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NAVAL AIR DEVELOPMENT CENTER

WARMINSTER, PA 18974

REPORT NO. NADC-72108-VT 15 JUNE 1972

EFFECT OF GRAIN ORIENTATION ON SUSCEPTIBILITY OF TWO TITANIUM PLATE ALLOYS TO STRESS CORROSION IN AQUEOUS CHLORIDE ENVIRONMENTS

PHASE REPORT

AIRTASK NO. A3205203/202B/2F00541201
WORK UNIT OD

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13. ABSTRACT

The susceptibility to stress corrosion cracking in 3.5 percent sodium chloride solution of Ti-6Al-4V and Ti-6Al-6V-2Sn alloy plates in the annealed and solution treated and aged conditions was determined by tests of notched C-ring specimens with longitudinal, long transverse, and short transverse orientations. Test results indicated that the annealed material of both alloys was more susceptible to cracking in the long transverse direction than in the longitudinal and short transverse directions. In the solution treated and aged material of both alloys the short transverse direction showed slightly less susceptibility to cracking than did the longitudinal and long transverse directions, but the differences were not considered significant. Based on these results a recommendation was made that for plate material of both alloys in airframe design maximum allowable stresses be 60 percent of yield strength in all directions.

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SUMMARY

INTRODUCTION

The planned use of large amounts of titanium alloys in thick sections for aerospace applications has disclosed a lack of information as to the directional sensitivity of these materials to stress corrosion cracking in a salt water environment. Thus, the same design load restrictions were placed on titanium alloys as had previously been applied to aluminum alloys used in similar applications. Because of stress corrosion problems associated with certain aluminum alloys, Naval Air Systems Command Specification SD-24J restricts the sustained or residual surface tensile stresses in most such alloys to maximums of 50 percent of the yield strength in the longitudinal direction, 35 percent of the yield strength in the long transverse direction, and 25 percent of the yield strength in the short transverse direction. The stress restriction in the short transverse direction in particular is considered to be too conservative for application to titanium alloys. Work was therefore initiated to determine the directional sensitivity of thick plates of Ti-6Al-4V and Ti-6Al-6V-2Sn to stress corrosion cracking in 3.5 percent sodium chloride solution.

SUMMARY OF RESULTS

Results of tests of notched C-ring specimens indicated that both the Ti-6Al-4V and the Ti-6Al-6V-2Sn alloys in the annealed condition are distinctly more susceptible to environmental cracking in the long transverse direction than in either the longitudinal or short transverse directions. Both alloys in the STA (solution treated and aged) condition were less susceptible to environmental cracking in the short transverse direction than in the longitudinal and long transverse directions; however, these directional differences were less distinct than those for the annealed material.

CONCLUSIONS

The results of these tests indicated that there is little or no similarity between the directional environmental cracking characteristics of titanium alloy plates and aluminum alloy plates in 3.5 percent sodium chloride solution. Thus the design allowable stress limits for aluminum plate in Naval Air Systems Command Specification SD-24J are not realistic for application to titanium.

RECOMMENDATIONS

It is recommended that for airframe designs based on yield strength the design allowable stress for all directions in Ti-6Al-4V and Ti-6Al-6V-2Sn plate be a maximum of 60 percent of yield strength.

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EXPERIMENTAL PROCEDURES

A. MATERIAL

The materials tested were a 2½ inch thick plate of Ti-6Al-4V alloy and a 1 3/4 inch thick plate of Ti-6Al-6V-2Sn alloy supplied by TMCA (Titanium Metals Corporation of America). Chemical analyses provided by the supplier are listed below:

Chemical Analyses of Titanium Alloy Plates -%

Material	Heat No.	Al	V	Sn	Fe	Cu	O	N	C	H
Ti-6Al-4V	K0363	6.4	4.2		0.19		.194	.015	.022	.0075
Ti-6Al-6V-2Sn	G9987	5.7	5.5	2.0	.72	.68	.138	.015	.023	.003

Both materials were tested in the annealed condition and in the STA condition. Tensile properties and heat treatments for each material in each heat treat condition are recorded in Table I.

B. SPECIMENS

Notched C-ring specimens of the type originally designed by Williams, Beck and Jankowsky (Figure 1, reference (a)) were used for the environmental cracking tests. Groups of specimens were prepared to represent the longitudinal, long transverse, and short transverse orientations with respect to the plate, as shown in Figure 2. Two sizes of specimens were employed for the Ti-6Al-4V plate evaluation, but only the smaller diameter specimens were employed for the thinner Ti-6Al-6V-2Sn plate. Both types of rings were 1.25 inch wide.

In addition to the notched specimens, a small number of smooth C-ring specimens were machined from each plate for elastic stress calibration measurements. These specimens were of the same inside diameter and cylinder height as the notched specimens with a uniform wall thickness equal to the thickness of the ligament below the notch so that for the same applied load the maximum outer fiber stress (midway between the load application points) would be the same as the net section stress at the base of the notch.

C. TEST METHODS

i. Smooth Specimen Tests

Foil strain gages 1/8 inch long were attached to the outer surfaces of the smooth C-rings at the point of maximum outer fiber stress. Strain measurements were recorded while the specimens were loaded incrementally on an Instron Universal Test Machine. Recorded strains were then converted to stresses by a simple Hooke's Law relationship, so that the stress vs. applied load relationship could be determined.

2. Notched Specimen Calibration Tests

Two or more specimens of each material, heat treat condition, size and orientation were loaded to failure in air on an Instron Universal Testing Machine and charts recorded of load vs specimen deflection (as indicated by machine crosshead position.) These charts were used to determine the specimen deflections corresponding to various percentages of the breaking loads.

3. Tests in 3.5% NaCl Solution

The notched C-rings were prepared for loading by taping polyethylene sheet around the notch area to form a temporary environmental cell. The cells were filled with solution in order to prevent atmospheric passivation of new crack surface, and the specimens were loaded to various percentages of the breaking loads in air by bolt tightening to the corresponding deflections determined above. Bolts and nuts were Ti-100A alloy. The first specimens tested were loaded to 75 percent of the breaking load in air; and depending upon whether or not failure occurred, load on subsequent specimens was adjusted downward or upward until failure threshold loads were determined.

As the specimens were loaded, they were placed in a tank of solution and the temporary cells removed. Failures were determined by periodic visual examination of the specimens in the tank. Runout time for the tests was chosen as 200 hours, the time previously used for high strength steel specimens.

Early in the program attempts were made to reuse specimens that had survived the 200 hour test by reloading them to higher percentages of the breaking loads in air. This practice was discontinued when it was found that reloaded specimens would not fail until loads approached the reference breaking loads in air.

RESULTS

A. SMOOTH SPECIMEN TESTS

The elastic range relationship between applied load and outer fiber stress was determined to be similar to that reported in reference (a). Stress-to-load ratio for the larger diameter specimen was approximately 800 $in.^{-2}$ and for the smaller specimen approximately 600 $in.^{-2}$.

B. NOTCHED SPECIMEN TESTS

Results of the stress corrosion tests for the various alloys, heat treat conditions, and specimen orientations are summarized in Table II and shown in a bar chart in Figures 3 and 4. Both the Ti-6Al-4V and Ti-6Al-6V-2Sn plates in the annealed condition were more sensitive to environmental cracking in the long transverse direction than in the longitudinal or short transverse directions. For the Ti-6Al-4V maximum load for no failure in salt solution was 50 percent of breaking load in the long transverse direction, as compared to 65 percent in the longitudinal and short transverse directions. For the Ti-6Al-6V-2Sn the corresponding values were 60 percent in the long transverse direction, as compared to 70 percent in the other two directions. There were no distinctive orientational differences evident in the solution treated and aged material results, although the short transverse specimens were slightly less susceptible to cracking than the longitudinal and long transverse specimens.

While the standard for evaluating these test results was pass or fail within 200 hours of environmental exposure, it should be noted that where times to failure were known accurately, (that is, when a specimen failed in the presence of an observer) no times to failure were longer than 30 minutes. Several specimens failed during loading, or within a few seconds of loading. Therefore longer testing times were not considered necessary. Room temperature creep, which results in stress relaxation on constant displacement loaded specimens such as these, may account in part for the absence of failures occurring between 30 minutes and 200 hours.

DISCUSSION

The greater susceptibility of the long transverse specimens in the annealed material of both alloys, as compared to the longitudinal and short transverse orientations, is consistent with similar behavior with Ti-8Al-1Mo-1V observed by Fager and Spurr using precracked specimens (reference (b)). These investigators found that environmental cracking occurred preferentially on higher order crystallographic planes close to the basal plane. The texture of wrought titanium alloys is such that basal planes are preferentially oriented perpendicular to the long transverse direction.

Metallographic examination of annealed samples of both alloys revealed that the microstructure of the longitudinal and short transverse directions were similar; the long transverse differed from the other two directions. Microstructural differences, however, did not appear to account for the increased susceptibility of the long transverse direction.

The smooth specimen load-stress relationships described above were used to convert the breaking loads in air to net section stresses. This information revealed that all failures in salt solution occurred at net section stresses nominally above the yield strength of the material. A maximum allowable of 60 percent of yield strength is considered to be a conservative figure for all directions in both Ti-6Al-4V and Ti-6Al-6V-2Sn plate.

A word of caution is in order regarding the use of these test results. Because all failures occurred at net section stresses above yield strength, these results are not necessarily applicable to design based on plane strain fracture criteria. In these situations K_{ISCC} tests as described in reference (c) provide the best information.

ACKNOWLEDGEMENTS

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REFERENCES

(a) Williams, F.S.; Beck, W; and Jankowsky, E.J. - ASTM Proceedings Volume 60, 1192 (1960)

(b) Fager, D.N. and Spurr, W.F. - ASM Transactions, Volume 61, 283 (1968)

(c) Brown, B.F. - ASTM Materials Research and Standards, 66, 129 (1966)

Table I

Data for Titanium Plates Used in Directionality Study

Mechanical Properties

Alloy	Condition	Direction	ksi .2% Offset Yield	ksi Ultimate Tensile	Elongation
Ti-6Al-4V	Annealed	L	130	139	13
		LT	130	139	16
		ST	129	143	12
	STA	L	135	149	12
		LT	137	150	13
		ST	136	153	10
Ti-6Al-6V-2Sn	Annealed	L	144	156	17
		LT	144	156	17
		ST	141	153	7
	STA	L	172	181	11
		LT	170	179	11
		ST	165	177	6

Heat Treatments

Ti-6Al-4V Annealed : 704C (2 hours), air cooled

STA : 843C (1 hour), water quench + 546C (4 hours), air cooled

Ti-6Al-6V-2Sn Annealed : 732C (2 hours), air cooled

STA : 954C (1 hour), water quench + 538C (4 hours), air cooled

TABLE II

Notched C-Ring Environmental Test Results

Material	Condition	Orientation	Maximum % of Breaking Load in Air for No Failure in 3.5% NaCl
Ti-6Al-6V-2Sn	Annealed	Longitudinal	70
Ti-6Al-6V-2Sn	Annealed	Long Transverse	60
Ti-6Al-6V-2Sn	Annealed	Short Transverse	70
Ti-6Al-6V-2Sn	STA	Longitudinal	70
Ti-6Al-6V-2Sn	STA	Long Transverse	70
Ti-6Al-6V-2Sn	STA	Short Transverse	75
Ti-6Al-4V	Annealed	Longitudinal	65
Ti-6Al-4V	Annealed	Long Transverse	50
Ti-6Al-4V	Annealed	Short Transverse	65
Ti-6Al-4V	STA	Longitudinal	75*
Ti-6Al-4V	STA	Long Transverse	75
Ti-6Al-4V	STA	Short Transverse	85

*One specimen failed at 70% upon reloading.

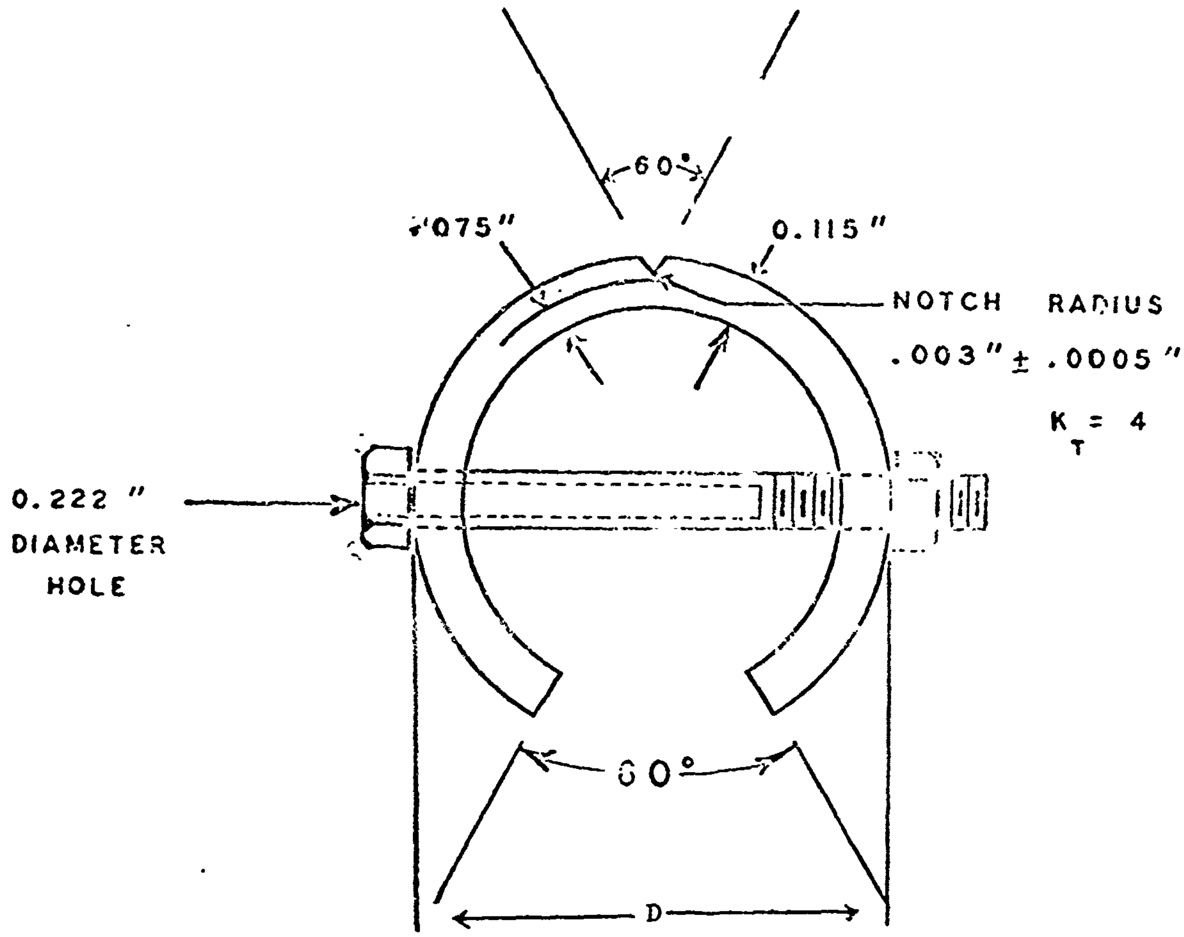

Figure 1. Drawing of Notched C-Ring

Large Diameter 1.98 inches
Small Diameter 1.65 inches

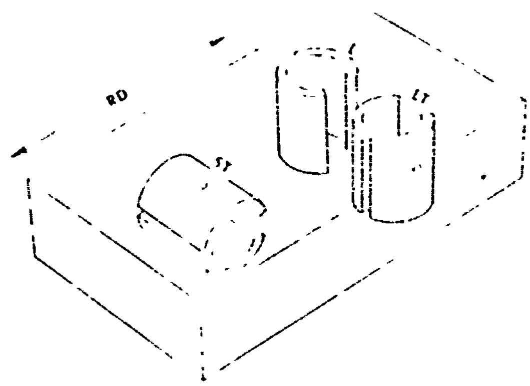

Figure 2. C-ring specimen orientation for titanium plate with respect to rolling direction (RD)

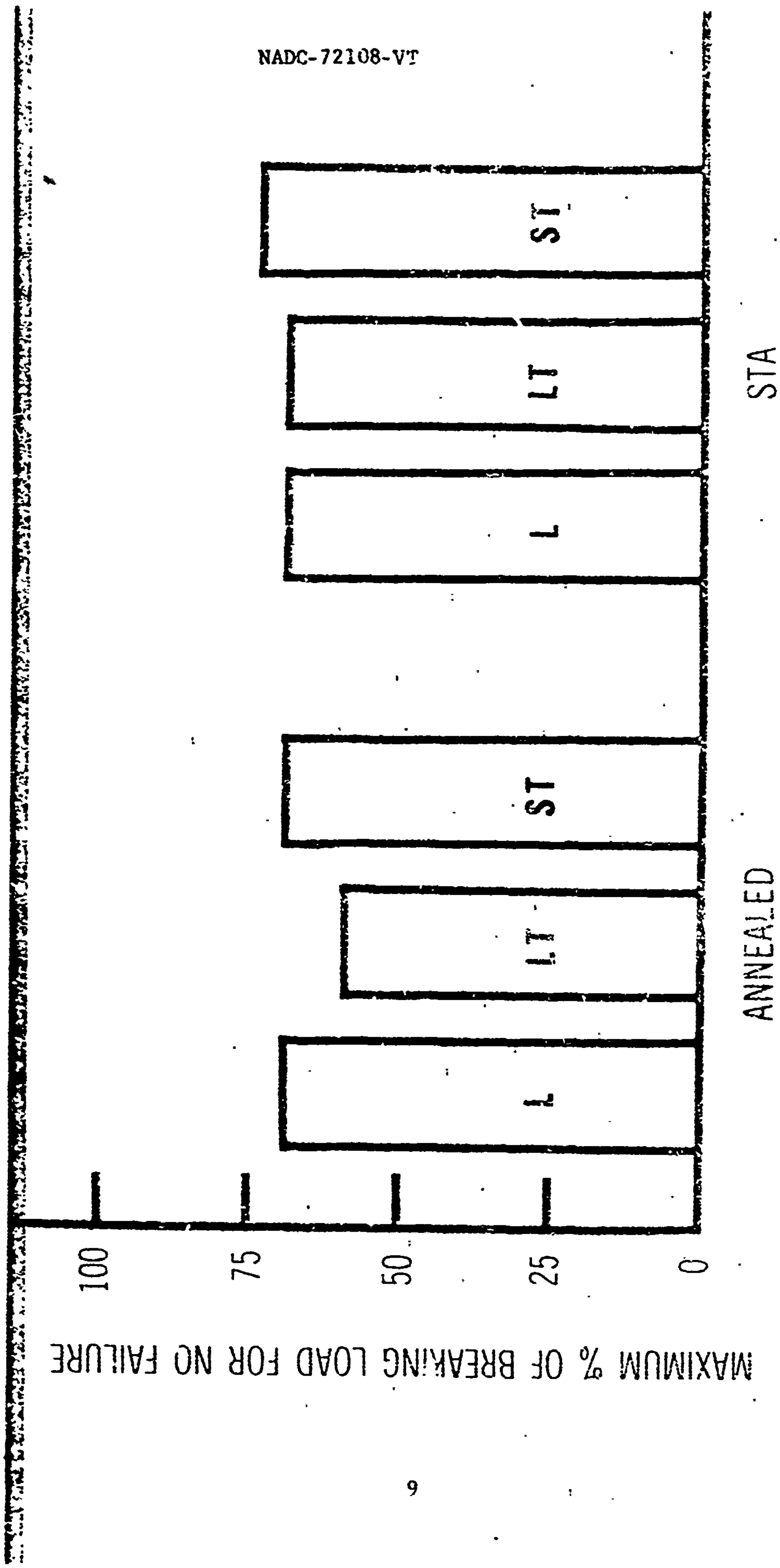

Figure 3. Ti-6Al-6V-2Sn Notched C-Ring Results in 3.5% NaCl

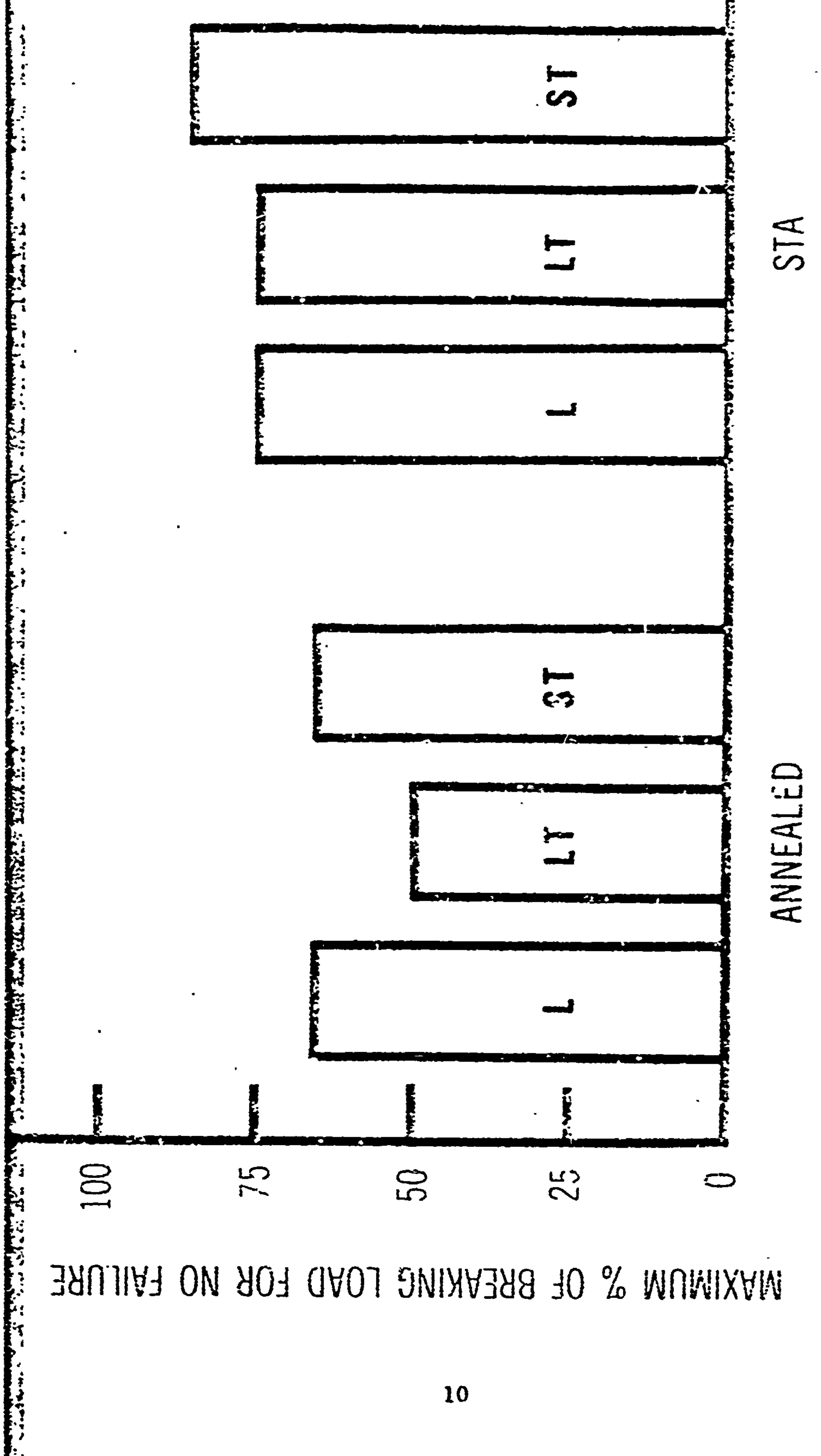

Figure 4. Ti-6Al-4V Notched C-Ring Results in 3.5% NaCl