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FIFTH PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

NOTCH SENSITIVITY OF STRUCTURAL ALLOYS

by

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INTRODUCTION

This research had its beginning under Contract AF 18(600)-62 as a search for factors which influence the rupture life of notched specimens tested under steady tension load at elevated temperatures. Analysis of the problem suggested that the prime factor in the observed different response of different materials to a stress concentration is the relative ability of the alloy to relax the initial stress peak before a major portion of the available rupture life is used up. Tests showed that under some conditions an important modifying effect is a pronounced reduction of the subsequent rupture strength after the metal is prestrained to an extent comparable to that which occurs near the root of a sharp notch during load application.

The current contract, AF 33(616)-3380 sought to verify and extend the indications found in the early work and to clarify questions left unanswered, particularly as to the role of ductility in notched-bar behavior. A tentative method developed in the early work for predicting notched bar behavior from smooth-bar data was to be subjected to critical evaluation and efforts made to generalize the proposed analysis for variable complex stresses other than those to be found around notches.

Additional aspects introduced for investigation under the current supplement to the contract involve the influence of trace-element content and of fabrication processes on the notch sensitivity of heat-resistant alloys.

Earlier experiments surveyed notch-rupture behavior of a variety of materials ranging from an aluminum alloy to heat-resistant turbine alloys. However, research with the original materials was qualitative in nature, without complete evaluation of smooth-bar behavior under all types of stress-strain history to be found in notched rupture specimens.

The present phase of the investigation seeks to remedy this situation through extensive work on a single alloy. A-286 alloy was selected in the expectation that both notch strengthening and notch weakening should be obtainable with the same heat of material by merely altering the solution temperature. The particular lot of A-286 obtained for the bulk of this study was 3/4-inch round from a commercial heat (No. 21,030) prepared by the Allegheny-Ludlum Steel Corporation by the vacuum consumable-electrode process. The stock was supplied as finish rolled from 2100°F.

The previous progress report (Ref. 1) included experimental results at 1200°F with this material. Specimen blanks were heat treated by a one-hour solution at a selected temperature, oil quenched, and then aged at 1325°F for 16 hours, air cooled. Preliminary survey tests covered solution temperatures between 1650° and 2300°F. Unnotched specimens tested at 60-70,000 psi stress exhibited a maximum in rupture life for solution temperatures of 2000 - 2100°F. Ductility in the rupture test showed a steady decline with increasing solution up to 2200°F and then rose again.

For more detailed research, solution temperatures of 1800° and 2200°F were selected as giving roughly comparable smooth-specimen lives but quite different elongations. The 2200°F solution temperature was realized to result in a coarse grain size but was chosen to give material with low rupture ductility. Initial tests results reported in Reference 1 for notched bars with K_t's of 1.27, 1.54, 1.8, 3.0, 4.1, 5.7 to 6.0 and 10 will be combined here with new data obtained through 30 September, 1957 to show the current status.

The present report also covers experiments on other lots of A-286 added to the program in an effort to locate a heat of this material which is more prone to notch weakening than is Heat 21,030.

CURRENT STATUS OF THE INVESTIGATION

When technical aspects of the project were reviewed in August, 1957, representatives of the University of Michigan and WADC agreed to pursue several experimental studies simultaneously:

1) Continue to round out the comparative properties at 1200°F for notched and unnotched specimens of A-286 Heat 21,030 solution treated at 1800° and at 2200°F.

2) Evaluate the notch sensitivity at 1200°F of A-286 stock transferred by WADC from a former research at the General Electric Company (Heat No. 52,853).

3) Prepare boron-free A-286 in the vacuum melting furnace at the University and compare notch sensitivity with that for commercial heats containing boron.

The size and possible non-homogeneity of the material under items (2) and (3) was such as to make re-rolling appropriate. The opportunity thereby arose to investigate rolling temperature as one fabrication variable.

Evaluation of Heat 21,030 on A-286 Alloy

Incomplete results available at the time Reference 1 was prepared suggested that notch weakening might result in longer time tests at 1200°F. Moreover, for the dullest notches employed (K_t = 1.27 and 1.54) a nominal stress of 55,000 psi or lower would eliminate plastic strain at the notch root during load application, thereby demonstrating whether such plastic strain was necessary to notch strengthening. Much of the experimentation during the past quarter has involved long-time tests to meet and answer questions on these two points.

As of the end of September, constant-load rupture tests were still in progress with both notched and unnotched specimens. The first of a series of tests have also been scheduled wherein the stress level will be changed during the test to learn how closely the life-fraction rules for creep rupture under variable stress apply to the present notched-bar test conditions. All results available to date for specimens solution treated at 1800° or at 2200°F are assembled in Table 1 for convenient reference. Figures 1 and 2 show tentative curves for the completed tests.

For both solution temperatures the elongation at rupture exhibits a four-fold decline as test duration increases from about 1 to about 1000 hours. At least for the 1800°F solution treatment and perhaps for the higher solution temperature as well, notch-bar life increases with notch acuity to about a K_t of 1.5 - 2 and then falls off for sharper notches, with indications of notch weakening for very sharp notches. The situation is not clear with respect to rather dull notches (K_t = 1.27 and 1.54) for the material heat treated at 2200°F. The very coarse grain (ASTM No. 1 or larger) for this treatment may have been accompanied by unusual data scatter. Alternately, a manifestation of a change in failure mechanism may be exhibited by the trend of the data obtained to date. Repeat tests at 70,000 and 60,000 psi are in progress for K_t = 1.27, while additional tests for K_t 1.27 and 1.54 are planned to extend the range of nominal stress beyond the present narrow limits.

These and other notched-specimen tests scheduled to be started in October are expected to satisfactorily establish the rupture-life trends for A-286 with either 1800° or 2200°F solution temperature.

<u>Initial Tests with Heat 52,853 of A-286 Alloy</u>

Research on this material has been reported by Sakamoto (Ref. 2). In that work, the alloy was forged from 2000°F, with a finishing temperature of approximately 1500°F. Tests on specimens with the following heat treatment suggested borderline notch weakening at 1100°F for a notch with K_t = 3.4 :

2150°F, 2 hr, O.Q. +
1650°F, 2 hr, O.Q. +
1300°F, 16 hr, A.C. +
1200°F, 16 hr, A.C.
(Grain Size 1-2).

Survey tests have been started to determine whether this lot of alloy might be more prone to notch sensitivity than was Heat 21,030 under comparable conditions. Three portions of the 4.5-inch diameter round transferred from the research of Reference 2 were re-rolled to 1/2-inch square stock at the University of Michigan, with the final 50% reduction from 2100°, 1950° and 1800°F, respectively, for the three portions.

Specimen blanks were solution treated one hour at 1800°F, oil quenched + aged at 1325°F, 16 hr, air cooled. Available results listed in Table 2 suggest borderline notch sensitivity at $K_t = 4.1$ for all three rolling temperatures, with possible slight influence from rolling temperature. A single pair of results at 55,000 psi indicate weakening from notches at lower nominal stresses.

Further testing is planned to include the effect of using a higher solution temperature with this heat of alloy.

Preparation of boron-free A-286

Attempts were made to prepare boron-free material with aim composition for major elements the same as is present in A-286 Heat 21,030. A pouring accident resulted in loss of most of the first experimental melt (Heat R-18) prepared in the University of Michigan research vacuum induction furnace. The second attempt (Heat UM-1177) produced a normal 8-lb. experimental ingot. The ingot from Heat UM-1177 was rolled to 1/2-inch square stock, with initial break-down at 2100°F and the final 50% reduction from 2100°F in seven passes without reheat.

Samples have been sent out for chemical analysis and both smooth and notched specimens prepared for preliminary evaluation of comparative rupture properties at 1200°F.

The part ingot from melt R-18 was rolled from 1800°F after initial break-down at 2150°F. A few specimens are scheduled for testing at 1200°F to help determine whether rolling-temperature effects vary between materials with differing levels of boron content.

FUTURE WORK

The first priority in planned further testing has been given to checking the smooth-bar creep-rupture properties at 1200°F of A-286 Heat 21,030 when the load is increased or decreased during the test. As soon as satisfactory smooth-bar properties are in hand, calculations can be made of expected life for notched specimens under conditions which are being used experimentally. By the time the predicted lives are computed, the actual experimental results should be ready for comparison with the predicted values.

Meanwhile, tests can progress with the other lots of A-286 in search of conditions producing greater notch sensitivity. Effort is also expected to be applied to find a way to evaluate the role of ductility in notched-bar rupture behavior.

BIBLIOGRAPHY

1. H. R. Voorhees and J. W. Freeman, Fourth Progress Report to Materials Laboratory, Wright Air Development Center on Notch Sensitivity of Structural Alloys," (Contract AF 33(616)-3380), June 30, 1957.

2. Richard Sakamoto, "Effects of Processing Variables on Fractured and Disk-Bursting Characteristics of Four High Temperature Materials," WADC TR 57-154, May 1957.

TABLE 1

RUPTURE-TEST RESULTS AT 1200°F FOR A-286 SPECIMENS

SOLUTION TREATED AT 1800° OR 2200°F

(Heat No. 21,030)

Heat Treatment: 1 hr solution, Oil Quench + 16 hr Age at 1325°F, Air Cool

Unnotched Specimens

Stress (psi)	Rupture Life (hours)	Elongation at Rupture (%)	Reduction of Area (%)
	1800°F Solution Temperature		
112,000	(Short-time tensile strength)	18.	19.
100,000	0.26	17.	18.
90,000	1.45	8.	9.
80,000	4.25	8.	8.5
70,000	14.9	9.5	13.5
70,000	20.3	6.5	8.5
65,000	62.4	5.5	10.5
60,000	79.9	5.	10.
60,000	99.1	7.	8.5
50,000	384.6	6.	8.
45,000	615.5	4.	8.
45,000	771.3	3.	4.5
	2200°F Solution Temperature		
101,500	(Short-time tensile strength)	10.5	12.5
80,000	0.87	4.	7.
75,000	3.8	2.5	5.5
70,000	7.2	1.5	7.
60,000	308.7	1.	2.5
55,000	587.9	1.	2.
50,000	(In Progress; 0.16% creep elongation at 1700 hours)		

TABLE 1 (con'd.)

Notched Specimens

1800°F Solution Temperature Stress (psi)	1800°F Solution Temperature Rupture Life (hours)	2200°F Solution Temperature Stress (psi)	2200°F Solution Temperature Rupture Life (hours)
$K_t = 1.27$			
70,000	22.6	70,000	451.3
70,000	97.2	70,000	(In Progress 476.2 hr)
65,000	241.6	65,000	416.4
60,000	319.3	60,000	417.5
		60,000	(In Progress 400.2 hr)
$K_t = 1.54$			
70,000	215.3	70,000	657.5
65,000	292.3		
60,000	481.3	60,000	568.7
$K_t = 1.82$			
70,000	239.6	70,000	206.3
65,000	366.2	65,000	257.7
60,000	543.4	60,000	1151.1
55,000	994.3	55,000	727.4
$K_t = 3.0$			
70,000	167.5		
		65,000	219.3
		60,000	414.2
$K_t = 4.1$			
70,000	112.8	70,000	14.2
65,000	168.1	65,000	43.5
60,000	227.6	60,000	288.8
$K_t = 5.7 - 6.0$			
70,000	27.3		
65,000	106.7		
*65,000	43.4		
60,000	119.7		
$K_t = 10$			
*70,000	6.5		
*65,000	6.65		
*60,000	11.1		

* Aging step performed after notching operation.

TABLE 2

RESULTS OF SURVEY TESTS AT 1200°F ON A-286 HEAT 52853

Heat Treatment: 1800°F, 1 hr, OQ + 1325°F, 16 hr, AC

Rolling Temp. (°F)	Stress (psi)	Rupture Life (hours)	Elongation at Rupture (%)	Reduction of Area (%)
		Smooth Specimens		
2100	70,000	8.7	7.5	10.
1950	65,000	16.4	6.	7.
1800	65,000	15.5	8.	11.
1950	55,000	125.2	5.5	8.5
		Notched, K_t = 1.27		
2100	70,000	41.8	---	---
1950	70,000	55.5	---	---
1950	65,000	140.5	---	---
1800	65,000	81.1	---	---
1950	60,000	45.6	---	---
		Notched, K_t = 4.1		
2100	70,000	16.0	---	---
1950	65,000	17.4	---	---
1800	65,000	21.8	---	---
1950	55,000	63.8	---	---

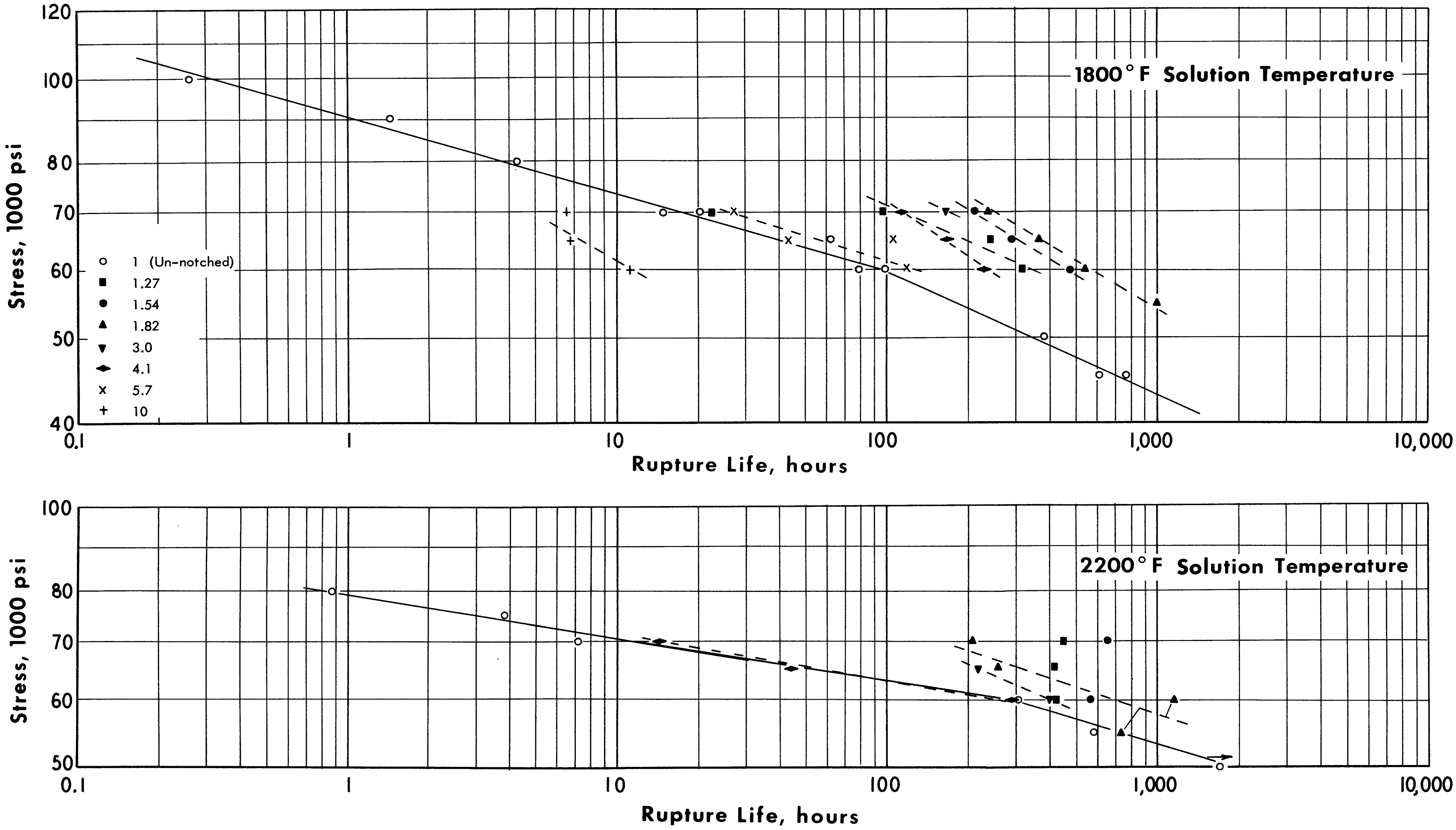

Fig. 1 - Rupture Properties at 1200 °F for Smooth and Notched Specimens of A-286 Heat 21,030.

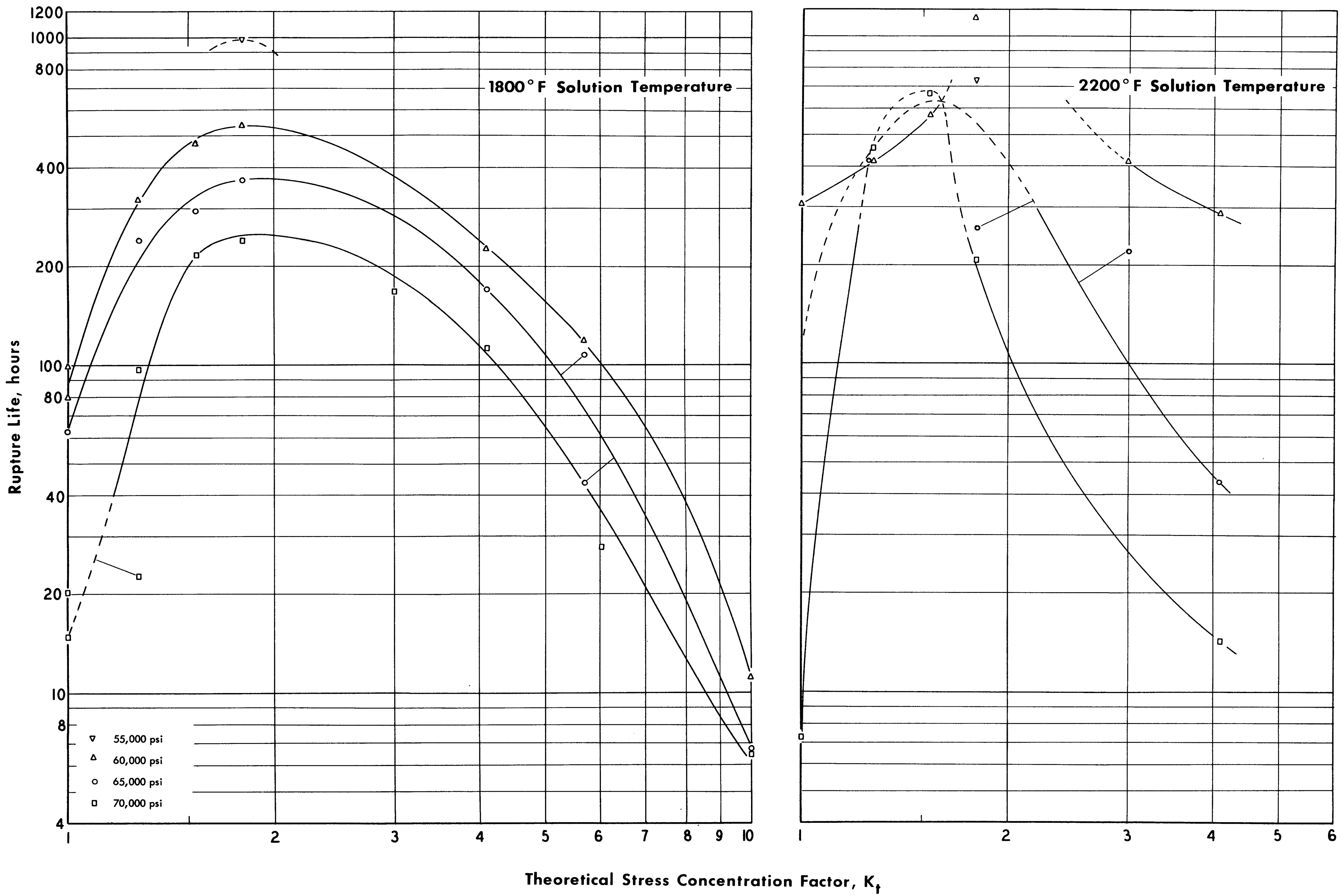

Fig. 2 – Effect of Notch Acuity on Rupture Life at 1200 °F for A-286 Heat 21,030 with 1800° and 2200 °F Solution Temperatures.