ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

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THE INFLUENCE OF SURFACE TREATMENT ON THE FATIGUE PROPERTIES OF TITANIUM AND TITANIUM ALLOYS

By

L. THOMASSEN
M. J. SINNOTT
A. W. DEMMLER, JR.

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SUMMARY

The effects of various types of notches on the fatigue strength of annealed Ti-75A and RC-130B, and a heat treated form of RC-130B have been determined.

The loss in fatigue strength of the annealed Ti-75A notched specimens, as compared to the unnotched, hand finished specimens varies from 0% to 62.5% depending on the type of notch and the fatigue life level.

The loss in fatigue strength of the annealed RC-130B notched specimens, as compared to the unnotched, hand finished specimens, varies from 13.5% to 59.0%, depending on the type of notch and the fatigue life level.

The loss in fatigue strength of the heat-treated RC-130B, water quenched from 1550°F, tempered 2 hours at 700°F, varies from 20.4% to 56.5% depending on the type of notch and the fatigue life level, as compared to the annealed, unnotched specimens.

INTRODUCTION

Previous progress reports and the Summary Report of this Project have presented the results of fatigue testing annealed Ti-75A and RC-130B. Various types of surface treatments were given these alloys to determine their effect on the fatigue properties. The purpose of the present investigation is to determine the effects of different notch types and methods of notch preparation on the fatigue properties of these same alloys. In addition, an all alpha, an all beta, and a heat treated form of RC-130B were to be included in this notch fatigue program.

EXPERIMENTAL PROCEDURE

Sufficient stock of Ti-75A and RC-130B from previous studies of various surface treatments on the unnotched fatigue properties of these alloys was available to enable the preparation of groups of specimens for notch fatigue studies. The analyses and mechanical properties of the alloys being reported are given in Table I.

The work on Ti-75A consisted in testing three types of machined notches: a V-notch, a square-notch, and a radius-notch. As in the work on the unnotched specimens, extreme care was taken in preparing the specimens in order to assure uniformity within any one group. Figure 1 gives sketches of each of the types used. The theoretical notch sensitivity, K, as determined from the literature, is 3.2 for the V-notch, 2.4 for the square-notch, and 1.4 for the radius notch (1)(2).

Because of the multiplicity of the notch types, methods of notch preparation, and alloys to be investigated, the replicate testing used in previous work to obtain statistical information was curtailed. In place of the six specimens tested at each stress level, only three, in most cases, were tested in these notch studies.

The data on Ti-75A notched fatigue specimens are given in Table II and the conventional S-N plots are given in Figure 2. The unnotched data are shown for comparative purposes.

The data on the annealed, notched, RC-130B specimens are given in Table III and the S-N plots are given in Figure 3.

The RC-130B was also tested in a heat treated form. The treatment given the alloy was a water quench from 1550°F followed by a two-hour tempering at 700°F. This treatment produces a 50% alpha-50% beta structure. The annealed RC-130B had a structure of approximately 75% alpha-25% beta phase. This quench and temper treatment was chosen in order to determine the effect of changing the proportions of alpha and beta. Other studies have shown that such a treatment produces properties that are superior to the annealed properties and the fatigue behavior might also be expected to show improvement (3). The data on the fatigue properties of the RC-130B that had been heat treated are given in Table IV and the resulting S-N plots are shown in Figure 4. The radius-notch specimens of this material showed a tendency to fracture in the threaded ends of the test specimens rather than in the notch region so tests on this type of notch with this material were abandoned.

ANALYSIS

Using the mean values of the unnotched fatigue results of previous work, it is possible to compute the actual notch sensitivity or what is usually termed the fatigue strength reduction factor. As a reference standard the surface termed Annealed-Hand Finished was used since this type of surface had been used on various heats of the same nominal analysis in the previous testing program.

Table V lists the mean stress for a stated fatigue life of the standard surfaces as taken from previously reported data, and for the fatigue life as determined for the notched specimens from Figures 2, 3, and 4. Fatigue data on the unnotched, heat treated RC-130B are not available because of the lack of sufficient test material.

Figure 5 is a plot of the fatigue strength reduction factors for each type of notch as a function of the fatigue life, for Ti-75A. Figure 6 is a similar plot for the annealed RC-130B, while Figure 7 is a plot for the heat treated RC-130B as compared to the unnotched, annealed, specimens.

CONCLUSIONS

The notch sensitivity of the titanium alloys tested is generally about the same as that reported for steels (4). The actual sensitivity, as measured by the fatigue strength reduction factors, is somewhat less than the theoretically predicted values.

The radius type of notch does not appear to be effective in reducing the fatigue strength of the Ti-75A to any appreciable extent as compared to the effects of the V-Notch and Square-Notch.

Heat-treating the RC-130B to a 50% alpha-50% beta structure improved the yield and tensile properties but appeared to affect only slightly the notched fatigue properties.

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3. Phillips, C. W. and Tobin, J. C.: "The Phase Transformations and Heat-Treatability of Titanium Base Alloys", Final Report U. S. Army Ordnance Corps, Contract DA-20-018-ORD-11456, June, 1953.

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TABLE I

Analyses and Mechanical Properties

Material	Heat Number	Carbon	Nitrogen	Iron	Tungsten	Hydrogen	Manganese	Aluminum
Ti-75A	M-270	0.04-0.07	0.10	0.20	0.01	0.02-0.05	(Oxygen-0.20)	
RC-130B	B-3413	0.1	0.08				3.9	3.9

Material	Treatment	Proportional Limit, psi	Tensile Strength, psi	Percent Elong. (2")	Percent Red. Area
Ti-75A M-270	Annealed 1450°F	47,900	84,300	27.3	42.0
RC-130B B-3413	Annealed 1450°F	119,000	160,000	18.0	47.0
RC-130B B-3413	W.Q. 1550°F T. 700°F	158,000	186,000	2.8	1.0*

* Fractured in gage marks

TABLE II

Fatigue Data, Notched Rotating Beam
Annealed Ti-75A, Heat M-270

1000 Cycles of Stress

V-Notch	Square Notch	Radius Notch
27,500 psi	27,500 psi	55,000 psi
51	117	31
87	111	34
60	93	38
25,000 psi	22,500 psi	50,000 psi
184	1129	56
642	1902	118
297	1154	59
22,500 psi	20,000 psi	47,500 psi
759	1510	725
536	2812	130
352	1976	186
20,000 psi	17,500 psi	46,250 psi
12000*	14872*	654
609	14119*	5124
1097	10165*	
18,000 psi	15,000 psi	45,000 psi
10939*	22682*	10506*
10663*	21617*	10780*
11122*	14687*	7541
		40,000 psi
		10173*

*Did not fail.

TABLE III

Fatigue Data, Notched Rotating Beam
Annealed RC-130B, Heat B-3413

1000 Cycles of Stress

V-Notch	Square Notch	Radius Notch
55,000 psi	65,000 psi	80,000 psi
19	93	89
38	64	78
35	86	32
50,000 psi	60,000 psi	75,000 psi
58	446	3517
65	192	72
39	3998	33
45,000 psi	57,500 psi	70,000 psi
57	1145	144
139	831	2254
83		2786
42,500 psi	55,000 psi	65,000 psi
80	7699	10500*
10000*	10130*	269
57	10671*	11000*
40,000 psi	45,000 psi	60,000 psi
5084	10445*	12895*
10126*	10000*	11500*
10260*	10545*	

*Did not fail.

TABLE IV

Fatigue Data, Notched Rotating Beam
Heat Treated RC-130B, Heat B 3413

1000 Cycles of Stress

V-Notch	Square Notch
50,000 psi	**70,000 psi**
84	36
83	42
64	27
47,500 psi	**60,000 psi**
150	110
113	108
93	10575*
45,000 psi	**57,500 psi**
1922	107
1766	932
1562	
42,500 psi	**55,000 psi**
16178*	10149*
569	10144*
15679*	10635*
40,000 psi	**50,000 psi**
326	17000*
10953*	17227*
11454*	12070*

* Did not fail.

TABLE V

Stress-Fatigue Life Data

Material and Treatment	10^4	10^5	10^6	10^7
	Cycles			
	Stress, 1000 psi			
Ti-75A Annealed Unnotched	63.0	52.0	48.0	46.5
Ti-75A Machined V-Notch	38.0	27.0	19.5	17.5
Ti-75A Machined Square Notch	42.0	28.5	22.0	18.0
Ti-75A Machined Radius Notch	63.0	50.0	46.5	45.0
RC-130B Annealed Unnotched	110	95.0	92.5	90.0
RC-130B Machined V-Notch	72.0	43.0	38.0	37.5
RC-130B Machined Square Notch	77.5	64.0	56.0	53.0
RC-130B Machined Radius Notch	95.0	76.0	62.5	60.0
Heat Treated RC-130B Machined V-Notch	64.0	48.0	41.5	39.0
Heat Treated RC-130B Machined Square Notch	87.5	60.0	53.5	51.5

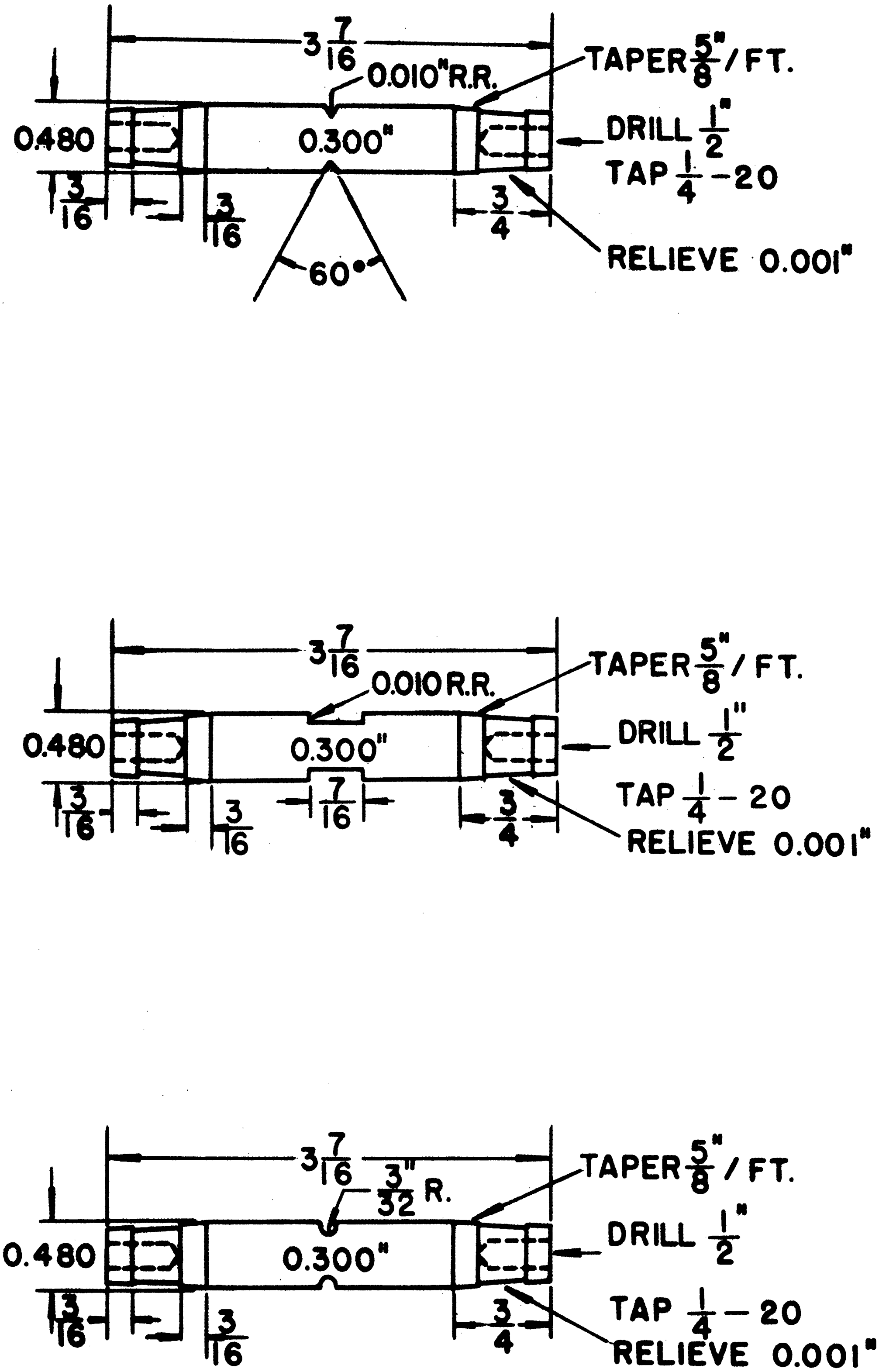

Figure 1. Sketches of Types of Notched Specimens.

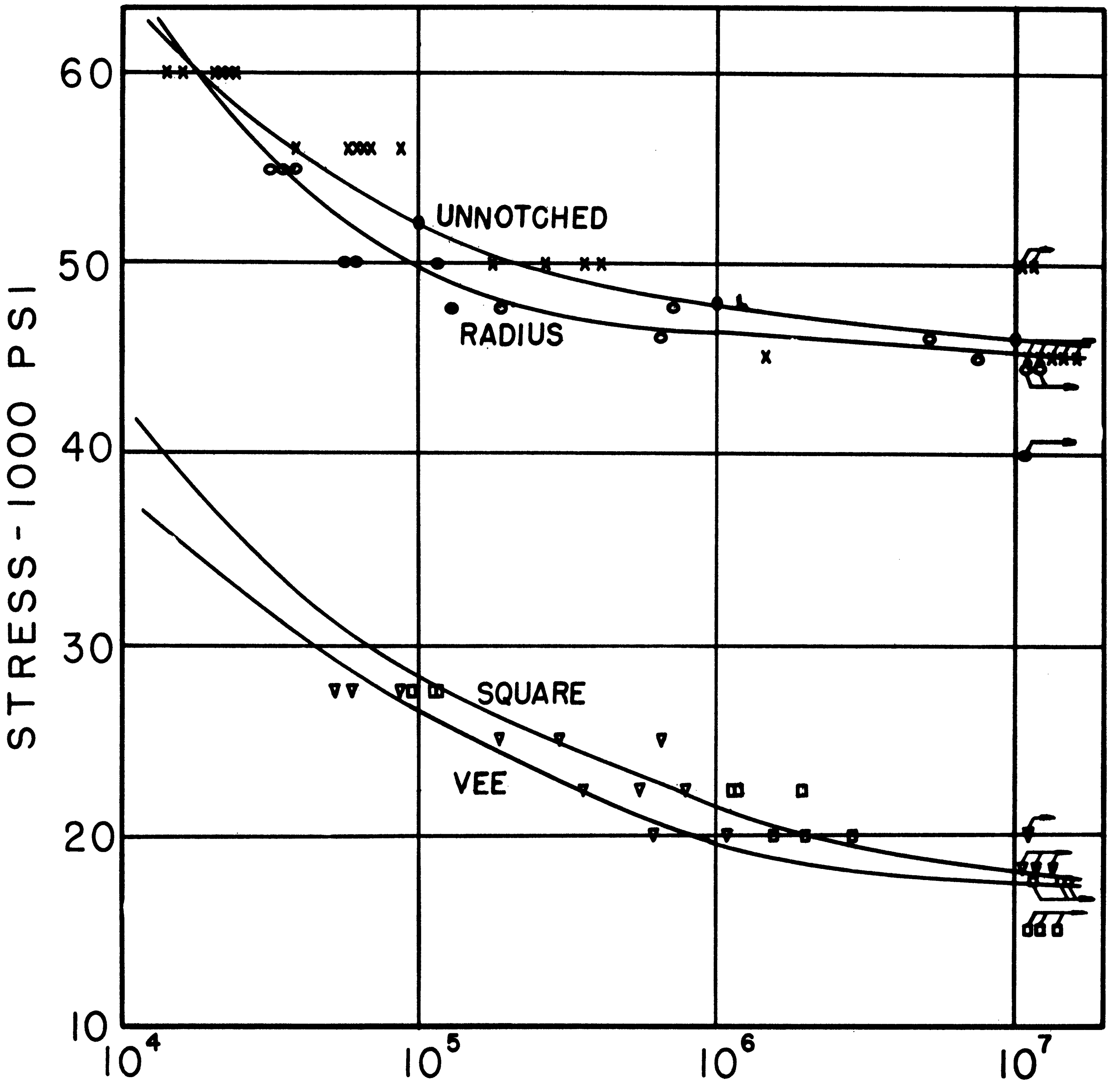

Figure 2. Stress-Cycles of Stress Plots. Un-notched and Notched Specimens. Annealed Ti-75A.

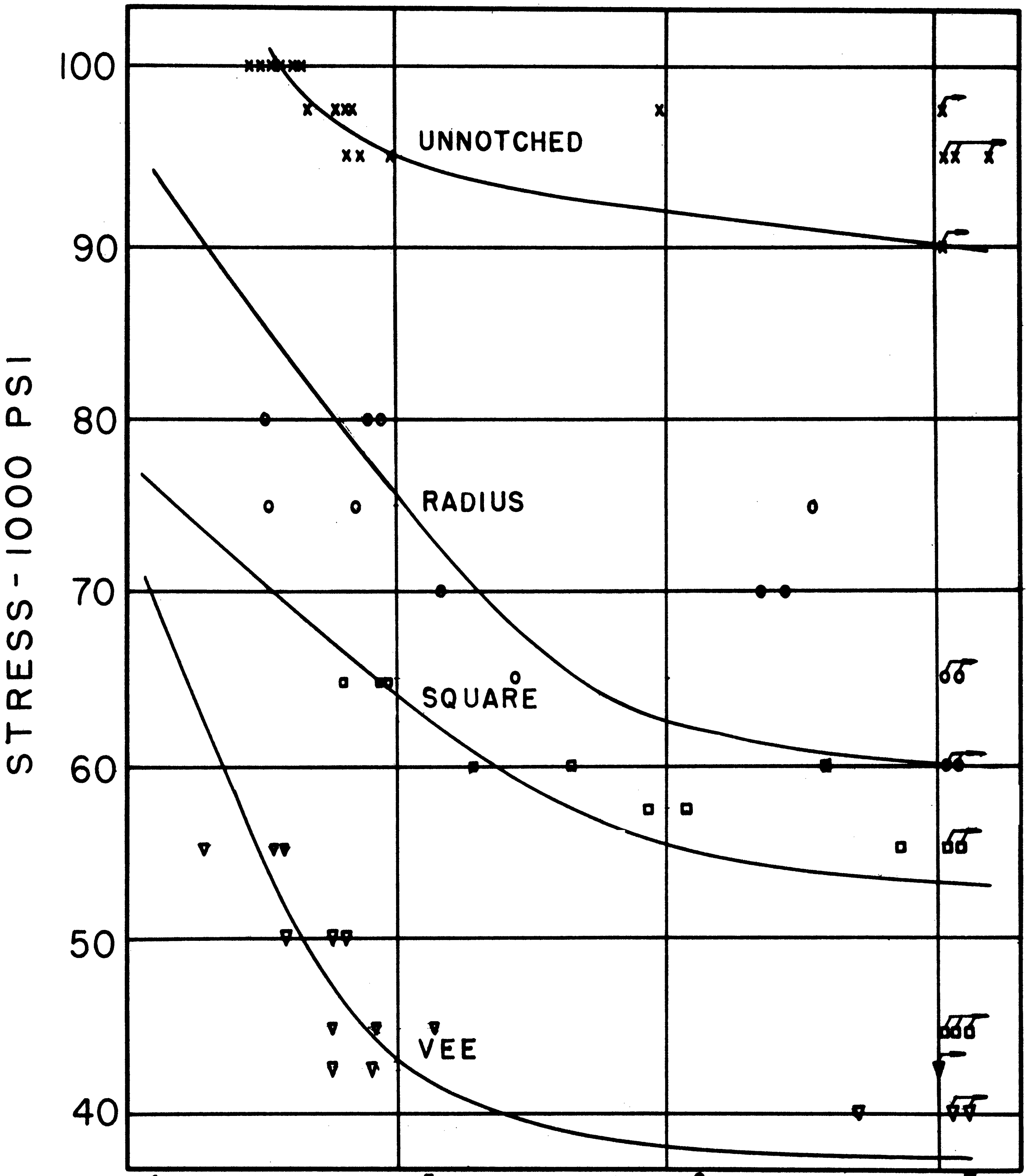

Figure 3. Stress-Cycles of Stress Plots. Un-notched and Notched Specimens. Annealed RC-130B.

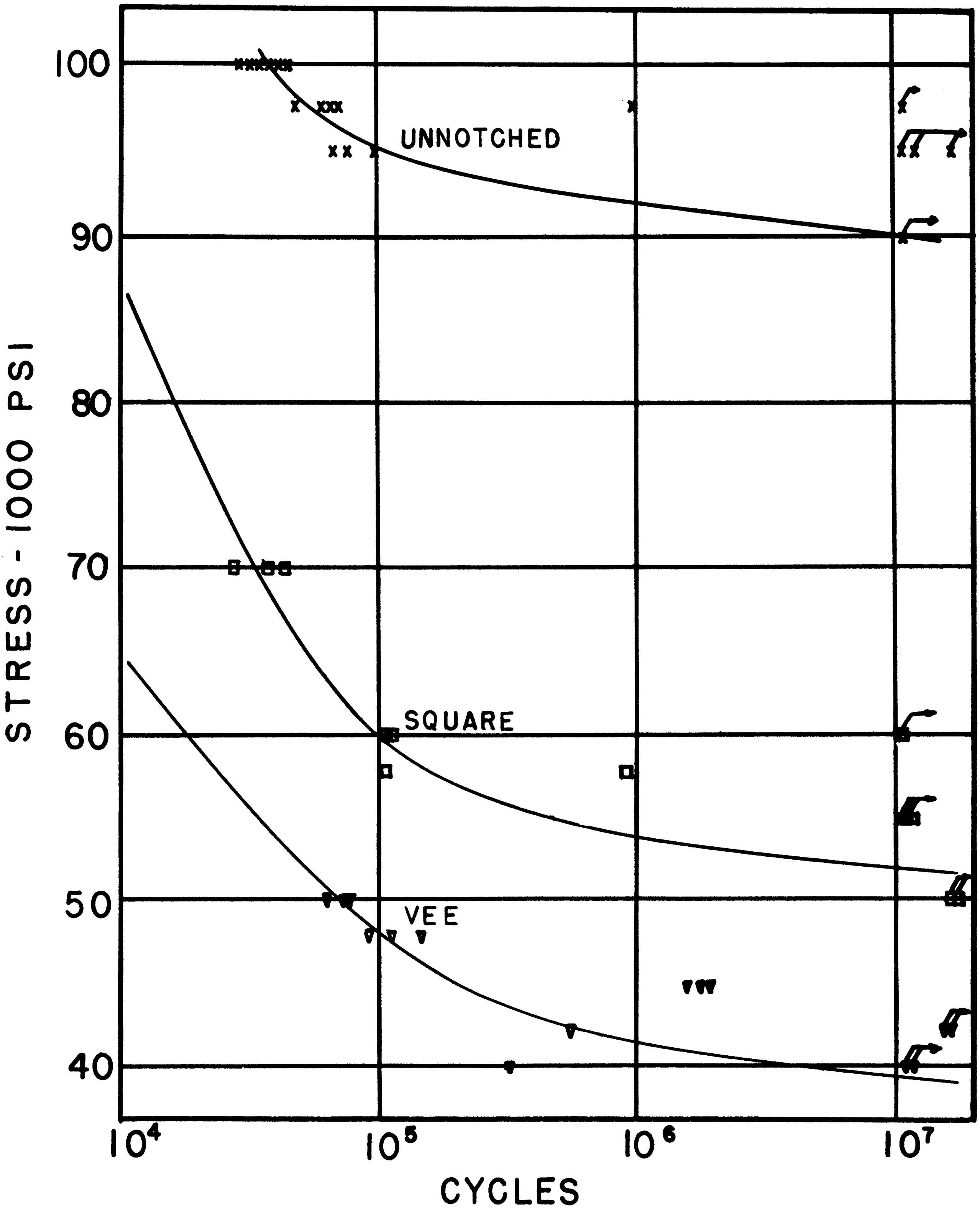

Figure 4. Stress-Cycles of Stress Plots. Annealed, Un-notched and Heat-Treated, Notched RC-130B.

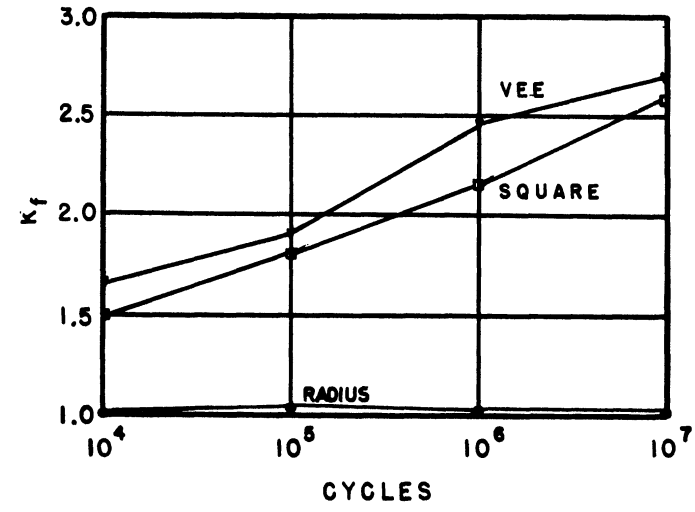

Figure 5. Fatigue Strength Reduction Factors versus Fatigue Life. Annealed Ti-75A.

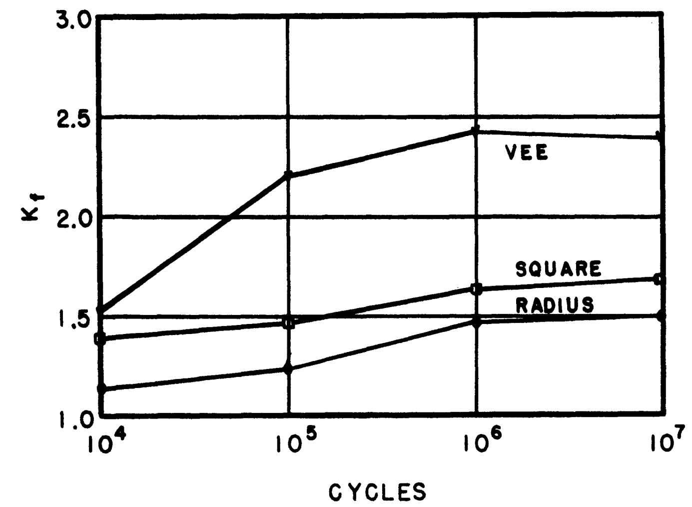

Figure 6. Fatigue Strength Reduction Factors versus Fatigue Life. Annealed RC-130B.

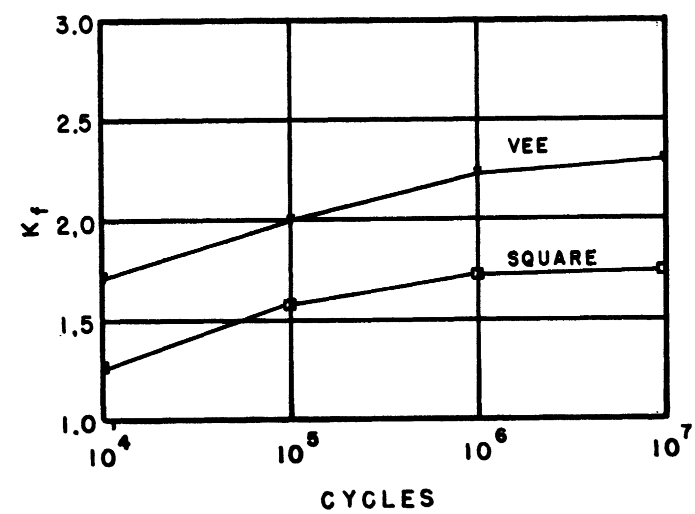

Figure 7. Fatigue Strength Reduction Factors versus Fatigue Life. Heat-Treated RC-130B.