for the problem at hand. For this cycle the inelastic strainrange bc contains only two partitioned inelastic strainrange components, $\Delta\varepsilon_{pp}$ = bc' and $\Delta\varepsilon_{cp}$ = c'e(= cd').

APPENDIX B

CORRELATION COEFFICIENT and STANDARD ERROR of ESTIMATE

The correlation coefficient (14) is a measure of how well the assumed equation represents the data. A correlation coefficient near -1.0 for negatively sloped relations (or +1.0 for positively sloped relations) indicates the assumed equation represents the data well. If the correlation coefficient is near zero, it means the assumed equation does not represent the data.

The standard error of estimate is a measure of the scatter in the data and is given by the following equation (15).

$$SE = \sqrt{\sum \left[\log(NOBS) - \log(NPRE)\right]^2 / n} \qquad B-(1)$$

This equation can also be written in the following form.

$$SE = \sqrt{\sum \left[\log(K)\right]^2 / n} \qquad B-(2)$$

Written in this form it is apparent that the standard error of estimate is the root mean square of the ratio of observed life to predicted life.

The advantage of determining the standard error of estimate in this manner is that its value is determined by the ratio of the lives. It is not affected by the actual value of the lives. Thus it is possible to directly compare results from the analyses of various data sources.

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TABLE 1

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 316 STAINLESS STEEL LIFE RELATIONS AT 705 deg C(1300 deg F)

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\varepsilon_{in}$ %	$\Delta\varepsilon_{pp}$ %	$\Delta\varepsilon_{pc}$ %	$\Delta\varepsilon_{cp}$ %	$\Delta\varepsilon_{cc}$ %	NOBS	NPRE
AYY-095	HRSC	705/705	0.424	0.424	--	--	--	1700	2528
AYY-096	BCCR	705/705	3.610	0.650	0.550	--	2.410	100	74
AYY-100	CCCR	705/705	3.590	1.050	2.540	--	--	88	79
AYY-103	BCCR	705/705	3.780	0.060	0.390	--	3.330	86	71
AYY-105	HRSC	705/705	0.105	0.105	--	--	--	35602	27483
AYY-106	CCCR	705/705	3.730	0.030	3.700	--	--	57	82
AYY-108	TCCR	705/705	3.680	0.450	--	3.230	--	8	7
AYY-109	CCCR	705/705	4.900	0.180	4.720	--	--	70	59
AYY-110	BCCR	705/705	3.810	0.060	0.090	--	3.660	41	70
AYY-128	BCCR	705/705	8.890	1.150	0.760	--	6.980	24	22
AYY-129	BCCR	705/705	3.760	0.230	0.220	--	3.310	98	71
AYY-132	HRSC	705/705	3.508	3.508	--	--	--	102	68
AYY-136	BCCR	705/705	0.445	0.103	--	--	0.342	1150	1182
AYY-137	HRSC	705/705	3.496	3.496	--	--	--	68	68
AYY-151	BCCR	705/705	1.380	0.230	0.220	--	0.930	285	264
AYY-153	BCCR	705/705	3.780	0.150	0.080	--	3.550	37	70
AYY-155	TCCR	705/705	1.328	0.260	--	1.068	--	38	48
AYY-159	TCCR	705/705	0.492	0.076	--	0.416	--	275	258
AYY-160	TCCR	705/705	3.660	1.200	--	2.460	--	12	9
AYY-161	TCCR	705/705	3.710	0.250	--	3.460	--	7	7
AYY-169	CCCR	705/705	1.280	0.693	0.587	--	--	345	336
AYY-202	HRSC	705/705	0.466	0.466	--	--	--	2333	2151
AYY-207	HRSC	705/705	2.066	2.066	--	--	--	116	168
AYY-210	HRSC	705/705	2.360	2.360	--	--	--	146	134
AYY-214	THSC	705/705	0.255	0.219	--	0.036	--	3000	2888

TABLE 2

STRAINHANGE PARTITIONING DATA FOR AISI TYPE 316 STAINLESS STEEL - REF.'S 1,2,4 PLUS NEW NASA DATA

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\varepsilon_{in}$ %	$\Delta\varepsilon_{pp}$ %	$\Delta\varepsilon_{pc}$ %	$\Delta\varepsilon_{cp}$ %	$\Delta\varepsilon_{cc}$ %	NOBS	NPRE
AYY-101	CCCR	705/705	3.680	0.650	2.150	--	0.880	130	77
AYY-102	BCCR	705/705	3.730	0.290	2.110	--	1.330	94	76
AYY-119	TCCR	705/705	3.635	0.525	--	1.580	1.530	18	14
AYY-127	TCCR	705/705	3.710	0.170	--	2.580	0.960	15	9
AYY-130	BCCR	705/705	3.660	1.700	1.100	--	0.860	130	71
AYY-133	THSC	705/705	3.603	3.460	--	0.143	--	58	49
AYY-139	BCCR	705/705	1.332	0.830	0.200	--	0.302	395	318
AYY-140	BCCR	705/705	3.760	0.030	--	1.230	2.500	18	17
AYY-144	THSC	705/705	1.363	1.270	--	0.093	--	225	223
AYY-145	BCCR	705/705	3.730	0.270	--	1.530	1.930	2	14
AYY-150	BCCR	705/705	0.492	0.327	0.025	--	0.140	1330	1412
AYY-152	BCCR	705/705	3.710	0.340	--	2.530	0.840	15	9
AYY-158	BCCR	705/705	3.730	0.180	--	1.100	2.450	21	19
AYY-162	BCCR	705/705	3.710	0.380	2.000	--	1.330	100	76
AYY-163	BCCR	705/705	3.680	0.290	--	1.280	2.110	15	17
AYY-164	BCCR	705/705	3.730	0.620	1.110	--	2.000	110	72
AYY-166	BCCR	705/705	3.680	0.260	1.580	--	1.840	103	76
AYY-167	BCCR	705/705	3.684	0.494	--	0.980	2.220	25	20
AYY-203	THSC	705/705	1.080	0.990	--	0.090	--	324	309
AYY-204	TCCP	705/316	0.334	0.212	--	0.122	--	632	994
AYY-205	CCCP	316/705	0.892	0.247	0.645	--	--	811	502
AYY-206	CCCP	316/705	2.350	0.730	1.620	--	--	264	141
AYY-208	THSC	705/705	3.552	3.459	--	0.093	--	141	55
AYY-209	TCCP	705/316	2.370	0.905	--	1.465	--	15	22
AYY-212	THSC	815/815	0.440	0.395	--	0.045	--	1054	1323
AYY-215	TCCP	815/316	1.870	0.445	--	1.425	--	10	28
AYY-216	CCCR	595/595	2.130	1.640	0.490	--	--	262	160
AYY-218	TCCR	815/815	0.187	0.072	--	0.115	--	3090	1791
AYY-219	TCCP	705/316	4.450	0.450	--	4.000	--	6	5
AYY-222	BCCR	815/815	4.815	0.222	--	--	4.593	23	51
AYY-223	TCCR	595/595	2.330	1.812	--	0.518	--	30	49
AYY-225	CCCR	815/815	0.670	0.130	0.540	--	--	911	695
AYY-227	BCCR	815/815	0.270	0.061	--	--	0.209	3560	2252
AYY-230	LRSC	815/815	4.072	0.001	--	--	4.071	53	64
AYY-231	BCCR	815/815	1.024	0.108	--	--	0.916	339	377
AYY-233	CCCR	815/815	4.610	0.180	4.430	--	--	51	63
AYY-234	TCCP	815/316	1.895	0.705	--	1.190	--	25	32
AYY-237	TCCR	815/815	2.220	0.110	--	2.110	--	17	17
AYY-239	TCCP	647/316	1.220	0.843	--	0.377	--	89	121
AYY-240	TCCP	647/316	2.040	0.840	--	1.200	--	22	30
AYY-241	TCCP	647/316	0.747	0.392	--	0.355	--	155	203

TABLE 3A

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 304 STAINLESS STEEL - REF. 6

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\varepsilon_{in}$ %	$\Delta\varepsilon_{pp}$ %	$\Delta\varepsilon_{pc}$ %	$\Delta\varepsilon_{cp}$ %	$\Delta\varepsilon_{cc}$ %	NOBS	NPRE
B-26	THSC	593/593	1.450	1.442	--	0.008	--	1068	296
BT-76	THSC	593/593	1.480	1.445	--	0.035	--	545	251
A-223	THSC	593/593	1.520	1.472	--	0.048	--	369	228
BT-75	THSC	593/593	1.410	1.369	--	0.041	--	272	263
B-27	THSC	593/593	1.400	1.357	--	0.043	--	1008	264
BT-15	THSC	593/593	1.380	1.332	--	0.048	--	382	263
BT-6	THSC	593/593	1.400	1.347	--	0.053	--	271	252
A-224	THSC	593/593	1.560	1.504	--	0.056	--	190	212
A-32	THSC	593/593	0.640	0.628	--	0.012	--	1190	1091
B-15	THSC	593/593	0.650	0.640	--	0.010	--	1650	1087
A1T5	THSC	593/593	0.640	0.630	--	0.010	--	1484	1114
B-20	THSC	593/593	0.670	0.648	--	0.022	--	1708	920
B-6	THSC	593/593	0.630	0.613	--	0.017	--	1555	1061
A-39	THSC	593/593	0.710	0.685	--	0.025	--	806	821
A1C2	THSC	593/593	0.630	0.607	--	0.023	--	631	1000
A1B10	THSC	593/593	0.620	0.593	--	0.027	--	588	985
A-33	THSC	593/593	0.710	0.679	--	0.031	--	593	781
A-70	THSC	593/593	0.750	0.711	--	0.039	--	418	678
B-7	THSC	593/593	0.210	0.204	--	0.006	--	12860	6890
B-17	THSC	593/593	0.240	0.238	--	0.002	--	13393	6285
BI4	THSC	593/593	0.200	0.198	--	0.002	--	10756	8483
A230	THSC	593/593	0.230	0.226	--	0.004	--	12083	6344
BT5	THSC	593/593	0.190	0.187	--	0.003	--	6245	8894
A-231	THSC	593/593	0.240	0.234	--	0.006	--	5874	5609
A-234	THSC	593/593	0.280	0.274	--	0.006	--	3725	4410
B-22	THSC	593/593	0.660	0.637	--	0.023	--	1574	933
BP-10	THSC	593/593	0.150	0.147	--	0.003	--	18271	12955

TABLE 3B

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 316 STAINLESS STEEL - REF. 7

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\varepsilon_{in}$ %	$\Delta\varepsilon_{pp}$ %	$\Delta\varepsilon_{pc}$ %	$\Delta\varepsilon_{cp}$ %	$\Delta\varepsilon_{cc}$ %	NOBS	NPRE
D-211	THSC	593/593	1.530	1.508	--	0.022	--	558	253
D-212	THSC	593/593	1.470	1.448	--	0.022	--	542	270
D-208	THSC	593/593	1.550	1.509	--	0.041	--	137	228
D-210	THSC	593/593	1.520	1.480	--	0.040	--	147	236

TABLE 4A

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 304 STAINLESS STEEL - REF. 8

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\varepsilon_{in}$ %	$\Delta\varepsilon_{pp}$ %	$\Delta\varepsilon_{pc}$ %	$\Delta\varepsilon_{cp}$ %	$\Delta\varepsilon_{cc}$ %	NOBS	NPRE
15A-10	THSC	565/565	0.230	0.222	--	0.008	--	3781	5674
15A-6	THSC	565/565	0.450	0.428	--	0.022	--	375	1655
15A-11	THSC	565/565	0.710	0.688	--	0.022	--	1509	843
5A-9	THSC	565/565	0.690	0.676	--	0.014	--	3574	949
7A-7	THSC	565/565	0.710	0.689	--	0.021	--	3027	850
15A-5	THSC	565/565	0.740	0.716	--	0.024	--	606	778
15A-4	THSC	565/565	0.750	0.706	--	0.044	--	672	653
14A-1	THSC	565/565	1.050	1.018	--	0.032	--	236	433
15A-8	THSC	565/565	1.650	1.594	--	0.056	--	190	195
12A-12	THSC	565/565	1.840	1.762	--	0.078	--	93	154
8A-9	THSC	593/593	0.250	0.248	--	0.002	--	9365	5876
10A-2	THSC	593/593	0.280	0.272	--	0.008	--	14970	4211
62-6	THSC	593/593	0.280	0.265	--	0.015	--	10441	3636
AA-28	THSC	593/593	0.280	0.271	--	0.009	--	3803	4118
T-38	THSC	593/593	0.420	0.401	--	0.019	--	2765	1902
T-72	THSC	593/593	0.680	0.656	--	0.024	--	1235	884
10A-10	CHSC	593/593	0.690	0.676	0.014	--	--	2272	1082
10A-1	CHSC	593/593	0.720	0.700	0.020	--	--	2353	1001
AA-27	THSC	593/593	0.720	0.686	--	0.034	--	338	747
AA-10	THSC	593/593	0.700	0.675	--	0.025	--	1664	839
T-30	THSC	593/593	0.740	0.710	--	0.030	--	666	741
10A-8	THSC	593/593	0.700	0.688	--	0.012	--	1046	946
T-13	THSC	593/593	0.710	0.689	--	0.021	--	1328	850
T-91	THSC	593/593	0.680	0.659	--	0.021	--	1619	908
10A-7	THSC	593/593	0.720	0.709	--	0.011	--	2719	913
10A-6	THSC	593/593	0.740	0.721	--	0.019	--	2961	812
9A-1	THSC	593/593	0.700	0.679	--	0.021	--	1470	869
9A-2	CHSC	593/593	0.700	0.691	0.009	--	--	2973	1062
AA-14	CHSC	593/593	0.700	0.689	0.011	--	--	3344	1060
T-18	CHSC	593/593	0.720	0.702	0.018	--	--	2995	1003
AA-23	THSC	593/593	0.710	0.681	--	0.029	--	636	794
T-56	THSC	593/593	0.740	0.708	--	0.032	--	553	729
51-9	CHSC	593/593	0.740	0.718	0.022	--	--	2810	955
T-74	THSC	593/593	0.960	0.925	--	0.035	--	656	486
T-217	THSC	593/593	1.660	1.612	--	0.048	--	112	199
T-44	THSC	593/593	1.660	1.606	--	0.054	--	237	195
4A-2	THSC	650/650	0.330	0.312	--	0.018	--	3198	2729
7A-2	CHSC	650/650	0.710	0.683	0.027	--	--	1944	1017
6A-11	THSC	650/650	0.770	0.725	--	0.045	--	645	625
6A-3	THSC	650/650	0.800	0.774	--	0.026	--	930	681
T-58	THSC	650/650	0.790	0.745	--	0.045	--	525	603
4A-7	THSC	650/650	1.770	1.701	--	0.069	--	253	168
12A-6	THSC	650/650	1.760	1.729	--	0.031	--	311	194

TABLE 4B

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 316 STAINLESS STEEL - REF. 8

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\epsilon_{in}$ %	$\Delta\epsilon_{pp}$ %	$\Delta\epsilon_{pc}$ %	$\Delta\epsilon_{cp}$ %	$\Delta\epsilon_{cc}$ %	NOBS	NPRE
GR1-5	THSC	565/565	0.590	0.584	--	0.006	--	1487	1331
35-7	THSC	565/565	0.580	0.573	--	0.007	--	1990	1352
18-10	THSC	565/565	0.570	0.544	--	0.026	--	411	1125
20-7	THSC	565/565	0.600	0.578	--	0.022	--	1333	1086
GR1-9	THSC	565/565	0.620	0.598	--	0.022	--	552	1034
20-1	THSC	565/565	1.490	1.436	--	0.054	--	155	229
20-9	THSC	565/565	1.460	1.411	--	0.049	--	363	241
GR2-4	CHSC	650/650	0.650	0.621	0.029	--	--	1690	1173
GR2-2	THSC	650/650	0.650	0.617	--	0.033	--	460	872
GR1-10	THSC	650/650	1.750	1.658	--	0.092	--	141	158
GR1-3	THSC	650/650	1.760	1.671	--	0.089	--	191	158

TABLE 5

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 304 STAINLESS STEEL - REF. 9

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\epsilon_{in}$ %	$\Delta\epsilon_{pp}$ %	$\Delta\epsilon_{pc}$ %	$\Delta\epsilon_{cp}$ %	$\Delta\epsilon_{cc}$ %	NOBS	NPRE
57- 8	BHSC	650/650	0.320	0.315	--	--	0.005	6916	3988
65- 3	BHSC	650/650	0.310	0.305	--	--	0.005	10266	4205
57-11	THSC	650/650	0.290	0.285	--	0.005	--	3869	4271
57- 9	THSC	650/650	0.280	0.275	--	0.005	--	5351	4517
57-12	THSC	650/650	0.320	0.300	--	0.020	--	1703	2758
65- 1	THSC	650/650	0.310	0.288	--	0.022	--	1713	2789
56- 2	THSC	650/650	0.340	0.307	--	0.033	--	862	2106
56- 3	THSC	650/650	0.330	0.292	--	0.038	--	1216	2053
65- 4	THSC	650/650	0.340	0.307	--	0.033	--	995	2106
53- 8	BHSC	650/650	1.710	1.660	--	--	0.050	526	231
65-11	UHSC	650/650	1.769	1.700	--	0.033	0.036	308	191
65- 9	UHSC	650/650	1.790	1.715	--	0.039	0.036	336	183
53- 9	BHSC	650/650	1.800	1.732	--	--	0.068	380	212
54- 9	BHSC	650/650	1.840	1.769	--	--	0.071	416	204
57- 2	THSC	650/650	1.640	1.607	--	0.033	--	570	216
56-12	THSC	650/650	1.640	1.595	--	0.045	--	545	205
57- 1	THSC	650/650	1.660	1.610	--	0.050	--	329	198
56-11	THSC	650/650	1.660	1.610	--	0.050	--	331	198
56- 5	THSC	650/650	1.710	1.643	--	0.067	--	193	178
56- 1	THSC	650/650	1.710	1.643	--	0.067	--	201	178
53-10	THSC	650/650	1.790	1.716	--	0.074	--	146	162
53-12	THSC	650/650	1.760	1.684	--	0.076	--	165	165
54- 2	THSC	650/650	1.770	1.677	--	0.093	--	144	155
54- 1	THSC	650/650	1.779	1.689	--	0.090	--	158	155
57- 6	THSC	650/650	1.780	1.680	--	0.100	--	150	150
57- 7	THSC	650/650	1.800	1.705	--	0.095	--	120	150
54- 3	CHSC	650/650	1.700	1.629	0.071	--	--	480	234
52-11	CHSC	650/650	1.700	1.626	0.074	--	--	409	234
67- 4	THSC	537/537	0.240	0.236	--	0.004	--	17920	5928
66-11	THSC	537/537	3.460	3.407	--	0.053	--	141	62

TABLE 6A

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 304 STAINLESS STEEL - REF. 10

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\epsilon_{in}$ %	$\Delta\epsilon_{pp}$ %	$\Delta\epsilon_{pc}$ %	$\Delta\epsilon_{cp}$ %	$\Delta\epsilon_{cc}$ %	NOBS	NPRE
SS07	THSC	537/537	1.800	1.768	--	0.032	--	366	187
SS22	THSC	537/537	0.650	0.623	--	0.027	--	1431	919
SS09	THSC	537/537	1.800	1.740	--	0.060	--	223	169
SS08	THSC	537/537	1.820	1.753	--	0.067	--	184	162

TABLE 6B

STRAINRANGE PARTITIONING DATA FOR AISI TYPE 316 STAINLESS STEEL - REF. 10

SPEC. NO.	TEST TYPE	TEMP. C TEN/COM	$\Delta\epsilon_{in}$ %	$\Delta\epsilon_{pp}$ %	$\Delta\epsilon_{pc}$ %	$\Delta\epsilon_{cp}$ %	$\Delta\epsilon_{cc}$ %	NOBS	NPRE
22	THSC	565/565	1.500	1.457	--	0.043	--	163	237
23	THSC	565/565	0.640	0.618	--	0.022	--	534	986
68	THSC	565/565	1.340	1.297	--	0.043	--	76	282
24	THSC	650/650	1.590	1.506	--	0.084	--	86	186
27L	THSC	650/650	1.650	1.598	--	0.052	--	81	198
25	THSC	650/650	0.720	0.688	--	0.032	--	412	759
71L	THSC	650/650	0.760	0.721	--	0.039	--	190	665
66L	THSC	650/650	0.280	0.260	--	0.020	--	753	3313
69L	THSC	650/650	0.260	0.241	--	0.019	--	799	3731
26	THSC	650/650	1.600	1.505	--	0.095	--	85	177

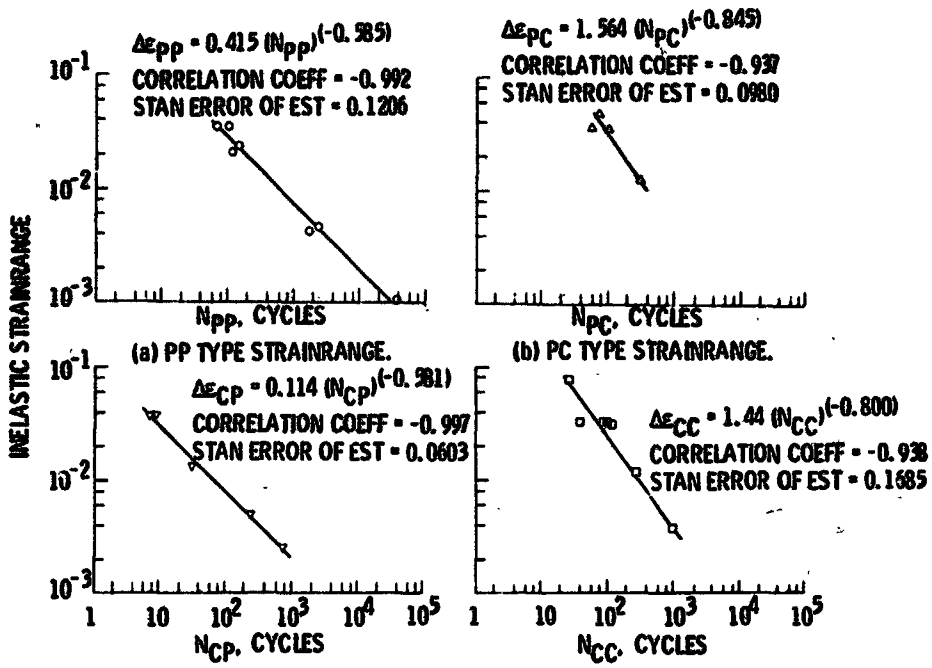

Figure 1. - Partitioned strainrange - life relations for AISI Type 316 stainless steel, 1300° F (705° C).

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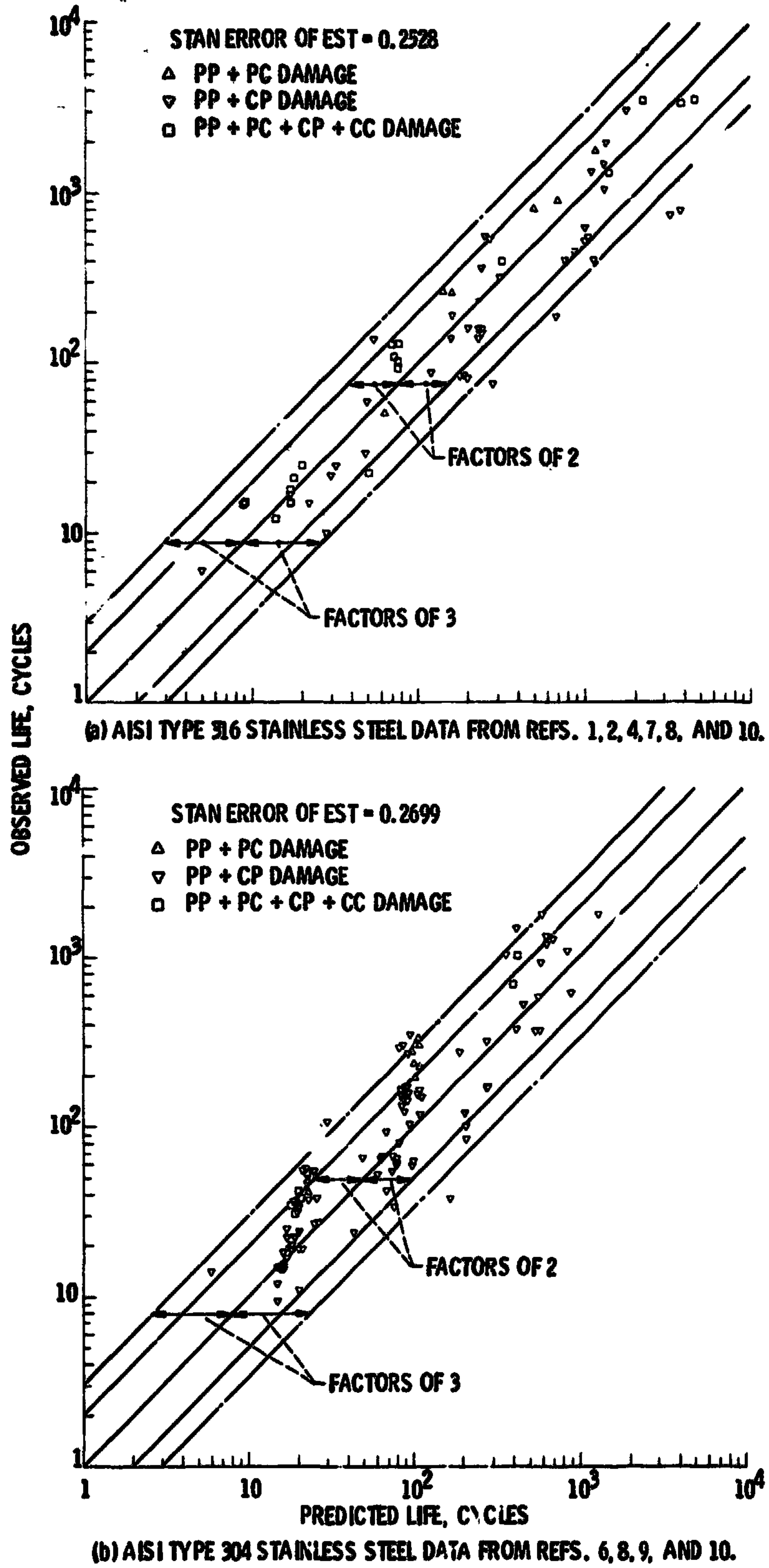

Figure 2. - Life prediction of high-temperature, creep-fatigue data from various sources. Predictions based on interaction damage rule and life relations for AISI Type 316 stainless steel at 1300° F (705° C).

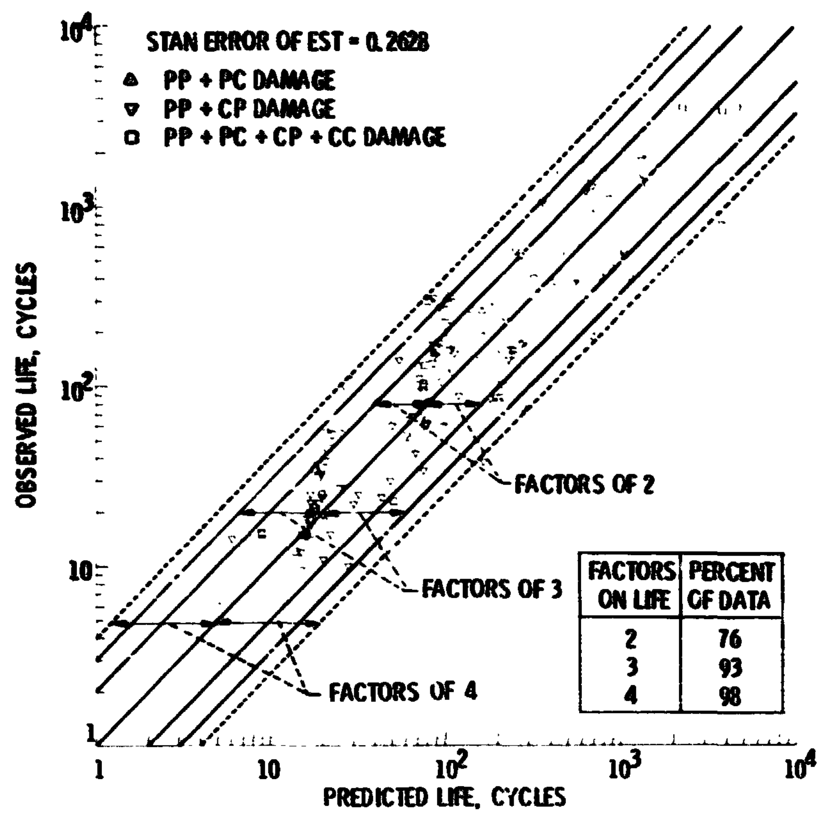

Figure 3. - Life prediction of high-temperature, creep-fatigue data on AISI Types 304 and 316 stainless steel. Composite data plot from Figs. 2(a) and (b).

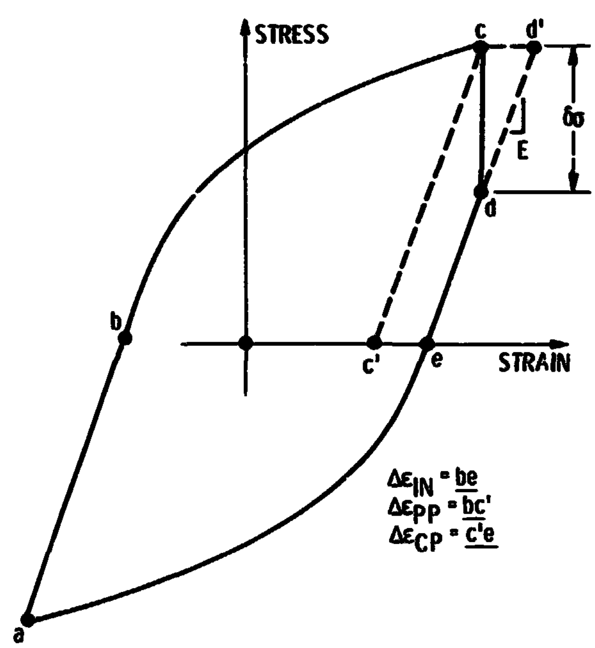

Figure A-1. - Schematic hysteresis loop for tensile strain hold-time test illustrating partitioning of inelastic strains.

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