ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROGRESS REPORT NO. 7

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

By

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

Project 2034

WRIGHT AIR DEVELOPMENT CENTER, U. S. AIR FORCE
CONTRACT NO. AF 33(616)-26 SUPPLEMENT S-2(53-582)
E. O. NO. R615-11-SR 3c, PROJECT NO. 53-670A-61

February, 1954

SUMMARY

The effect of surface rolling annealed V-notched specimens of Ti-75A, RC-130B, and A-110AT titanium alloys has been evaluated. In all alloys a very marked increase in fatigue life, as compared to specimens given a machined notch or a ground notch, was obtained.

The effect of grinding a V-notch and a square notch in Ti-75A and V-notches in RC-130B and A-110AT alloys has been evaluated. The fatigue properties of the ground notches were inferior to the properties obtained on the same type of notches that were machined or rolled.

INTRODUCTION

Previous progress reports and the summary report have presented the results of fatigue testing titanium alloys Ti-75A, RC-130B, and A-110AT to determine the influence of various types of surface treatments and notches on the resulting fatigue life characteristics. The present report deals with the fatigue life characteristics of ground notched specimens and rolled notch specimens of these same alloys.

EXPERIMENTAL PROCEDURES

Two of the three alloys used had been previously used in work already reported. The analyses and tensile properties, as determined after a one-half hour anneal in argon at 1450°F, are given in Table I. Also included are the properties of a new heat of RC-130B that was used in this work.

Since the previous work on the influence of surface conditions on the fatigue properties of these alloys had shown that the method used to prepare the surface had, in some cases, a pronounced effect on the resulting fatigue life the work on the notch fatigue strength properties was planned to evaluate the effect of the method of notch preparation. The previous progress report (No. 6) gave the fatigue properties of machined notches. The present report presents results of notches prepared by grinding and surface rolling.

The ground notches were prepared by machining the specimens to size except for the tapers and the notch proper. These regions were left 0.007 inch oversize. The specimens were then annealed in argon for one-half hour at 1450°F to remove the effects of the prior machining. The tapers were then ground to finish size and the unfinished notches were forwarded to Dawson Carbide Industries of Detroit, Michigan, for the diamond grinding of the notches to the finish dimensions. This diamond grinding procedure was found to be necessary since it was impossible to grind the notches to a controlled root radius of 0.010 inch, using the conventional alundum or silicon carbide types of grinding wheels. The wear and fracture, particularly the fracture, of these wheels was excessive and gave poor root radii and surface finish. The diamond grinding gave excellent results. The root radius was held exactly to dimension and an excellent surface was obtained. Diamond grinding from the oversize diameter to the finished size was done in steps of 0.002 to 0.003 inch.

Since shot peening the surface of specimens improved the fatigue life properties it was believed that a thread rolling type of operation, if used on the V-notch specimens, might improve the notch fatigue properties by cold working the surface layers of the notch in somewhat the same fashion that the shot peening works the surface of a metal.

Notch rolling was accomplished by machining the specimens to size except for the notch which was made 0.005 inch oversize. The specimens were then annealed for one-half hour in argon at 1450°F to remove the effects of the machining. The notches of the specimens were then rolled by adapting a pipe cutting tool in such a fashion that the cutting wheel which had been remade, hardened, ground, and polished, rolled the material to the finished notch size with a root radius of 0.010 inch. It was found that 0.005 inch could be reduced on Ti-75A and yield a good surface in the root radius. The surface on the RC-130B and A-110AT alloy was not as good as that obtained on the Ti-75A, in that it tended to be rough, although the root radii were on dimension.

The first tests on Ti-75A specimens of the rolled notch type showed that such a treatment very markedly increased the fatigue strength. It raised the strength to such a level that the capacity of the testing machines was exceeded. This necessitated the redesign of the test specimen. The notch diameter was decreased to 0. 250 inch in place of the previous 0. 300 inch. The outside diameter was decreased from 0. 480 inch to 0. 400 inch. The theoretical notch sensitivity is not particularly sensitive to these changes and is more dependent on the root radius which was held at the original value of 0. 010 inch. The notch sensitivity of these new type specimens is on the order of 2. 7 to 2. 9 versus the value of 3. 2 of the previously used notches.

The actual fatigue data on the various alloys are presented in Tables II and III. The lack of sufficient stock prevented the use of extensive replicate testing; generally duplicate or triplicate specimens were tested at each stress level for each alloy.

SUMMARY AND DISCUSSION

The stress-cycles of stress plots constructed from the data of Tables II and III are given in Figures 1 and 2. Table IV is the estimated mean fatigue life data taken from these plots.

Figure 3 is a plot of the fatigue strength reduction factor, the ratio of the fatigue life of the hand finished unnotched specimens to the fatigue life of the notched specimens, as a function of fatigue life.

It is apparent from these data that a rolling operation very markedly improves the fatigue life properties. The notch effect is completely obliterated and the fatigue properties are superior to those chosen as the standard, the annealed hand finished surfaces. The amount of reduction given during rolling was quite small, on the order of 4.0%, but this was sufficient to give the improvement noted. It is questionable whether still further reduction would give a correspondingly greater increase. This evidence seems to confirm the conclusions drawn from the data on the shot-peened surfaces, i.e., the improvement is due to residual compressive stresses and surface and sub-surface working of the metal. The large scatter noticeable in the data on the RC-130B and A-110AT alloy may be traceable to the non-homogeneity of the working operation.

An interesting development occurred in testing these rolled notches. The specimens of all the alloys showed no tendency to heat internally to any appreciable extent but the notch radius of the Ti-75A was noticeably oxidized at the conclusion of testing and some tendency for oxidation was observed in the notches of the RC-130B and A-110AT alloy. It is believed that the rolling operation changed the internal friction characteristics of the material to such an extent in these areas that localized overheating of the surfaces occurred. In spite of the overheating, however, the fatigue life properties still showed an improvement over the unnotched surface properties.

The diamond grinding was not as severe a grinding operation as has been performed on the specimens that had been surface ground. It was anticipated that such grinding would not adversely affect the properties. The results indicate that generally this is true but that the ground notches tend to have slightly higher fatigue reduction factors indicating a slightly greater notch sensitivity. In view of the fact that the grinding gives such similar results to the machined notches, further work on ground notches is being discontinued.

FUTURE WORK

A heat of an all beta alloy (30% Mo) has been received and work is proceeding on evaluating this alloy under the conditions used in testing the previous alloys. An all alpha alloy (6% Al) ordered at the same time as the all beta alloy has not yet been delivered. Unless receipt is obtained shortly, the work on this alloy will not be completed at the termination of the project.

The effect of annealing at various temperatures a ground surface of Ti-75A is being investigated to determine if such a procedure will produce a recovery in fatigue life.

TABLE I

Analyses and Mechanical Properties*

Ti-75A	Heat M-270	C-0.055%; N-0.10%; Fe-0.20%; W-0.01%
RC-130B	Heat B-5331	C-0.1%; N-0.04%; Mn-4.4%; Al-3.9%
A-110AT	Heat R-31314	C-0.1%; N-0.05%; Al-4.13%; Sn-2.58%

	Prop. Limit psi	Tens. Str. psi	% Elong. 2"	% Red. in Area
Ti-75A	47,900	84,300	27.3	42.0
RC-130B	138,000	148,000	18.7	46.0
A-110AT	124,000	138,100	16.0	40.0

*Duplicate Specimens

TABLE II

R. R. Moore Rotating Beam Fatigue Data
Rolled 60° V-Notch Specimens
6000 Cycles per Minute
1000 Cycles of Stres

Ti-75A	RC-130B	A-110AT
70,000 psi	**120,000 psi**	**115,000 psi**
38	59	58
19	15	263
81	432	
65,000 psi	**110,000 psi**	**110,000 psi**
188	496	69
203	555	87
	169	2,852
		844
62,500 psi	**105,000 psi**	**105,000 psi**
250	1,496	557
678	704	4,143
	686	
57,500 psi	**100,000 psi**	**100,000 psi**
794	782	5,470
1,314	1,078	5,617
		13,013 *
50,000 psi	**95,000 psi**	**95,000 psi**
11,454 *	1,113	10,195 *
10,052 *	7,904	11,655 *
11,543 *		
	90,000 psi	
	5,541	
	2,853	

*Did not fail.

TABLE III

R. R. Moore Rotating Beam Fatigue Data
Diamond Ground Notches
6000 Cycles per Minute
1000 Cycles of Stress

60° V-Notch			Square Notch
Ti-75A	RC-130B	A-110AT	Ti-75A
30,000 psi	**55,000 psi**	**40,000 psi**	**35,000 psi**
73	11	54	40
41	12	42	52
56			43
25,000 psi	**50,000 psi**	**35,000 psi**	**30,000 psi**
132	15	92	137
284	19	125	181
564		90	128
20,000 psi	**45,000 psi**	**30,000 psi**	**25,000 psi**
1,003	28	250	1,116
1,079	26	244	251
648		121	361
17,500 psi	**40,000 psi**	**25,000 psi**	**22,600 psi**
2,773	61	908	2,187
10,043 *	52	945	1,285
10,162 *		660	10,000 *
	35,000 psi	**20,000 psi**	**20,000 psi**
	127	11,043 *	10,000 *
	172	11,012 *	11,104 *
		10,595 *	2,357
	30,000 psi		
	690		
	370		
	25,000 psi		
	10,000 *		
	10,000 *		

* Did not fail.

TABLE IV

Estimated Stress-Mean Fatigue Life Data

	Cycles			
	10^4	10^5	10^6	10^7
	Stress, 1000 psi			
Ti-75A, Ground V-Notch	44.0	27.5	19.0	16.5
RC-130B, Ground V-Notch	56.0	37.0	28.5	25.0
A-110AT, Ground V-Notch	51.0	35.0	24.0	20.5
Ti-75A, Ground Square Notch	48.0	32.0	23.0	20.0
Ti-75A, Rolled V-Notch	78.5	67.0	56.0	50.0
RC-130B, Rolled V-Notch	136.0	119.0	103.0	87.0
A-110AT, Rolled V-Notch	128.0	116.0	105.0	96.0

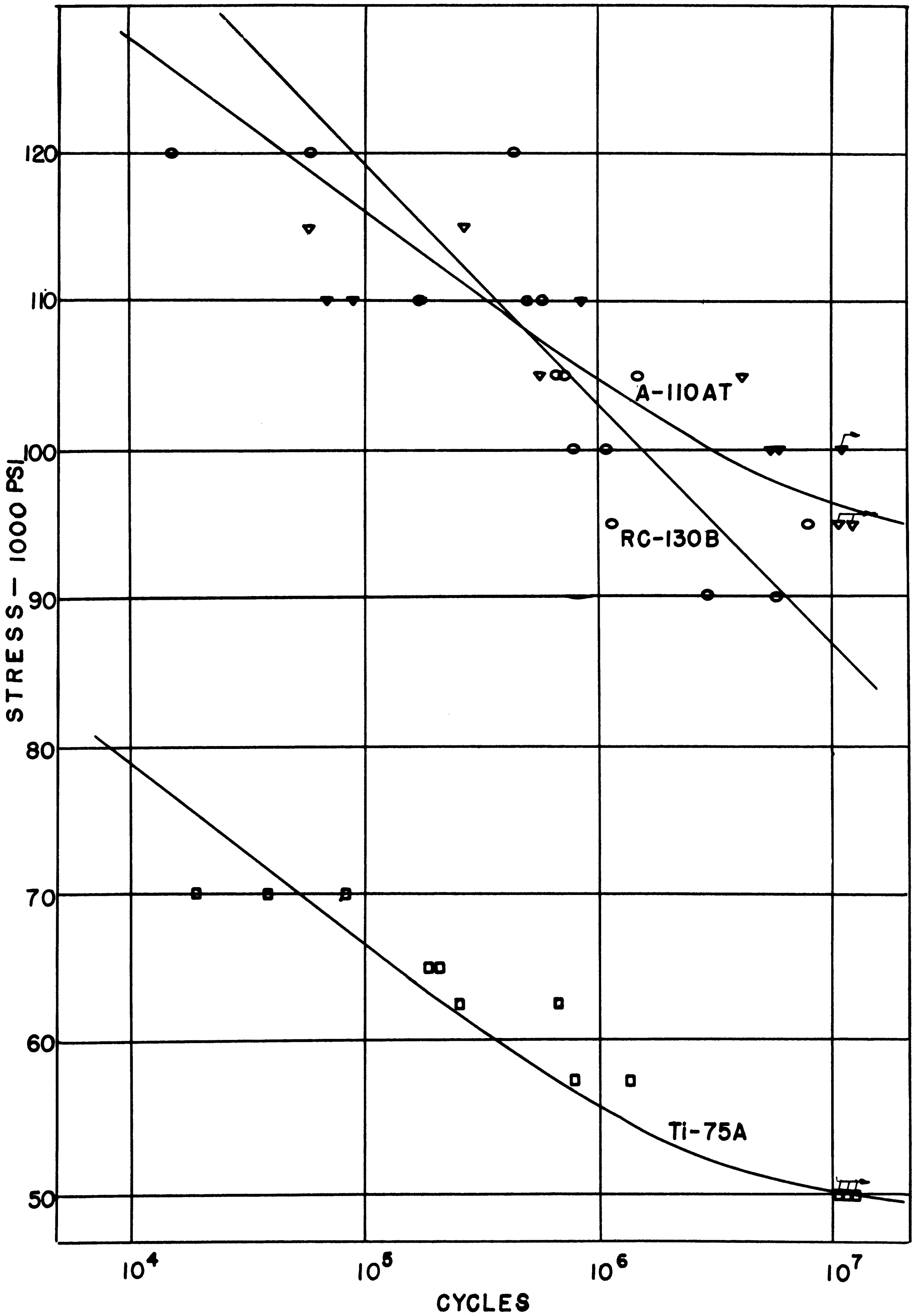

FIGURE 1. STRESS-CYCLES OF STRESS PLOTS. ROLLED 60° V-NOTCH.

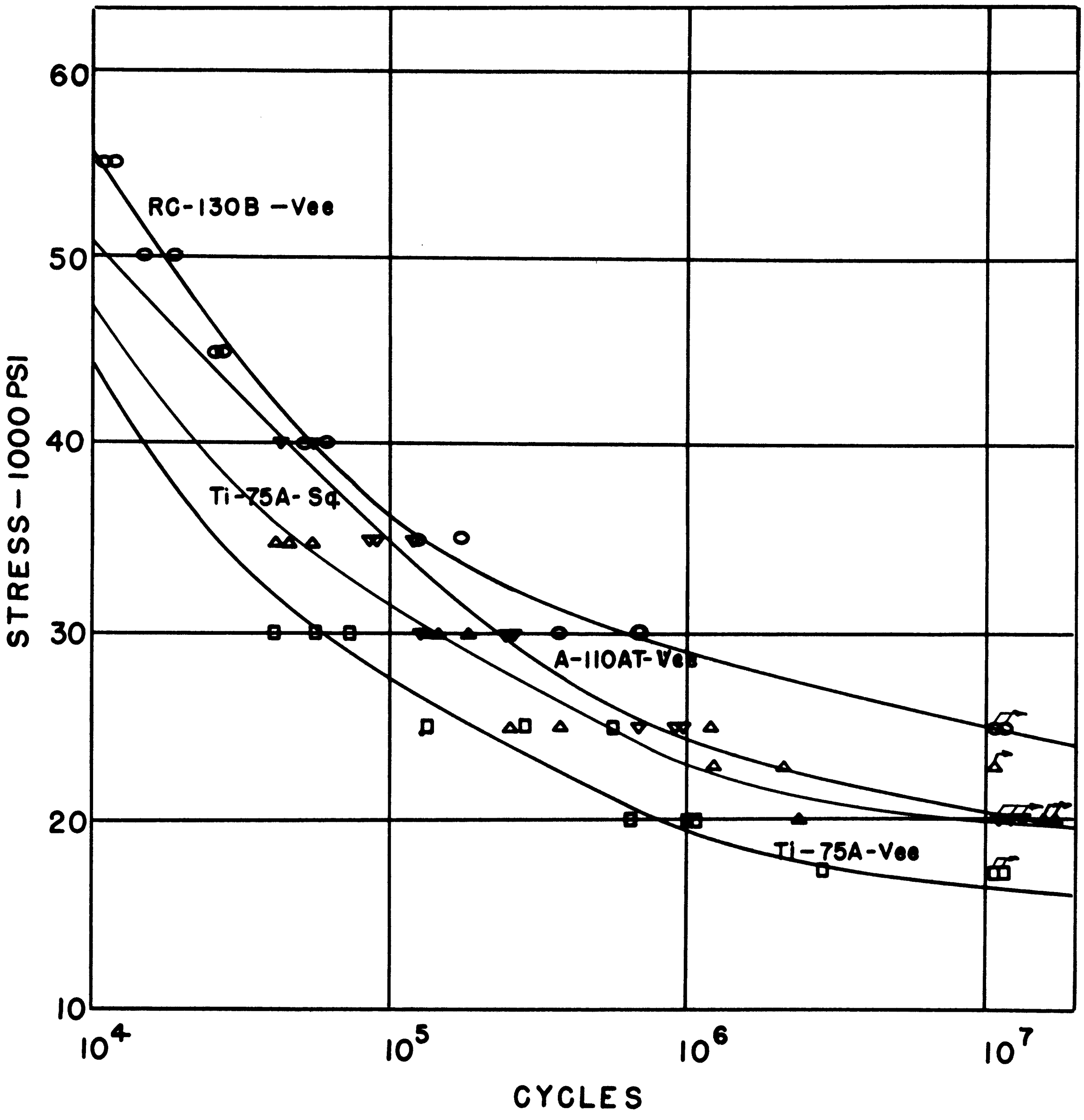

FIGURE 2. STRESS-CYCLES OF STRESS PLOTS. DIAMOND GROUND NOTCHES.

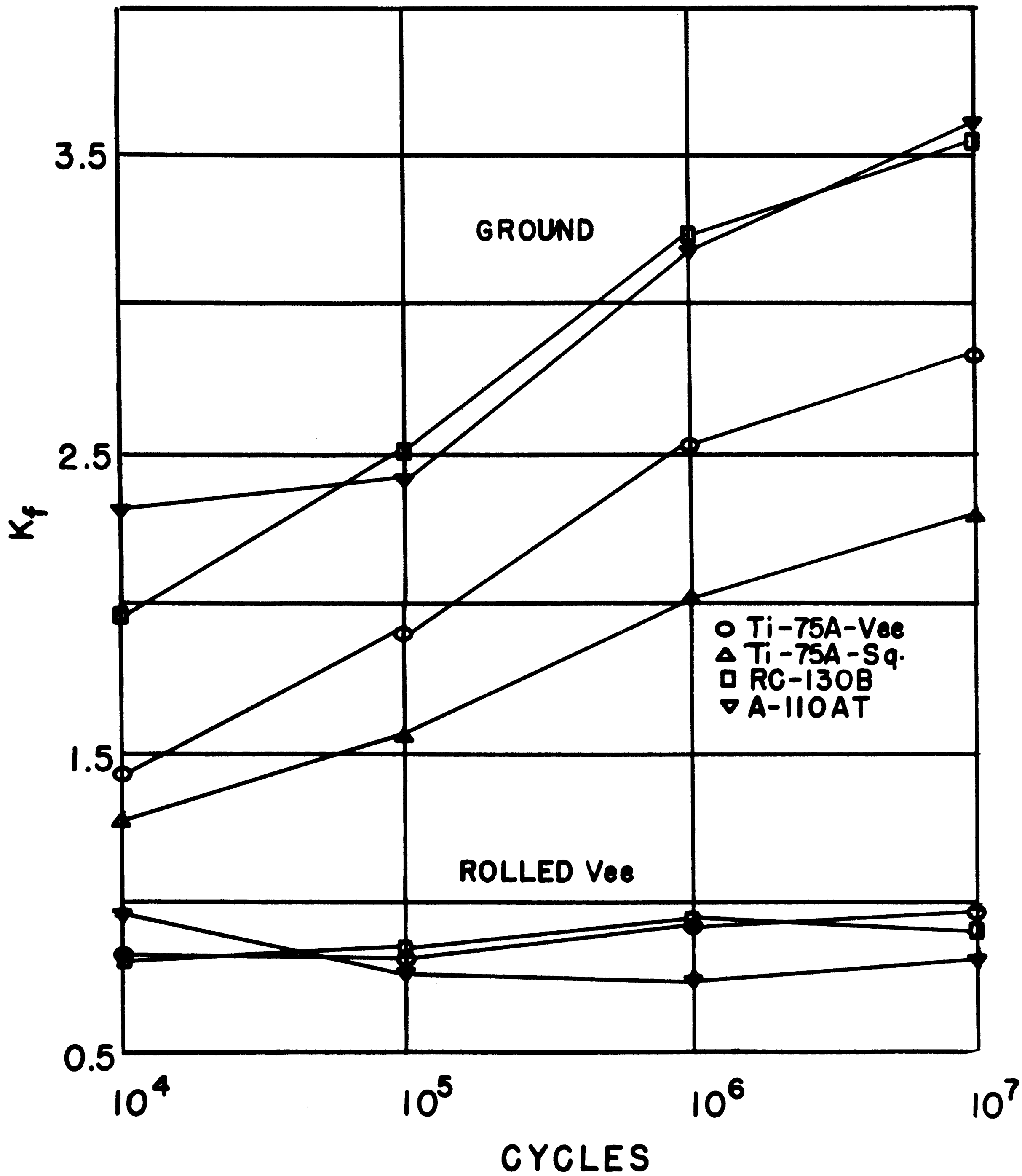

FIGURE 3. FATIGUE STRENGTH REDUCTION FACTOR VERSUS FATIGUE LIFE.