The University of Michigan • Office of Research Administration
Ann Arbor, Michigan

32549-1-F

CREEP-RUPTURE PROPERTIES OF SANDVIK SANICRO 31 TUBING

By

David J. Wilson
James W. Freeman
Clarence A. Siebert

Prepared For:

Gulf General Atomic, Inc.
Post Office Box 608
San Diego, California 92121

June 1968

CREEP-RUPTURE PROPERTIES OF SANDVIK SANICRO 31 TUBING

An investigation was conducted to determine the rupture strength of Sanicro 31 tubing made by Sandvik of Sweden. Gulf General Atomic, Inc., supplied machined specimens and specified a testing program designed to determine rupture times suitable for parametric extrapolation. The work was authorized by Purchase Order 2109, dated March 22, 1968, from Gulf General Atomic, Inc.

It was understood that Sandvik had furnished data indicating that the rupture strength of the tubing was lower than had been expected based on data for the same alloy made in the United States. Gulf General Atomic, Inc., had conducted a few tests which indicated higher strengths than the data reported by Sandvik.

SUMMARY

Three replicate tests were conducted at the following stresses and temperatures--a schedule of testing apparently designed for parametric extrapolation to prolonged time periods.

	Test Temperature, °F				
Stress, psi	1400	1450	1500	1550	1600
12,000	x				
10,000	x	x	x		
8,000		x	x	x	
6,000			x	x	x

The following comparative rupture strengths at 1300°F were derived from the data using computer programs for optimizing constants for parametric analyses; the usual constant of C = 20.0 was used for the Larson-Miller Parameter.

Parameter	Rupture Strengths, psi	
	10,000 Hours	100,000 Hours
Manson-Haferd (Linear) (optimized constants)	9,860	6,380
Larson-Miller (optimized constant, C = 18.74)	10,000	7,300
Larson-Miller (C = 20.0)	10,650	7,700
Published Values (domestic material)	10,300	7,000

Values for rupture in 100, 1000, 10,000, and 100,000 hours at 50°F intervals which could be derived from the parametric analyses are included as part of the computer output of Appendices 2 and 3.

The data indicate stress-rupture time curves with less slope for the tubing than the published values for domestic alloy. Thus, even though short-time tests were shorter than the published curves indicated, long-time strengths tended to be as high, or higher for the tubes. It is believed that the Sandvik data shows the same trend.

Estimates based on Michigan tests for 12,000 psi at 1400°F, using the parameters, suggest rupture times at 1292°F which are below those indicated by Gulf General Atomic, Inc., tests, and on the high side of the range of the Sandvik data.

MATERIAL

In a letter dated March 21, 1968, the specimens were indicated as having all been machined from the wall of one tube. The analysis was reported to be the following.

Heat No.	C	Si	Mn	P	S	Cr	Ni
7-07766	.035	.29	1.31	.008	.005	20.47	33.45

Cu	Ti	Al	N
.03	.47	.49	.018

Rods approximately 0.19-inch in diameter by 4.5 inches long had been machined from longitudinal strips from the tube. A gage length approximately 0.175-inch in diameter by 1.2 inches long was machined at the middle of the rod. The ends of the bars had been inserted into holes drilled through 3/4-inch by 10 threaded adapters and welded.

There was a slight tendency for the gage lengths to be smaller near the fillets than in the center. This had a considerable effect on elongation and reduction of area.

PROCEDURE

The specimens were gage marked on the shoulders, and the lengths of the reduced sections were measured. Elongations were computed by assuming that all of the increase in length, as measured on the shoulders, occurred in the reduced gage section. After attaching three thermocouples, each specimen was placed in a furnace of a creep-rupture unit which was at temperature. The temperatures were adjusted in four hours and the specimens loaded. The rupture time was recorded automatically. Each test was conducted in a single-specimen, beam-loaded unit without interruption. Temperatures were automatically controlled to less than $\pm$ 3°F throughout the tests and along the gage length.

Loads for the tests were computed from the minimum diameter in the gage length.

RESULTS

The results of the tests are reported in Table 1. All but two of the tests were successful. Two specimens (Specimen Nos. 36 and 42) pulled out of the weld to the threaded adapter. The two spares were used for these two tests.

The "Estimated Approximate Rupture Times" were supplied by Gulf General Atomic, Inc., and were apparently taken from published typical curves for domestic alloy. It will be noted that, in general, the higher stress tests at each temperature were shorter in duration than the estimated times. The lower-stress tests tended to be longer than the estimated rupture times.

Gulf General Atomic, Inc., sent Professor C. A. Siebert a copy of the stress-rupture curves for domestic alloy. The results of tests reported by Sandvik were superimposed along with five tests by Gulf General Atomic, Inc., at 1292°F. This has been replotted and the results of the tests at Michigan added (Fig. 1). The following comments are offered:

1. The comparatively short rupture times at high stresses and longer times at lower stresses for a given temperature indicates stress-rupture time curves with less slope than the published values.

2. Apparently, a longer rupture time is required to bring the rupture strength up to that of the published values, the lower the test temperature.

3. Curves could be drawn through the Sandvik data with slopes consistent with the Michigan data. The scatter in the Sandvik data leads to some questions regarding this conclusion.

4. The tests at Michigan generally indicate less scatter than the Sandvik and Gulf General Atomic, Inc., data. However, if the latter tests were conducted on specimens from more than one tube, it is easily possible that variation among the tubes could account for the scatter. The better agreement for the Michigan tests could be due to the specimens all being from one tube.

5. The variation among the three replicate tests is less than is frequently found in tubes. On the other hand, it is greater than we normally expect for known uniform material. Cold straightening of tubes will generally introduce as much, and usually more, scatter than was found.

6. Part of the scatter was probably due to variations in diameter. Diameter variation was particularly noticeable in elongation and reduction of area values. Many of the specimens underwent extensive reduction of area at both fillets, and fractured near one fillet. The extreme cases of this are noted in Table 1.

DISCUSSION

The test program was apparently designed to furnish information suitable for parametric extrapolation to long time periods. Because there is an extensive study of computerized parametric treatment of data currently in progress at the University of Michigan, the data were partially analyzed from this viewpoint. The program is currently set up to do the following:

1. Using the computer program proposed by Mendelson, Roberts, and Manson[1], the data can be analyzed for "optimum" constants for the Manson-Haferd ("Linear") and the Larson-Miller parameters. The program output includes optimum parameter constants for the data set and parameter values for each data point, based on the determined constants. It uses orthogonal polynomials and selects the constants which give the minimum standard deviation in the two equations involved:

---

*Mendelson, A.; Roberts, Ernest Jr.; and Manson, S.: Optimization of the Time-Temperature Parameters for Creep and Stress Rupture with Application to Data from German Cooperative Long-Time Creep Program. NASA Technical Note D-2975, August, 1965.

$$P = \frac{\log t - \log t_A}{T_1 - T_A} \qquad \text{(Manson-Haferd Linear Parameter)}$$

$$P = T_2 (C + \text{Log } t) \qquad \text{(Larson-Miller Parameter)}$$

where, t = rupture time in hours

T_1 = °F

T_2 = °F + 460

$\log t_A$ = constant (Time Intercept, Y_a, of computer output)

T_A = constant (Temperature Intercept of computer output)

C = Constant (-Ya, Time Intercept of computer output)

Appendix 1 gives the computer output for this program for the two parameters.

2. A computer program was developed at Michigan which calculates rupture strengths from the parameters for optimized constants. It carries out multiple polynomial regression analyses of the log stress versus parameter data, using varying degree polynomials to obtain minumum standard deviation and then computes the rupture strengths for the minimum standard deviation. The rupture strengths are limited to the range of stresses of the actual tests. (When the strengths are outside this range of stresses, the computer prints out "0.0".) The strengths are computed at 50°F intervals for 100, 1000, 10,000, and 100,000 hours. The computer output for this program is given in Appendix 2 for both the Manson Haferd and the Larson-Miller parameters with optimized constants.

3. The program described under (2) above can be made to "force fit" a Larson-Miller constant and carry out the calculations described under (2). Accordingly, the data were analyzed for the widely used constant C = 20.0. The computer output is included as Appendix 3.

The log stress versus parameter values are shown graphically as Figures 2, 3, and 4. The curves established by the computer programs of Appendices 2 and 3 for the Larson-Miller Parameter (Figs. 3 and 4) were

third-order polynomials. This resulted in more curvature than was probably warranted by the data. Accordingly, "hand-fitted" curves were also drawn as a probably better curve. (Note--this is equivalent to using a polynomial of the second order. It will be noted from Appendices 2 and 3 that this would not significantly change the standard deviations.) It also does not significantly change the indicated strengths. The computer program resulted in a curve through the Manson-Haferd parameter points (Fig. 2) which appears to be reasonable.

Based on these parametric analyses of the data, the following observations can be made.

1. The indicated stresses for rupture in 100,000 hours, along with the comparative value from the log-log curves for this domestic material, are as follows:

	100,000-Hour Rupture Strengths, psi		
	1200°F	1250°F	1300°F
Domestic log-log curves	11,800	-----	7,000
Manson-Haferd Parameter (Linear)	10,500	8,360	6,380
Larson-Miller Parameter (C = 18.74)			
Computer	10,690	9,280	7,220
"Hand-fitted" curve	11,100	9,150	7,300
Larson-Miller Parameter (C = 20.0)			
Computer	11,240	9,580	7,710
"Hand-fitted" curve	11,500	9,500	7,700

Note - Rupture strengths for 100, 1000, 10,000, and 100,000 hours at 50°F intervals are given with the computer output in Appendices 2 and 3 when the data warrant. Intermediate values could be read from Figures 2, 3, and 4 by calculating the parameters using the appropriate constants. The reader is cautioned not to extrapolate beyond the range of the actual tests because the shapes of the curves are uncertain beyond this.

The Manson-Haferd (Linear) parameter indicated lower long-time strengths than either the log-log curves or the Larson-Miller parameter. The optimized constant of C = 18.74 for the Larson-Miller parameter resulted in somewhat lower strengths than the common constant value of C = 20.0. The parameters gave slightly lower strengths at 1200°F than the log-log curve, and somewhat higher strengths at 1300°F. This was to be expected from the lower slopes of the stress-rupture time curves indicated by the Michigan tests. An "eyeball" average 100,000-hour strength at 1300°F for the Sandvik data was estimated as 6,500 psi, a rather questionable estimate in view of the data scatter.

2. An attempt was made to estimate the rupture times which would have been obtained if tests had been run at 1292°F for comparison with the Gulf General Atomic, Inc., and Sandvik data at this temperature. This was done in two ways. Parameter values calculated for the Gulf General Atomic, Inc., data would plot about 2,000 psi higher than the tests at Michigan. Rupture times at 1292°F for a stress of 12,000 psi were calculated using the average parameters for the 12,000 psi tests at 1400°F. The results were as follows:

Manson-Haferd (Linear)	3,100 hours
Larson-Miller (C = 18.74)	2,900 hours
Larson-Miller (C = 20.0)	3,550 hours

These values were then plotted on Figure 1. They appear to be on the high side of the range for the Sandvik data. Apparently, the Michigan tests came out between the other two sets of data. It would have been more satisfactory to have had comparative tests at 1292°F.

3. It will be noted that the points on the log stress versus parameter curves exhibit greater scatter than seemed to be suggested by the actual rupture times. The scales used were quite extended. However, there is also a variation in parameter values at the same stress for tests at different temperatures.

APPENDIX 1

Values of Larson-Miller and Manson-Haferd (Linear) Parameters
Based on Computer Program Optimized Constants
of Michigan Tests on Sandvik Sanicro 31 Tubing

GULF GENERAL ATOMIC INC 800
LARSON PARAMETER

CREEP/RUPTURE PARAMETERS ARE INVESTIGATED FOR
1 VALUE(S) OF T(A), 1 TEMPERATURE EXPONENT(S), 1 STRESS EXPONENT(S), AND 6 POLYNOMIAL(S)
USING 30 DATA POINTS

Q	R	M	T(A)	Y(A)	STD.DEV.	Q	R	M	T(A)	Y(A)	STD.
0.0	-1.00	2	-460.	-18.74	0.0791730						
0.0	-1.00	3	-460.	-18.74	0.0781771						
0.0	-1.00	4	-460.	2.37	0.4809470						
0.0	-1.00	5	-460.	2.43	0.4969609						
0.0	-1.00	6	-460.	2.37	0.5140435						
0.0	-1.00	7	-460.	2.34	0.5681457						

GULF GENERAL ATOMIC INC 800

LARSON PARAMETER

VALUES PRODUCING SMALLEST STANDARD DEVIATION

Q= 0.0 , R=-1.00, M= 3, T(A)= -460., Y(A)= -18.743, AND STANDARD DEVIATION = 0.0781771

TEMP	STRESS (*E-3)	LOG STRESS	TIME	CALCTD TIME	LOG TIME	CALC LOG TIME	DEV/SD	PARAMETER
1400.	12.0	4.079	122.0	150.3	2.086	2.177	1.158	0.3874E 05
1400.	12.0	4.079	171.8	150.3	2.235	2.177	0.744	0.3902E 05
1400.	12.0	4.079	162.1	150.3	2.210	2.177	0.421	0.3897E 05
1400.	10.0	4.000	543.4	562.4	2.735	2.750	0.191	0.3995E 05
1400.	10.0	4.000	566.4	562.4	2.753	2.750	0.040	0.3998E 05
1400.	10.0	4.000	521.7	562.4	2.717	2.750	0.417	0.3992E 05
1450.	10.0	4.000	226.5	154.0	2.355	2.187	2.145	0.4030E 05
1450.	10.0	4.000	185.8	154.0	2.269	2.187	1.044	0.4013E 05
1450.	10.0	4.000	182.1	154.0	2.260	2.187	0.933	0.4012E 05
1450.	8.0	3.903	866.4	810.4	2.938	2.909	0.371	0.4141E 05
1450.	8.0	3.903	755.2	810.4	2.878	2.909	0.392	0.4130E 05
1450.	8.0	3.903	784.8	810.4	2.895	2.909	0.178	0.4133E 05
1500.	10.0	4.000	54.2	45.0	1.734	1.653	1.030	0.4013E 05
1500.	10.0	4.000	31.6	45.0	1.500	1.653	1.967	0.3968E 05
1500.	10.0	4.000	27.7	45.0	1.442	1.653	2.699	0.3956E 05
1500.	8.0	3.903	210.0	227.1	2.322	2.356	0.436	0.4129E 05
1500.	8.0	3.903	251.4	227.1	2.400	2.356	0.564	0.4144E 05
1500.	8.0	3.903	190.5	227.1	2.280	2.356	0.977	0.4120E 05
1500.	6.0	3.778	1448.1	1219.5	3.161	3.086	0.955	0.4293E 05
1500.	6.0	3.778	1118.9	1219.5	3.049	3.086	0.478	0.4271E 05
1500.	6.0	3.778	1199.1	1219.5	3.079	3.086	0.094	0.4277E 05
1550.	8.0	3.903	76.0	67.8	1.881	1.831	0.631	0.4145E 05
1550.	8.0	3.903	74.2	67.8	1.870	1.831	0.498	0.4143E 05
1550.	8.0	3.903	67.4	67.8	1.829	1.831	0.036	0.4135E 05
1550.	6.0	3.778	317.6	349.3	2.502	2.543	0.528	0.4270E 05
1550.	6.0	3.778	336.3	349.3	2.527	2.543	0.210	0.4275E 05
1550.	6.0	3.778	357.0	349.3	2.553	2.543	0.122	0.4280E 05
1600.	6.0	3.778	106.7	106.3	2.028	2.027	0.021	0.4279E 05
1600.	6.0	3.778	108.3	106.3	2.035	2.027	0.104	0.4280E 05
1600.	6.0	3.778	108.4	106.3	2.035	2.027	0.109	0.4280E 05

GULF GENERAL ATOMIC INC 800
LINEAR PARAMETER

CREEP/RUPTURE PARAMETERS ARE INVESTIGATED FOR
13 VALUE(S) OF T(A), 1 TEMPERATURE EXPONENT(S), 1 STRESS EXPONENT(S), AND 6 POLYNOMIAL(S)
USING 30 DATA POINTS

Q	R	M	T(A)	Y(A)	STD.DEV.
0.0	1.00	2	3050.	-14.54	0.0859361
0.0	1.00	3	3050.	-14.54	0.0851344
0.0	1.00	4	3050.	3.00	0.5108153
0.0	1.00	5	3050.	2.45	0.5183544
0.0	1.00	6	3050.	2.41	0.5381156
0.0	1.00	7	3050.	2.41	0.5511519
0.0	1.00	2	2550.	-9.06	0.0894175
0.0	1.00	3	2550.	-9.06	0.0887100
0.0	1.00	4	2550.	2.38	0.4912130
0.0	1.00	5	2550.	2.42	0.5249175
0.0	1.00	6	2550.	2.43	0.5436739
0.0	1.00	7	2550.	2.40	0.5593435
0.0	1.00	2	2050.	-3.54	0.1013277
0.0	1.00	3	2050.	-3.54	0.1012641
0.0	1.00	4	2050.	2.66	0.5224547
0.0	1.00	5	2050.	2.75	0.5516979
0.0	1.00	6	2050.	2.51	0.5459752
0.0	1.00	7	2050.	2.45	0.5558422
0.0	1.00	2	1550.	1.97	0.4031944
0.0	1.00	3	1550.	1.97	0.4071965
0.0	1.00	4	1550.	7.70	4.6296377
0.0	1.00	5	1550.	7.54	4.6020975
0.0	1.00	6	1550.	3.27	1.0932178
0.0	1.00	7	1550.	3.26	1.1178322
0.0	1.00	2	1050.	7.21	0.0831372
0.0	1.00	3	1050.	7.21	0.0848492
0.0	1.00	4	1050.	2.41	0.4951664
0.0	1.00	5	1050.	2.32	0.5249423
0.0	1.00	6	1050.	2.33	0.5354290
0.0	1.00	7	1050.	2.30	0.5557079
0.0	1.00	2	550.	12.74	0.0767541
0.0	1.00	3	550.	12.73	0.0771896
0.0	1.00	4	550.	2.30	0.4939420
0.0	1.00	5	550.	2.33	0.5294659
0.0	1.00	6	550.	2.33	0.5472484
0.0	1.00	7	550.	2.36	0.5606937
0.0	1.00	2	0.	18.79	0.0770860
0.0	1.00	3	0.	18.77	0.0770104
0.0	1.00	4	0.	2.40	0.4900005
0.0	1.00	5	0.	2.42	0.5051261
0.0	1.00	6	0.	2.36	0.5279683
0.0	1.00	7	0.	2.40	0.5509080
0.0	1.00	2	-500.	24.18	0.0776013
0.0	1.00	3	-500.	24.16	0.0773345
0.0	1.00	4	-500.	2.72	0.4849977
0.0	1.00	5	-500.	2.39	0.5176132
0.0	1.00	6	-500.	2.37	0.5367544
0.0	1.00	7	-500.	2.34	0.5533186
0.0	1.00	2	-1000.	29.65	0.0779899
0.0	1.00	3	-1000.	29.64	0.0776187
0.0	1.00	4	-1000.	2.05	0.4966237
0.0	1.00	5	-1000.	2.29	0.5185353
0.0	1.00	6	-1000.	2.36	0.5362298
0.0	1.00	7	-1000.	2.33	0.5578928
0.0	1.00	2	-1500.	34.92	0.0784003
0.0	1.00	3	-1500.	34.90	0.0779697
0.0	1.00	4	-1500.	2.45	0.4897152
0.0	1.00	5	-1500.	2.47	0.5137443
0.0	1.00	6	-1500.	2.48	0.5254104
0.0	1.00	7	-1500.	2.34	0.5608695
0.0	1.00	2	-2000.	40.84	0.0785252
0.0	1.00	3	-2000.	40.82	0.0780451
0.0	1.00	4	-2000.	2.32	0.4914196
0.0	1.00	5	-2000.	2.39	0.5111592
0.0	1.00	6	-2000.	2.36	0.5261917
0.0	1.00	7	-2000.	2.37	0.5580807
0.0	1.00	2	-2500.	46.27	0.0786982
0.0	1.00	3	-2500.	46.24	0.0781885
0.0	1.00	4	-2500.	2.36	0.4909297
0.0	1.00	5	-2500.	2.36	0.5280685
0.0	1.00	6	-2500.	2.36	0.5487229
0.0	1.00	7	-2500.	2.36	0.5622753
0.0	1.00	2	-3000.	52.92	0.0797490
0.0	1.00	3	-3000.	52.89	0.0792474
0.0	1.00	4	-3000.	2.38	0.4908093
0.0	1.00	5	-3000.	2.42	0.5063344
0.0	1.00	6	-3000.	2.36	0.5252824
0.0	1.00	7	-3000.	2.38	0.5560027

GULF GENERAL ATOMIC INC 800

LINEAR PARAMETER

VALUES PRODUCING SMALLEST STANDARD DEVIATION

Q= 0.0 , R= 1.00, M= 2, T(A)= 550., Y(A)= 12.742, AND STANDARD DEVIATION = 0.0767541

TEMP	STRESS (*E-3)	LOG STRESS	TIME	CALCTD TIME	LOG TIME	CALC LOG TIME	DEV/SD	PARAMETER
1400.	12.0	4.079	122.0	143.8	2.086	2.158	0.932	-0.1254E-01
1400.	12.0	4.079	171.8	143.8	2.235	2.158	1.005	-0.1236E-01
1400.	12.0	4.079	162.1	143.8	2.210	2.158	0.676	-0.1239E-01
1400.	10.0	4.000	543.4	625.2	2.735	2.796	0.794	-0.1177E-01
1400.	10.0	4.000	566.4	625.2	2.753	2.796	0.559	-0.1175E-01
1400.	10.0	4.000	521.7	625.2	2.717	2.796	1.024	-0.1179E-01
1450.	10.0	4.000	226.5	162.6	2.355	2.211	1.877	-0.1154E-01
1450.	10.0	4.000	185.8	162.6	2.269	2.211	0.756	-0.1164E-01
1450.	10.0	4.000	182.1	162.6	2.260	2.211	0.642	-0.1165E-01
1450.	8.0	3.903	866.4	798.3	2.938	2.902	0.463	-0.1089E-01
1450.	8.0	3.903	755.2	798.3	2.878	2.902	0.314	-0.1096E-01
1450.	8.0	3.903	784.8	798.3	2.895	2.902	0.097	-0.1094E-01
1500.	10.0	4.000	54.2	42.3	1.734	1.626	1.408	-0.1159E-01
1500.	10.0	4.000	31.6	42.3	1.500	1.626	1.645	-0.1183E-01
1500.	10.0	4.000	27.7	42.3	1.442	1.626	2.390	-0.1189E-01
1500.	8.0	3.903	210.0	226.7	2.322	2.356	0.434	-0.1097E-01
1500.	8.0	3.903	251.4	226.7	2.400	2.356	0.584	-0.1089E-01
1500.	8.0	3.903	190.5	226.7	2.280	2.356	0.985	-0.1101E-01
1500.	6.0	3.778	1448.1	1156.9	3.161	3.063	1.270	-0.1009E-01
1500.	6.0	3.778	1118.9	1156.9	3.049	3.063	0.189	-0.1020E-01
1500.	6.0	3.778	1199.1	1156.9	3.079	3.063	0.203	-0.1017E-01
1550.	8.0	3.903	76.0	64.4	1.881	1.809	0.937	-0.1086E-01
1550.	8.0	3.903	74.2	64.4	1.870	1.809	0.802	-0.1087E-01
1550.	8.0	3.903	67.4	64.4	1.829	1.809	0.258	-0.1091E-01
1550.	6.0	3.778	317.6	358.0	2.502	2.554	0.678	-0.1024E-01
1550.	6.0	3.778	336.3	358.0	2.527	2.554	0.354	-0.1021E-01
1550.	6.0	3.778	357.0	358.0	2.553	2.554	0.016	-0.1019E-01
1600.	6.0	3.778	106.7	110.8	2.028	2.045	0.213	-0.1020E-01
1600.	6.0	3.778	108.3	110.8	2.035	2.045	0.129	-0.1020E-01
1600.	6.0	3.778	108.4	110.8	2.035	2.045	0.124	-0.1020E-01

APPENDIX 2

Computer Calculated Rupture Strengths of Sandvik Sanicro 31 Tubing Derived from Larson-Miller and Manson-Haferd (Linear) Parameters Based on Optimized Constants for Michigan Data

PARAMETRIC ANALYSIS OF STRESS-RUPTURE DATA, BY THE UNIVERSITY OF MICHIGAN HIGH TEMPERATURE METALLURGY GROUP. THIS IS COPY 4 OF 4.

ANALYSIS FOR: GULF GENERAL ATOMIC INC 800

RANGES OF THE 30 ORIGINAL DATA ANALYZED:	LOWEST	HIGHEST
STRESS (KSI)	6.00	12.00
TIME (HR)	27.7	1448.
TEMPERATURE (DEG. F)	1400.	1600.
PARAMETER VALUE	0.387D 05	0.429D 05

THE OPTIMIZED STRESS-RUPTURE PARAMETRIC CONSTANTS PRODUCED BY THE USE OF ORTHOGONAL POLYNOMIALS IN A SLIGHTLY MODIFIED VERSION OF THE MENDELSON-ROBERTS-MANSON FORTRAN IV PROGRAM (NASA TECHNICAL NOTE TN D-2975) ARE LISTED BELOW:

PARAMETER TYPE = LARSON, STRESS EXPONENT Q = 0.0, TEMPERATURE EXPONENT R = -1.0, TEMPERATURE INTERCEPT T(A) = -460.0, LOG TIME INTERCEPT Y(A) = -18.742966, AND FOR THIS SET OF DATA THESE CONSTANTS PRODUCED A STANDARD DEVIATION OF 0.0781771.

MULTIPLE POLYNOMIAL REGRESSION FOR POLYNOMIALS FROM ORDER 1 TO 6, USING DOUBLE-PRECISION (64-BIT WORD SIZE) ARITHMETIC PRODUCED THE FOLLOWING STANDARD DEVIATIONS FOR EACH ORDER OF POLYNOMIAL OF THE FORM LOG(STRESS IN KSI)=FUNCTION(PARAMETER) INVESTIGATED:

WHERE A STD. DEVIATION OF 10.0 MEANS NEAR SINGULAR MATRIX	ORDER OF POLYNOMIAL =	1	2	3	4	5	6
	STANDARD DEVIATION =	0.0126409	0.0107827	0.0107717	0.0098044	0.0100880	0.0101556

AND USING THE SMALLEST STANDARD DEVIATION AS THE CRITERION FOR 'BEST,' THE ENTIRE 'BEST' EQUATION IS GIVEN BELOW:

LOG OF STRESS IN KSI = (0.1387D 05) +(-0.1360D 04)|P| +(0.5004D 02)|P|^2 +(-0.8176D 00)|P|^3 +(0.5007D-02)|P|^4 +(0.0)|P|^5 +(0.0)|P|^6

(WHERE P, AS LARSON PARAMETER, IS DIVIDED BY 1000.)

USING THE ABOVE EQUATION, THE FOLLOWING TABLE OF STRESSES TO PRODUCE RUPTURE AT THE SPECIFIED TIMES AND TEMPERATURES WAS CALCULATED. NOTE THAT A STRESS OF ZERO INDICATES THAT THE CALCULATED STRESS WAS OUT OF THE RANGE OF THE ORIGINAL DATA ANALYZED.

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.415	9.200	7.389	6.019
1000.	0.0	0.0	0.0	0.0	0.0	0.0	10.781	9.491	7.694	6.088	0.0	0.0
10000.	0.0	0.0	0.0	0.0	11.873	9.968	8.367	6.409	0.0	0.0	0.0	0.0
100000.	0.0	0.0	0.0	10.690	9.279	7.218	0.0	0.0	0.0	0.0	0.0	0.0

USING THE CONSTANTS LISTED ABOVE, THE FOLLOWING PARAMETER VALUES WERE CALCULATED FOR THE TIMES AND TEMPERATURES INDICATED:

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.313D 05	0.324D 05	0.334D 05	0.344D 05	0.355D 05	0.365D 05	0.375D 05	0.386D 05	0.396D 05	0.407D 05	0.417D 05	0.427D 05
1000.	0.328D 05	0.339D 05	0.350D 05	0.361D 05	0.372D 05	0.383D 05	0.394D 05	0.404D 05	0.415D 05	0.426D 05	0.437D 05	0.448D 05
10000.	0.343D 05	0.355D 05	0.366D 05	0.378D 05	0.389D 05	0.400D 05	0.412D 05	0.423D 05	0.434D 05	0.446D 05	0.457D 05	0.469D 05
100000.	0.359D 05	0.370D 05	0.382D 05	0.394D 05	0.406D 05	0.418D 05	0.430D 05	0.442D 05	0.453D 05	0.465D 05	0.477D 05	0.489D 05

THE ORIGINAL DATA USED FOR THE ABOVE ANALYSES FOLLOWS:

TEMPERATURE, DEG F =	1400.	1400.	1400.	1400.	1400.	1400.	1450.	1450.	1450.	1450.
STRESS IN KSI =	12.000	12.000	12.000	10.000	10.000	10.000	10.000	10.000	10.000	8.000
LOG OF KSI STRESS =	1.0792	1.0792	1.0792	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9031
TIME IN HOURS =	122.00	171.80	162.10	543.40	566.40	521.70	226.50	185.80	182.10	866.40
PARAMETER VALUE =	0.387D 05	0.390D 05	0.390D 05	0.399D 05	0.400D 05	0.399D 05	0.403D 05	0.401D 05	0.401D 05	0.414D 05

TEMPERATURE, DEG F =	1450.	1450.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
STRESS IN KSI =	8.000	8.000	10.000	10.000	10.000	8.000	8.000	8.000	6.000	6.000
LOG OF KSI STRESS =	0.9031	0.9031	1.0000	1.0000	1.0000	0.9031	0.9031	0.9031	0.7782	0.7782
TIME IN HOURS =	755.20	784.80	54.20	31.60	27.70	210.00	251.40	190.50	1448.10	1118.90
PARAMETER VALUE =	0.413D 05	0.413D 05	0.401D 05	0.397D 05	0.396D 05	0.413D 05	0.414D 05	0.412D 05	0.429D 05	0.427D 05

TEMPERATURE, DEG F =	1500.	1550.	1550.	1550.	1550.	1550.	1550.	1600.	1600.	1600.
STRESS IN KSI =	6.000	8.000	8.000	8.000	6.000	6.000	6.000	6.000	6.000	6.000
LOG OF KSI STRESS =	0.7782	0.9031	0.9031	0.9031	0.7782	0.7782	0.7782	0.7782	0.7782	0.7782
TIME IN HOURS =	1199.10	76.00	74.20	67.40	317.60	336.30	357.00	106.70	108.30	108.40
PARAMETER VALUE =	0.428D 05	0.415D 05	0.414D 05	0.413D 05	0.427D 05	0.428D 05	0.428D 05	0.428D 05	0.428D 05	0.428D 05

PARAMETRIC ANALYSIS OF STRESS-RUPTURE DATA, BY THE UNIVERSITY OF MICHIGAN HIGH TEMPERATURE METALLURGY GROUP. THIS IS COPY 4 OF 4.

ANALYSIS FOR: GULF GENERAL ATOMIC INC 800

RANGES OF THE 30 ORIGINAL DATA ANALYZED:	LOWEST	HIGHEST
STRESS (KSI)	6.00	12.00
TIME (HR)	27.7	1448.
TEMPERATURE (DEG. F)	1400.	1600.
PARAMETER VALUE	-0.125D-01	-0.101D-01

THE OPTIMIZED STRESS-RUPTURE PARAMETRIC CONSTANTS PRODUCED BY THE USE OF ORTHOGONAL POLYNOMIALS IN A SLIGHTLY MODIFIED VERSION OF THE MENDELSON-ROBERTS-MANSON FORTRAN IV PROGRAM (NASA TECHNICAL NOTE TN D-2975) ARE LISTED BELOW:

PARAMETER TYPE = LINEAR, STRESS EXPONENT Q = 0.0, TEMPERATURE EXPONENT R = 1.0, TEMPERATURE INTERCEPT T(A) = 550.0, LOG TIME INTERCEPT Y(A) = 12.741699, AND FOR THIS SET OF DATA THESE CONSTANTS PRODUCED A STANDARD DEVIATION OF 0.0767541.

MULTIPLE POLYNOMIAL REGRESSION FOR POLYNOMIALS FROM ORDER 1 TO 6, USING DOUBLE-PRECISION (64-BIT WORD SIZE) ARITHMETIC PRODUCED THE FOLLOWING STANDARD DEVIATIONS FOR EACH ORDER OF POLYNOMIAL OF THE FORM LOG(STRESS IN KSI)=FUNCTION(PARAMETER) INVESTIGATED:

WHERE A STD. DEVIATION OF 10.0 MEANS NEAR SINGULAR MATRIX	ORDER OF POLYNOMIAL =	1	2	3	4	5	6
	STANDARD DEVIATION =	0.0154739	0.0102662	0.0100706	10.0000000	10.0000000	10.0000000

AND USING THE SMALLEST STANDARD DEVIATION AS THE CRITERION FOR 'BEST,' THE ENTIRE 'BEST' EQUATION IS GIVEN BELOW:

LOG OF STRESS IN KSI = (-0.1529D 02) + (0.3823D 04)|P| + (-0.3059D 06)|P|^2 + (0.8388D 07)|P|^3 + (0.0)|P|^4 + (0.0)|P|^5 + (0.0)|P|^6

(WHERE P, ORIGINALLY NEGATIVE, WAS USED AS |P|)

USING THE ABOVE EQUATION, THE FOLLOWING TABLE OF STRESSES TO PRODUCE RUPTURE AT THE SPECIFIED TIMES AND TEMPERATURES WAS CALCULATED. NOTE THAT A STRESS OF ZERO INDICATES THAT THE CALCULATED STRESS WAS OUT OF THE RANGE OF THE ORIGINAL DATA ANALYZED.

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.563	8.988	7.524	6.127
1000.	0.0	0.0	0.0	0.0	0.0	0.0	11.192	9.374	7.743	6.194	0.0	0.0
10000.	0.0	0.0	0.0	0.0	0.0	9.860	8.014	6.277	0.0	0.0	0.0	0.0
100000.	0.0	0.0	0.0	10.499	8.358	6.382	0.0	0.0	0.0	0.0	0.0	0.0

USING THE CONSTANTS LISTED ABOVE, THE FOLLOWING PARAMETER VALUES WERE CALCULATED FOR THE TIMES AND TEMPERATURES INDICATED:

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.215D-01	0.195D-01	0.179D-01	0.165D-01	0.153D-01	0.143D-01	0.134D-01	0.126D-01	0.119D-01	0.113D-01	0.107D-01	0.102D-01
1000.	0.195D-01	0.177D-01	0.162D-01	0.150D-01	0.139D-01	0.130D-01	0.122D-01	0.115D-01	0.108D-01	0.103D-01	0.974D-02	0.928D-02
10000.	0.175D-01	0.159D-01	0.146D-01	0.134D-01	0.125D-01	0.117D-01	0.109D-01	0.103D-01	0.971D-02	0.920D-02	0.874D-02	0.833D-02
100000.	0.155D-01	0.141D-01	0.129D-01	0.119D-01	0.111D-01	0.103D-01	0.968D-02	0.911D-02	0.860D-02	0.815D-02	0.774D-02	0.737D-02

THE ORIGINAL DATA USED FOR THE ABOVE ANALYSES FOLLOWS:

TEMPERATURE, DEG F =	1400.	1400.	1400.	1400.	1400.	1400.	1450.	1450.	1450.	1450.
STRESS IN KSI =	12.000	12.000	12.000	10.000	10.000	10.000	10.000	10.000	10.000	8.000
LOG OF KSI STRESS =	1.0792	1.0792	1.0792	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9031
TIME IN HOURS =	122.00	171.80	162.10	543.40	566.40	521.70	226.50	185.80	182.10	866.40
PARAMETER VALUE =	-0.125D-01	-0.124D-01	-0.124D-01	-0.118D-01	-0.118D-01	-0.118D-01	-0.115D-01	-0.116D-01	-0.116D-01	-0.109D-01

TEMPERATURE, DEG F =	1450.	1450.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
STRESS IN KSI =	8.000	8.000	10.000	10.000	10.000	8.000	8.000	8.000	6.000	6.000
LOG OF KSI STRESS =	0.9031	0.9031	1.0000	1.0000	1.0000	0.9031	0.9031	0.9031	0.7782	0.7782
TIME IN HOURS =	755.20	784.80	54.20	31.60	27.70	210.00	251.40	190.50	1448.10	1118.90
PARAMETER VALUE =	-0.110D-01	-0.109D-01	-0.116D-01	-0.118D-01	-0.119D-01	-0.110D-01	-0.109D-01	-0.110D-01	-0.101D-01	-0.102D-01

TEMPERATURE, DEG F =	1500.	1550.	1550.	1550.	1550.	1550.	1550.	1600.	1600.	1600.
STRESS IN KSI =	6.000	8.000	8.000	8.000	6.000	6.000	6.000	6.000	6.000	6.000
LOG OF KSI STRESS =	0.7782	0.9031	0.9031	0.9031	0.7782	0.7782	0.7782	0.7782	0.7782	0.7782
TIME IN HOURS =	1199.10	76.00	74.20	67.40	317.60	336.30	357.00	106.70	108.30	108.40
PARAMETER VALUE =	-0.102D-01	-0.109D-01	-0.109D-01	-0.109D-01	-0.102D-01	-0.102D-01	-0.102D-01	-0.102D-01	-0.102D-01	-0.102D-01

APPENDIX 3

Computer Calculated Rupture Strengths of Sandvik Sanicro 31 Tubing
Derived from Larson-Miller Parameter
using a Constant of C = 20 with the Michigan Data

PARAMETRIC ANALYSIS OF STRESS-RUPTURE DATA, BY THE UNIVERSITY OF MICHIGAN HIGH TEMPERATURE METALLURGY GROUP. THIS IS COPY 2 OF 4.

ANALYSIS FOR: GULF GENERAL ATOMIC INC 800

RANGES OF THE 30 ORIGINAL DATA ANALYZED:	LOWEST	HIGHEST
STRESS (KSI)	6.00	12.00
TIME (HR)	27.7	1448.
TEMPERATURE (DEG. F)	1400.	1600.
PARAMETER VALUE	0.411D 05	0.454D 05

NOTE THAT FOR THE ANALYSIS OF THESE DATA, THE FOLLOWING FORCED-FIT SET OF CONSTANTS WAS SPECIFIED:
STRESS EXPONENT Q = 0.0, TEMPERATURE EXPONENT R =-1.0, TEMPERATURE INTERCEPT T(A) = -460.0, LOG TIME INTERCEPT Y(A) = -20.000000

MULTIPLE POLYNOMIAL REGRESSION FOR POLYNOMIALS FROM ORDER 1 TO 6, USING DOUBLE-PRECISION (64-BIT WORD SIZE) ARITHMETIC PRODUCED THE FOLLOWING STANDARD DEVIATIONS FOR EACH ORDER OF POLYNOMIAL OF THE FORM LOG(STRESS IN KSI)=FUNCTION(PARAMETER) INVESTIGATED:

WHERE A STD. DEVIATION OF 10.0 MEANS NEAR SINGULAR MATRIX	ORDER OF POLYNOMIAL =	1	2	3	4	5	6
	STANDARD DEVIATION =	0.0125550	0.0108606	0.0108205	0.0102476	0.0104796	0.0105188

AND USING THE SMALLEST STANDARD DEVIATION AS THE CRITERION FOR 'BEST,' THE ENTIRE 'BEST' EQUATION IS GIVEN BELOW:

LOG OF STRESS IN KSI=(0.1109D 05) +(-0.1026D 04)|P| +(0.3558D 02)|P|^2 +(-0.5482D 00)|P|^3 +(0.3166D-02)|P|^4 +(0.0)|P|^5 +(0.0)|P|^6

(WHERE P, AS LARSON PARAMETER, IS DIVIDED BY 1000.)

USING THE ABOVE EQUATION, THE FOLLOWING TABLE OF STRESSES TO PRODUCE RUPTURE AT THE SPECIFIED TIMES AND TEMPERATURES WAS CALCULATED. NOTE THAT A STRESS OF ZERO INDICATES THAT THE CALCULATED STRESS WAS OUT OF THE RANGE OF THE ORIGINAL DATA ANALYZED.

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.424	9.102	7.348	0.0
1000.	0.0	0.0	0.0	0.0	0.0	0.0	10.992	9.545	7.831	6.179	0.0	0.0
10000.	0.0	0.0	0.0	0.0	0.0	10.165	8.629	6.702	0.0	0.0	0.0	0.0
100000.	0.0	0.0	0.0	11.238	9.581	7.713	6.040	0.0	0.0	0.0	0.0	0.0

USING THE CONSTANTS LISTED ABOVE, THE FOLLOWING PARAMETER VALUES WERE CALCULATED FOR THE TIMES AND TEMPERATURES INDICATED:

TIME IN HOURS	T 1050.	E 1100.	M 1150.	P 1200.	E 1250.	R 1300.	A 1350.	T 1400.	U 1450.	R 1500.	E 1550.	S 1600.
100.	0.332D 05	0.343D 05	0.354D 05	0.365D 05	0.376D 05	0.387D 05	0.398D 05	0.409D 05	0.420D 05	0.431D 05	0.442D 05	0.453D 05
1000.	0.347D 05	0.359D 05	0.370D 05	0.382D 05	0.393D 05	0.405D 05	0.416D 05	0.428D 05	0.439D 05	0.451D 05	0.462D 05	0.474D 05
10000.	0.362D 05	0.374D 05	0.386D 05	0.398D 05	0.410D 05	0.422D 05	0.434D 05	0.446D 05	0.458D 05	0.470D 05	0.482D 05	0.494D 05
100000.	0.377D 05	0.390D 05	0.402D 05	0.415D 05	0.427D 05	0.440D 05	0.452D 05	0.465D 05	0.477D 05	0.490D 05	0.502D 05	0.515D 05

THE ORIGINAL DATA USED FOR THE ABOVE ANALYSES FOLLOWS:

TEMPERATURE, DEG F =	1400.	1400.	1400.	1400.	1400.	1400.	1450.	1450.	1450.	1450.
STRESS IN KSI =	12.000	12.000	12.000	10.000	10.000	10.000	10.000	10.000	10.000	8.000
LOG OF KSI STRESS =	1.0792	1.0792	1.0792	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9031
TIME IN HOURS =	122.00	171.80	162.10	543.40	566.40	521.70	226.50	185.80	182.10	866.40
PARAMETER VALUE =	0.411D 05	0.414D 05	0.413D 05	0.423D 05	0.423D 05	0.423D 05	0.427D 05	0.425D 05	0.425D 05	0.438D 05

TEMPERATURE, DEG F =	1450.	1450.	1500.	1500.	1500.	1500.	1500.	1500.	1500.	1500.
STRESS IN KSI =	8.000	8.000	10.000	10.000	10.000	8.000	8.000	8.000	6.000	6.000
LOG OF KSI STRESS =	0.9031	0.9031	1.0000	1.0000	1.0000	0.9031	0.9031	0.9031	0.7782	0.7782
TIME IN HOURS =	755.20	784.80	54.20	31.60	27.70	210.00	251.40	190.50	1448.10	1118.90
PARAMETER VALUE =	0.437D 05	0.437D 05	0.426D 05	0.421D 05	0.420D 05	0.438D 05	0.439D 05	0.437D 05	0.454D 05	0.452D 05

TEMPERATURE, DEG F =	1500.	1550.	1550.	1550.	1550.	1550.	1550.	1600.	1600.	1600.
STRESS IN KSI =	6.000	8.000	8.000	8.000	6.000	6.000	6.000	6.000	6.000	6.000
LOG OF KSI STRESS =	0.7782	0.9031	0.9031	0.9031	0.7782	0.7782	0.7782	0.7782	0.7782	0.7782
TIME IN HOURS =	1199.10	76.00	74.20	67.40	317.60	336.30	357.00	106.70	108.30	108.40
PARAMETER VALUE =	0.452D 05	0.440D 05	0.440D 05	0.439D 05	0.452D 05	0.453D 05	0.453D 05	0.454D 05	0.454D 05	0.454D 05

2
1
0
9
8
7
6
5
4
3

Table 1

RUPTURE-TEST DATA FOR SANDVIK SANICRO 31 TUBING

Spec. No.	Test Temp., (°F)	Stress (psi)	Estimated Approximate Rupture Time (hours)	Rupture Time (hours)	Elong. (%)	R. A. (%)
34	1400	12,000	250	122.0	50.5	61.5
20	1400	12,000	250	162.1	51	54.5
25	1400	12,000	250	171.8	50	66
26	1400	10,000	660	521.7	34	27.5
1	1400	10,000	660	543.4	37.5	45.5
41	1400	10,000	660	566.4	44	44.5
21	1450	10,000	200	182.1	71	50
31	1450	10,000	200	185.8	26*	38.5*
28	1450	10,000	200	226.5	50.5	54.5
3	1450	8,000	660	755.2	43.5	38
4	1450	8,000	660	748.2	38.5	38.5
19	1450	8,000	660	866.4	37.5	38.2
18	1500	10,000	60	27.7	53	55.5
17	1500	10,000	60	31.6	51.5	56.5
33	1500	10,000	60	54.2	49.5	48.5
16	1500	8,000	200	190.5	36.5*	45*
23	1500	8,000	200	210.5	66	43
27	1500	8,000	200	251.4	50	45
9	1500	6,000	900	1118.9	26.5	34
40	1500	6,000	900	1199.1	31.5	30
2	1500	6,000	900	1448.1	29	27
7	1550	8,000	60	67.4	41.5	43
29	1550	8,000	60	74.2	47.5	45
30	1550	8,000	60	76.0	34	36
22	1550	6,000	300	317.6	30	32.5
15	1550	6,000	300	336.3	29	36.5
35	1550	6,000	300	357.0	36	35.5
24	1600	6,000	80	106.7	43.5	31.5
12	1600	6,000	80	108.3	39	34.5
10	1600	6,000	80	108.4	34	31.5

* Fractured at the end of the gage length.

Figure 1

COMPARATIVE STRESS-RUPTURE TIME DATA FOR SANDVIK SANICRO 31 TUBING

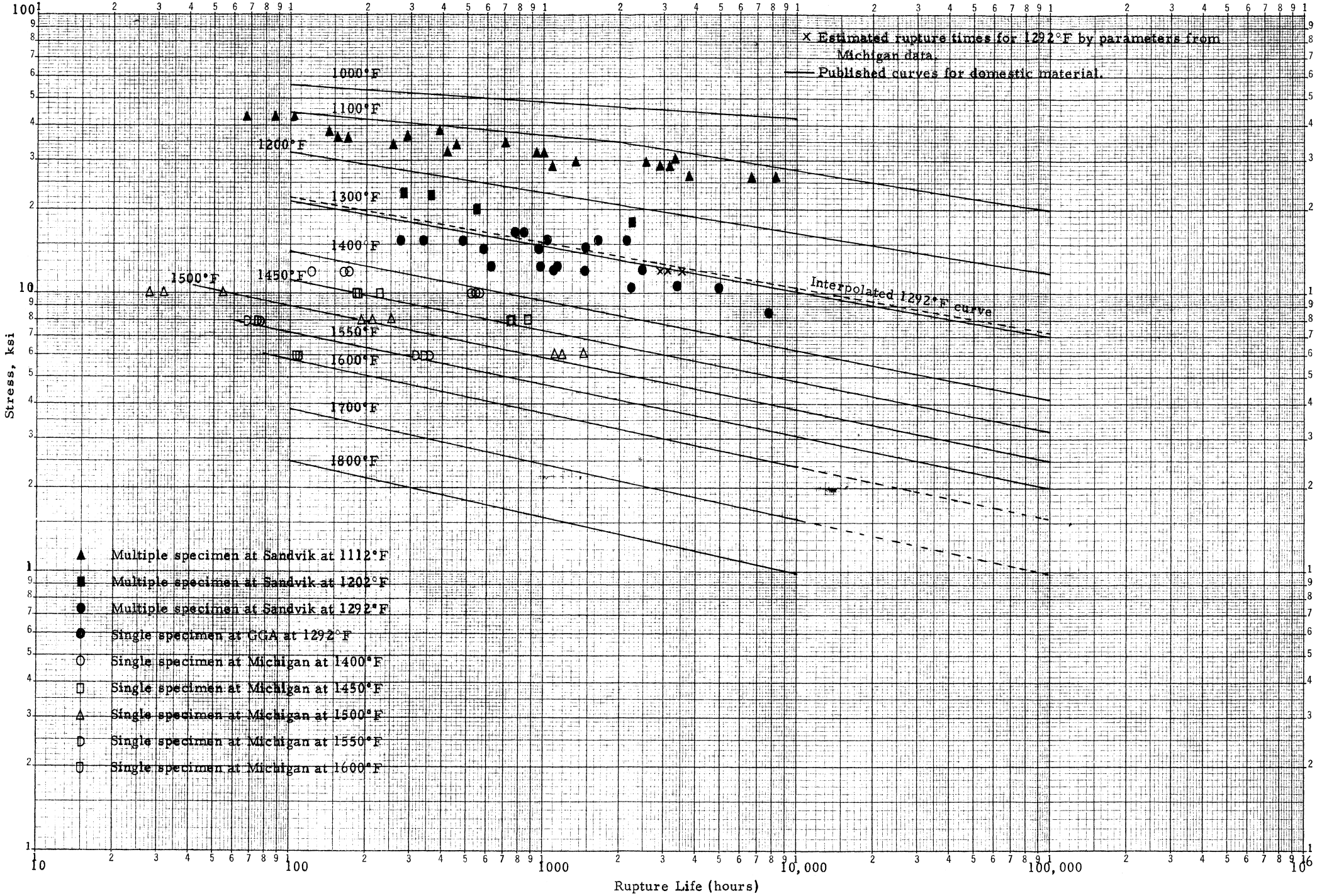

Figure 2

STRESS-PARAMETER DATA FOR SANDVIK SANICRO 31 TUBING
MANSON-HAFERD PARAMETER ("LINEAR")

Temperature Intercept, T_A = 550

Time Intercept, Y_A = 12.74

Standard Deviation = 0.077

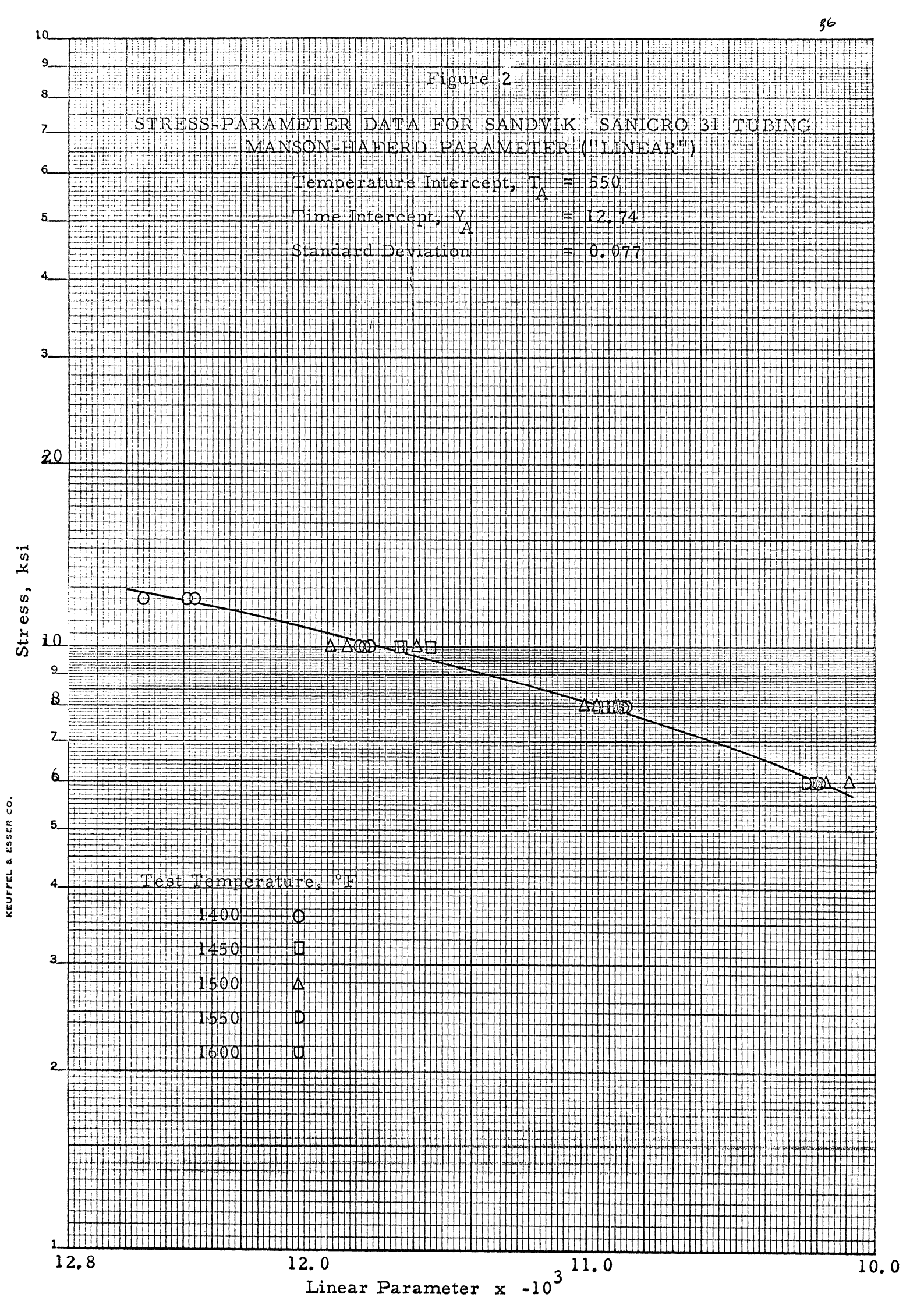

Figure 3

OPTIMIZED CONSTANT

STRESS-PARAMETER DATA FOR SANDVIK SANICRO 31 TUBING

LARSON-MILLER PARAMETER

Time Intercept, Y_A = -18.74

i.e., Parameter "Constant" = 18.74

Standard Deviation = 0.078

Solid Line - Computer-fitted curve

Dotted Line - Hand-fitted curve

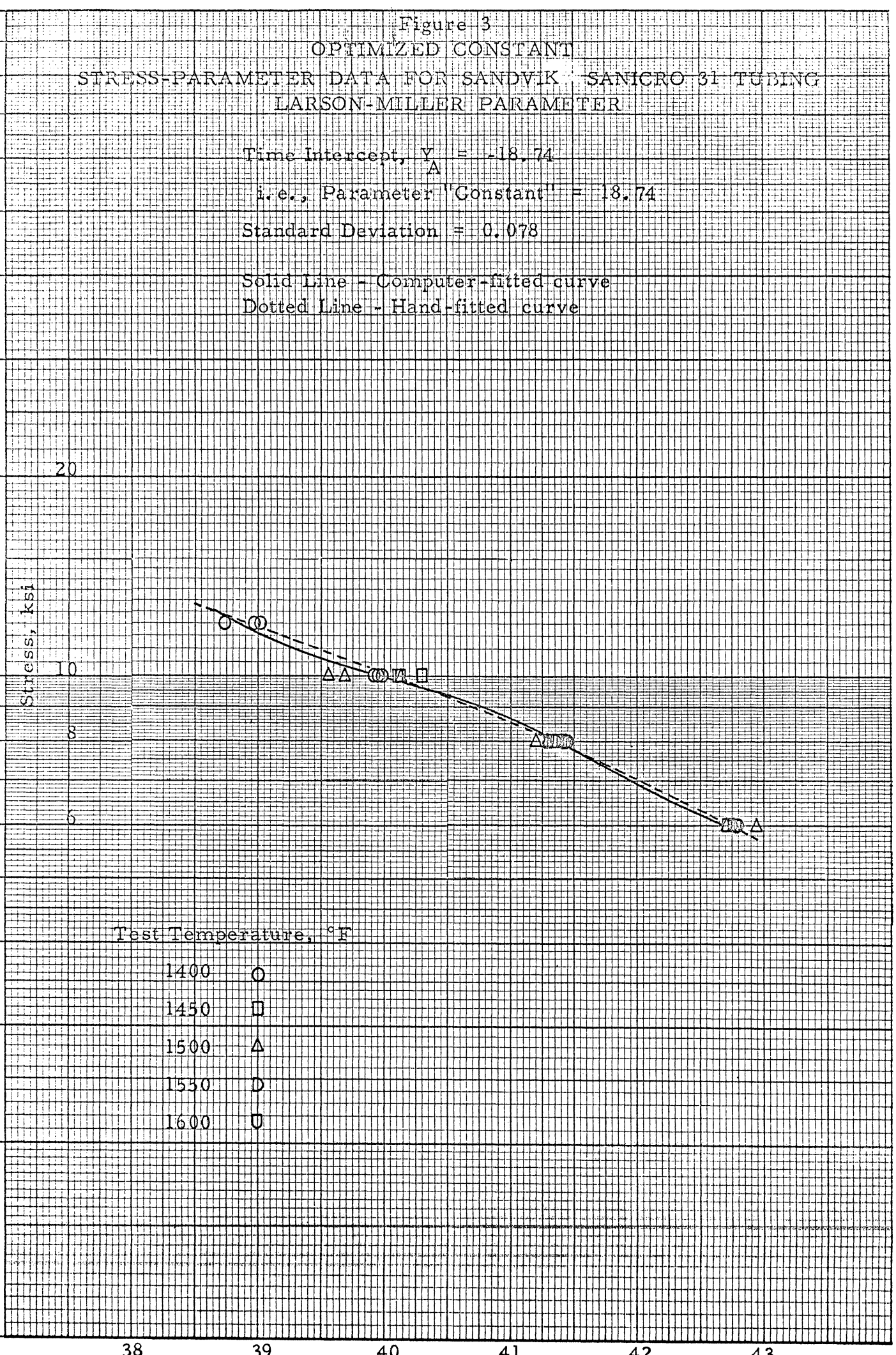

Figure 4

PARAMETER CONSTANT = 20.0

STRESS-PARAMETER DATA FOR SANDVIK SANICRO 31 TUBING

LARSON-MILLER PARAMETER

Time Intercept, Y_A = -20

i.e., Parameter "Constant" = 20

Solid Line - Computer-fitted curve

Dotted Line - Hand-fitted curve