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NOTCH SENSITIVITY EFFECT ON FATIGUE OF AERMET 100 STEEL IN AIR AND SALT WATER

by

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3 August 1998

Aerospace Materials Division
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Naval Air Warfare Center Aircraft Division
Patuxent River, Maryland

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ACKNOWLEDGMENT

This study was supported by the F/A-18E/F Project Office.

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APPENDIX

SUMMARY

This study was conducted to characterize the notch sensitivity effect on the fatigue behavior of an AerMet 100 steel and to compare this effect to a 300M steel. The test specimens were subjected to constant amplitude tension-tension fatigue test in both laboratory air and a salt water environment.

INTRODUCTION

Since its development by Carpenter Technology Corp. in 1990, the use of AerMet 100 steel increased in aircraft and other structural components, including F/A-18E/F aircraft landing gear. Many naval aircraft components are exposed to corrosive environments and subjected to repeated loading, and their corrosion and fatigue susceptibility is a great concern. During production, small notches or tool marks are sometimes identified by nondestructive inspection techniques. The effect of these surface imperfections upon the fatigue properties of the material is not understood. Therefore, a study was initiated to identify the notch sensitivity effect on the fatigue resistance of AerMet 100 steel. In this fatigue investigation, the fatigue behavior of notched specimens of AerMet 100 steel in both air and salt water environments has been characterized. This detrimental effect upon fatigue life was then compared with that of previous landing gear steels, mainly 300M.

The notch sensitivity effect is of paramount importance due to recent concerns surrounding the inspection and quality of surface roughness in production of long internally bored components, mainly the F/A-18E/F arresting hook shank.

EXPERIMENTAL PROCEDURE

MATERIAL AND SPECIMEN

The specimen material, AerMet 100 steel, was purchased from Carpenter Technology Corp. in the form of barstock, 17/32 in. diameter. Its chemical composition is shown in table 1.

Table 1
CHEMICAL COMPOSITION OF AERMET 100 STEEL

Element	Weight (%)
C	0.23
Mn	0.03
Si	0.03
P	0.003
S	0.0009
Cr	3.03
Ni	11.09
Mo	1.18
Co	13.44
Cu	0.01
Fe	bal

This material was subjected to the following heat treatment: solution treatment at 885°C (1,625°F) for 1 hr, oil quenching to room temperature, refrigeration in a solution of alcohol and dry ice for 1 hr, and aging at 482°C (900°F) for 5 hr. This heat treatment resulted in the mechanical properties shown in table 2 and the microstructure shown in figure A-1.

Table 2
ULTIMATE TENSILE PROPERTIES OF AERMET 100 STEEL

Orientation	MPa	ksi
L-T	1,972	286

Hardness Rockwell C-52.

The comparison material, 300M steel, was purchased as a 4-in. thick plate. This material was subjected to the following heat treatment: solution treatment at 857°C to 885°C (1,575°F to 1,625°F) for 1 hr, oil quenched to room temperature, and double tempered at 273°C to 329°C (525°F to 625°F) for 2 hr each temper. This heat treatment resulted in the mechanical properties shown in table 3 and the microstructure shown in figure A-2.

Table 3
ULTIMATE TENSILE PROPERTIES OF 300M STEEL

Orientation	MPa	ksi
L-T	2,055	298

Hardness Rockwell C-52.

The fatigue test specimens were round continuos radius between ends in accordance with ASTM E466, figure A-3. The application of notches was accomplished by two different methods to produce a dull notch 0.396mm (0.0156 in.) and a sharp notch 0.1016mm (0.004 in.), figure A-4. The dull notch was accomplished in a lathe using Valenite-coated carbide inserts. The sharp notch was accomplished by using a 60-deg angle dressed on a Norton grinding wheel, which was selected for its excellent edge retention, thus maintaining a minimal radius in the bottom of the groove 0.1016mm (0.004 in. ±0.0005 in.) with only one cut and one dress per sample. The sharp notch specimens were notched circumferentially by using a standard 5C collet spin-dex to rotate the specimen under the grinding wheel.

FATIGUE TESTS

The fatigue tests were performed on a closed-loop servo-hydraulic MTS machine in laboratory air and 3.5% aqueous NaCl solution at room temperature. The round tension test specimens were subjected to constant amplitude tension-tension loading with a haversine waveform, stress ratio R=0.1. The frequency of the specimens tested in air was 20 Hz, while the salt water environment specimens were tested at 1.0 Hz.

The fatigue life was defined as the number of loading cycles to fracture and was plotted against maximum applied stress.

RESULTS AND DISCUSSION

FATIGUE BEHAVIOR

The fatigue life (number of loading cycles to fracture) is plotted against the maximum applied stress for the as-polished specimens and the notched specimens as shown in figures A-5 through A-9.

The effects of a sharp notch upon the fatigue life of AerMet 100 specimens is shown in figure A-5 for both 0.076mm (0.003 in.) and 0.1778mm (0.007 in.) notch depths. The detrimental effect of the notch is shown by the curves with the deeper notch exhibiting a greater decrease in fatigue life. It is interesting that the magnitude of the notch depth does not imply a linear reduction in fatigue lifetimes, but instead only slightly further increases the reduction from shallower notches. In figure A-5, it is clearly evident for the AerMet 100 specimens that notched specimens suffer in a salt water environment as compared with the polished baseline. However, the figure shows that the magnitude of the notch does not quantify the fatigue lifetime reduction. Specifically, one could speculate that the continued increasing of the notch depth may lead to smaller impacts upon the existing detrimental effect upon fatigue life. In our study, the shallow notch results in a significant reduction in fatigue lifetime, while the additional reduction from the deeper notch is small in comparison.

The effects of a greater radii upon AerMet 100 specimens is clearly evident in figure A-6. A larger radii at the notch is less detrimental than the smaller sharper notch. The lack of 0.003 in. data in figure A-6 is a result of scatter and nonreproducible results, suggesting that perhaps the detrimental effects of a notch are not so great if the root radius is large enough to overcome the stress concentration effect normally associated with notches.

The comparison material, 300M steel, exhibited similar tendencies as the AerMet 100 (figures A-7 and A-8). The results of the sharp notch salt water environment are nearly identical, and the dull notch shallow (0.003 in.) data were not repeatable or valid.

The air environment test specimens (figure A-9) showed somewhat longer lifetimes as is expected with the lack of an aggressive environment such as the 3.5% NaCl used in the earlier work. Again, the greater depth notches resulted in greater reductions of fatigue lifetimes with the greatest differences seen in the lower stress levels.

Air environment test specimens for AerMet 100 continues and is not presently available for publication. Preliminary results show an unusually large scatter band with the air environment specimens, and this is being studied closely to try and ascertain a plausible explanation for this phenomena.

Summary graphs for both the AerMet 100 and the 300M material are provided that plot the combined data for notch depths and notch radii in salt water environments (figures A-10 and A-11).

CONCLUSIONS

The detrimental effects of notches upon the steels in this study were at their worst when sharp radii existed more so than with greater depths of notches. This does not imply that greater depth notches do not degrade the fatigue properties more than shallower notches because they do. It simply restates the findings of the data in that the greatest change in fatigue properties is the sharpness of the notch at the root.

Comparison of figures A-10 and A-11 shows the AerMet 100 material to have equal or greater fatigue lifetimes than the 300M material. The knockdown in fatigue lifetimes due to notches is approximately equal for both materials.

RECOMMENDATIONS

The generation of notches in high strength steels should be avoided especially when exposed to aggressive environments such as salt water.

Realistically, an immediate and significant improvement in notched fatigue properties can be realized if sharp machine notch radii are avoided. This is the obvious intent of such machining operations like honing, polishing, or other good machining practices.

FUTURE WORK

Future work planned includes the completion of the AerMet 100 air environment notched specimens, the evaluation of shot peening upon notched specimens, and a preliminary characterization of an innovative new process, Laser Shock Peening, upon the notched specimens.

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APPENDIX A
FIGURES

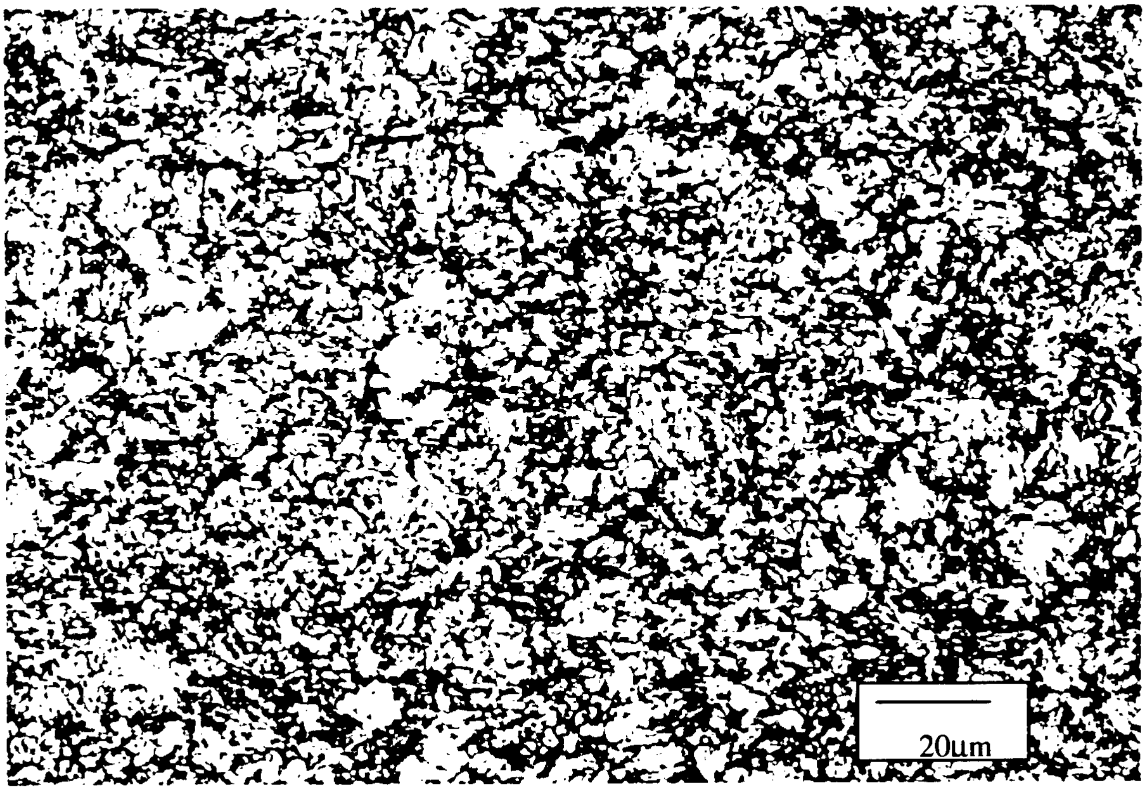


Figure A-1
AERMET 100 SPECIMEN MICROSTRUCTURE

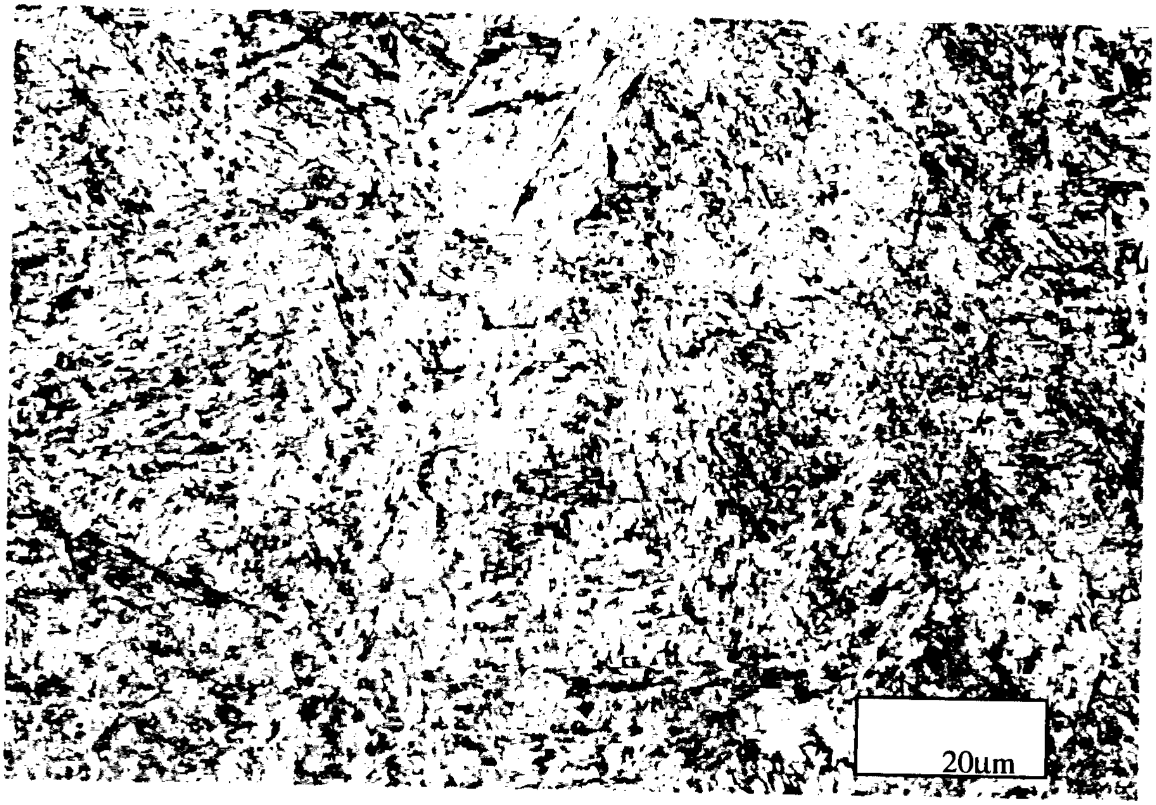


Figure A-2
300M SPECIMEN MICROSTRUCTURE

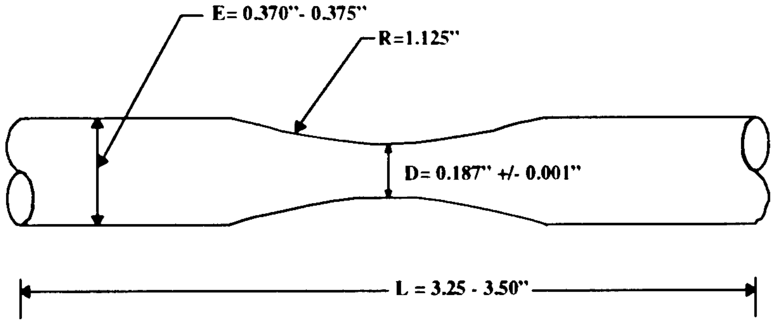
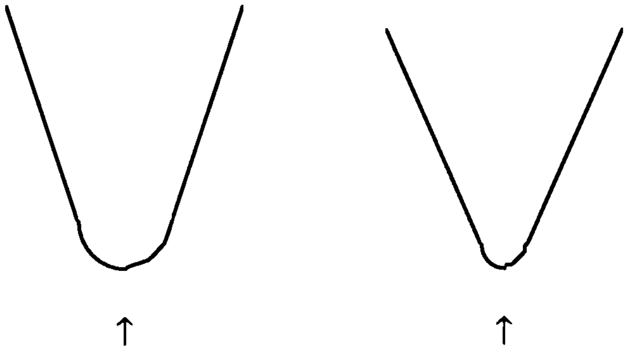


Figure A-3
FATIGUE SPECIMEN GEOMETRY



0.0156 IN. RADII

0.004 IN. RADII

Figure A-4
NOTCH GEOMETRY

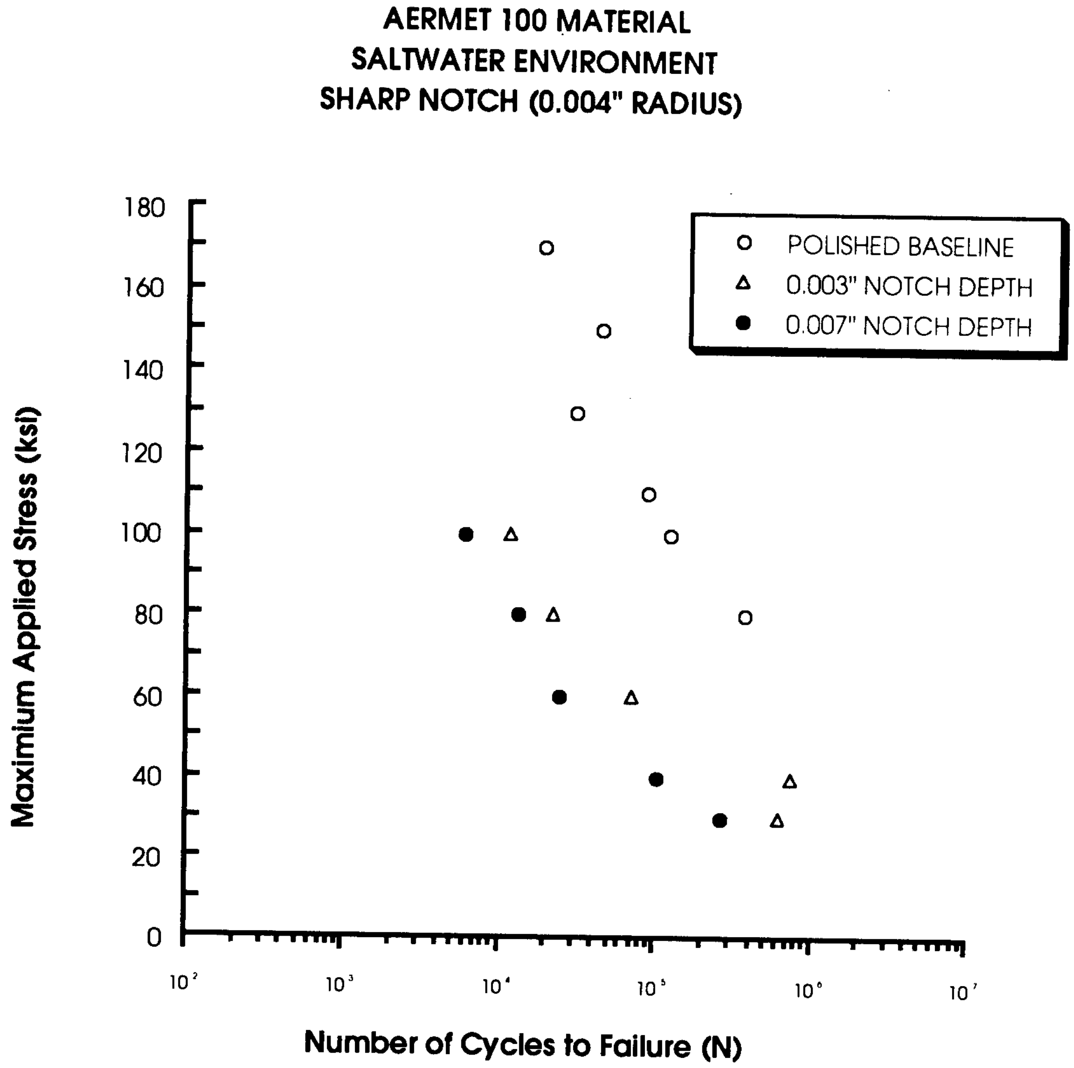


Figure A-5
FATIGUE LIFE VARIATION WITH NOTCH DEPTH AND APPLIED STRESS

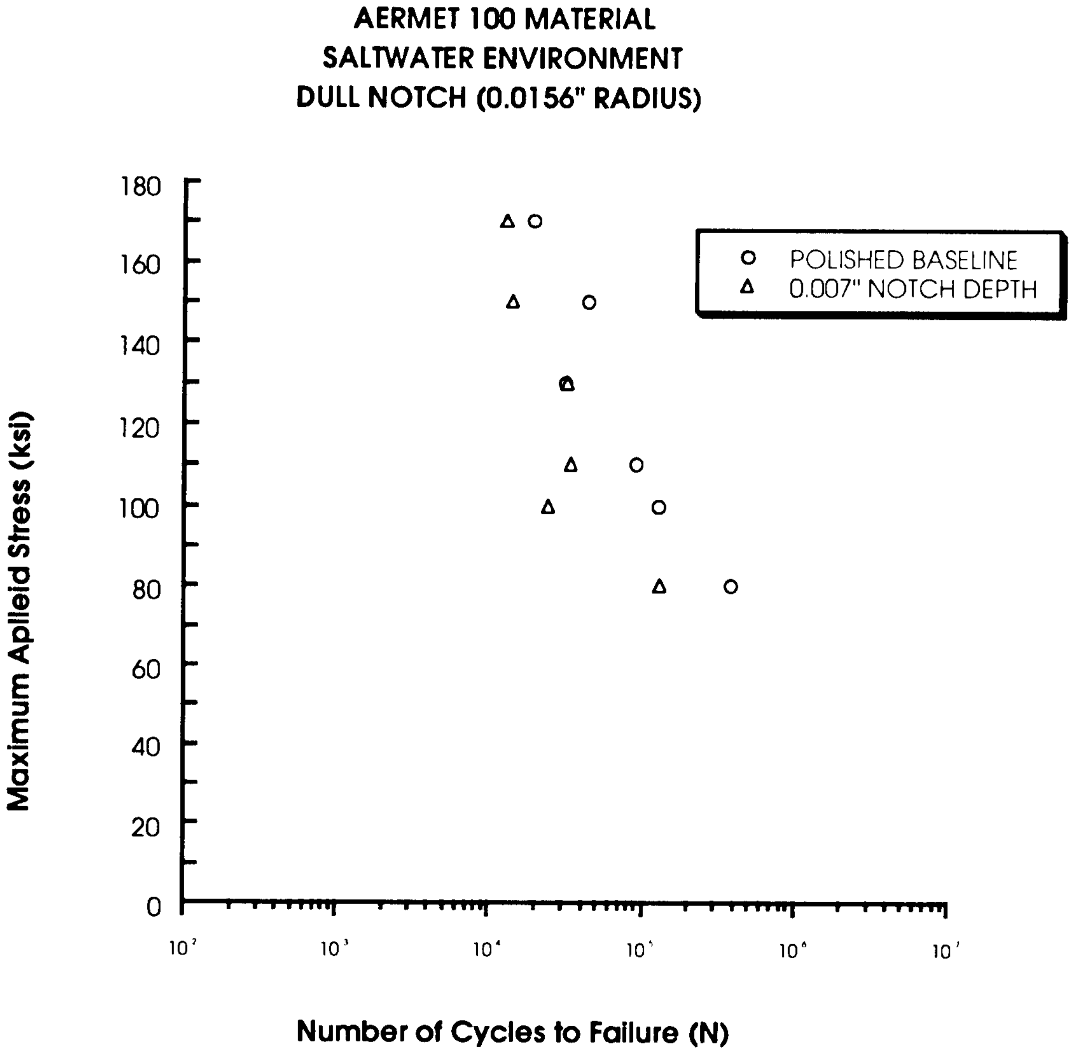


Figure A-6
FATIGUE LIFE VARIATION WITH NOTCH DEPTH AND APPLIED STRESS

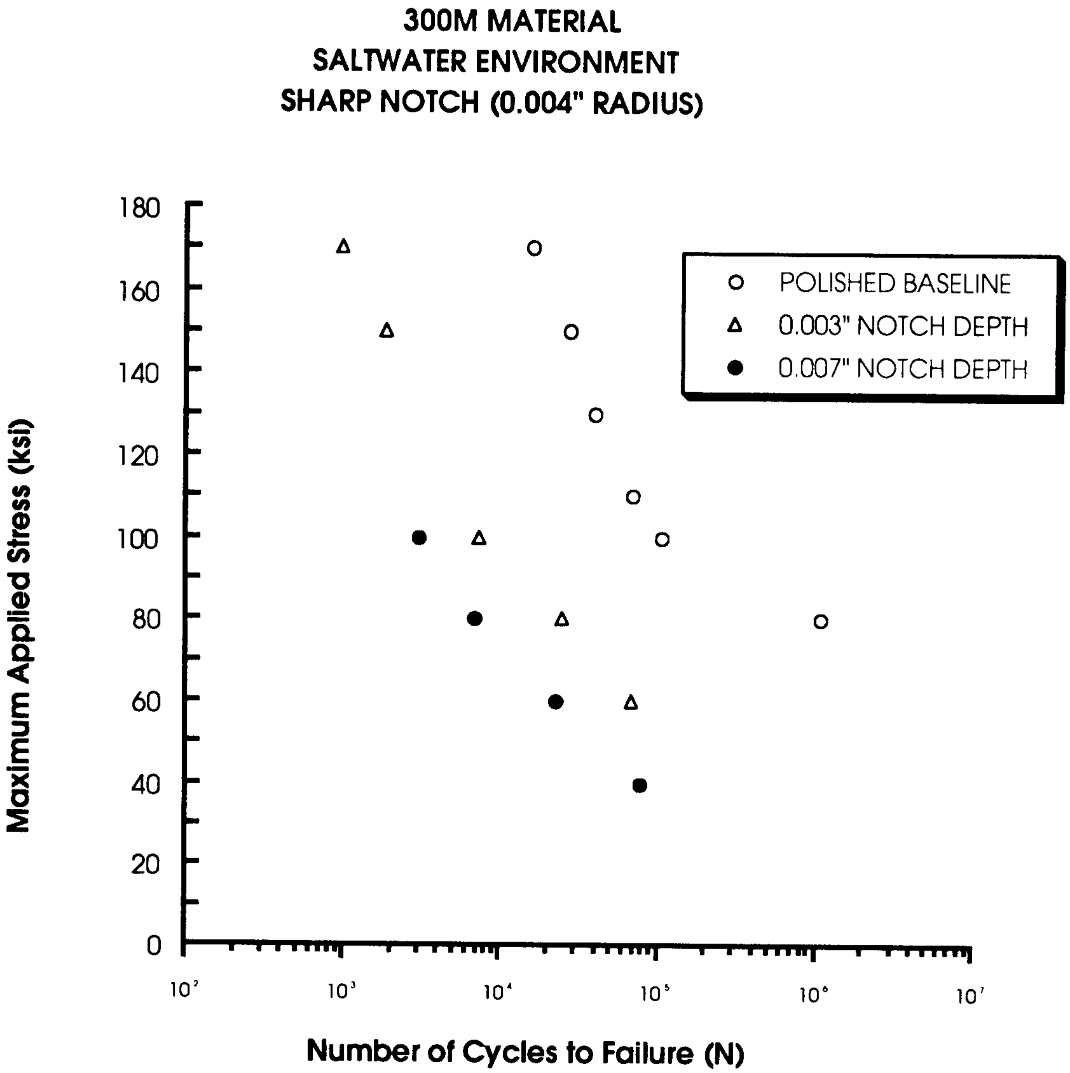


Figure A-7
FATIGUE LIFE VARIATION WITH NOTCH DEPTH AND APPLIED STRESS

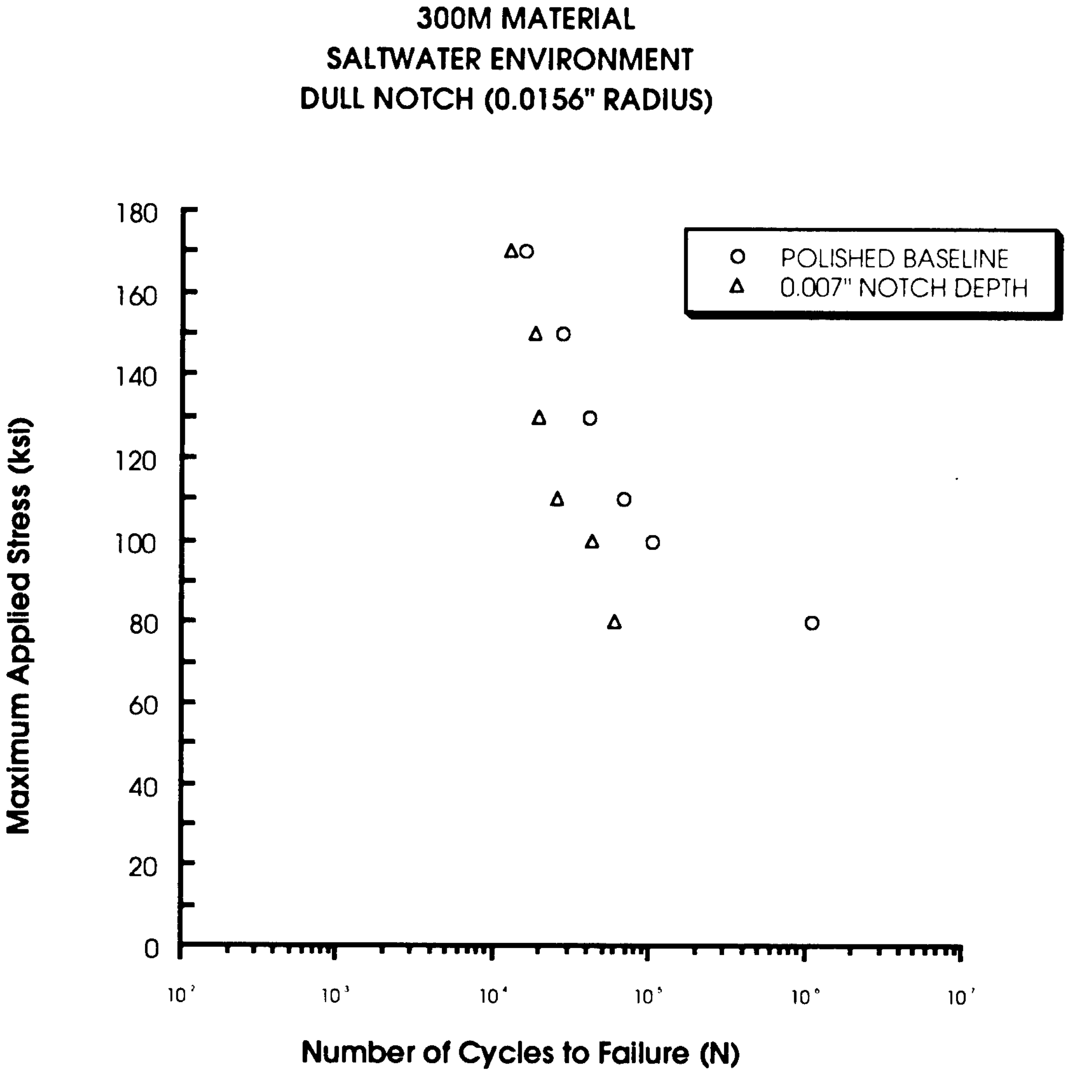


Figure A-8
FATIGUE LIFE VARIATION WITH NOTCH DEPTH AND APPLIED STRESS

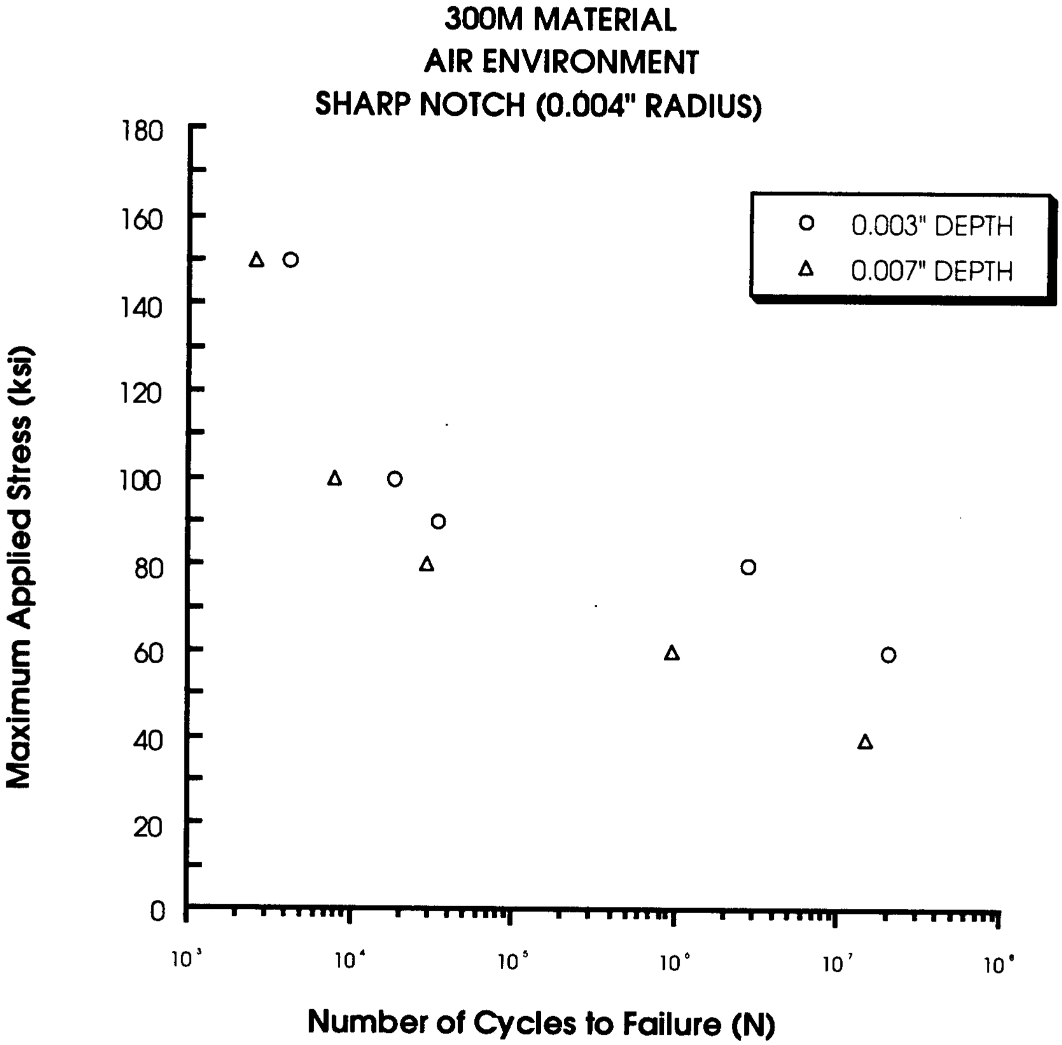


Figure A-9
FATIGUE LIFE VARIATION WITH NOTCH DEPTH AND APPLIED STRESS

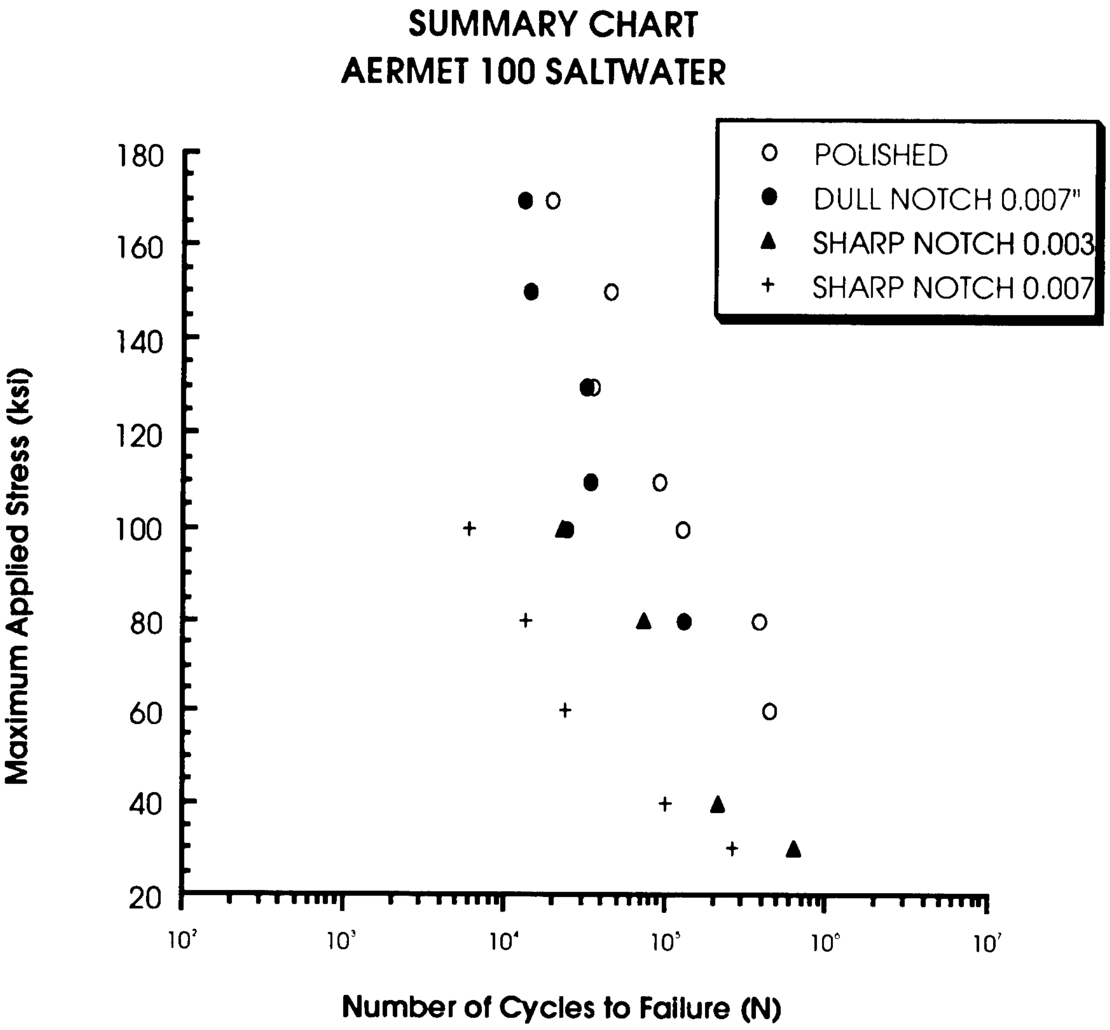


Figure A-10
AERMET 100 SUMMARY CHART

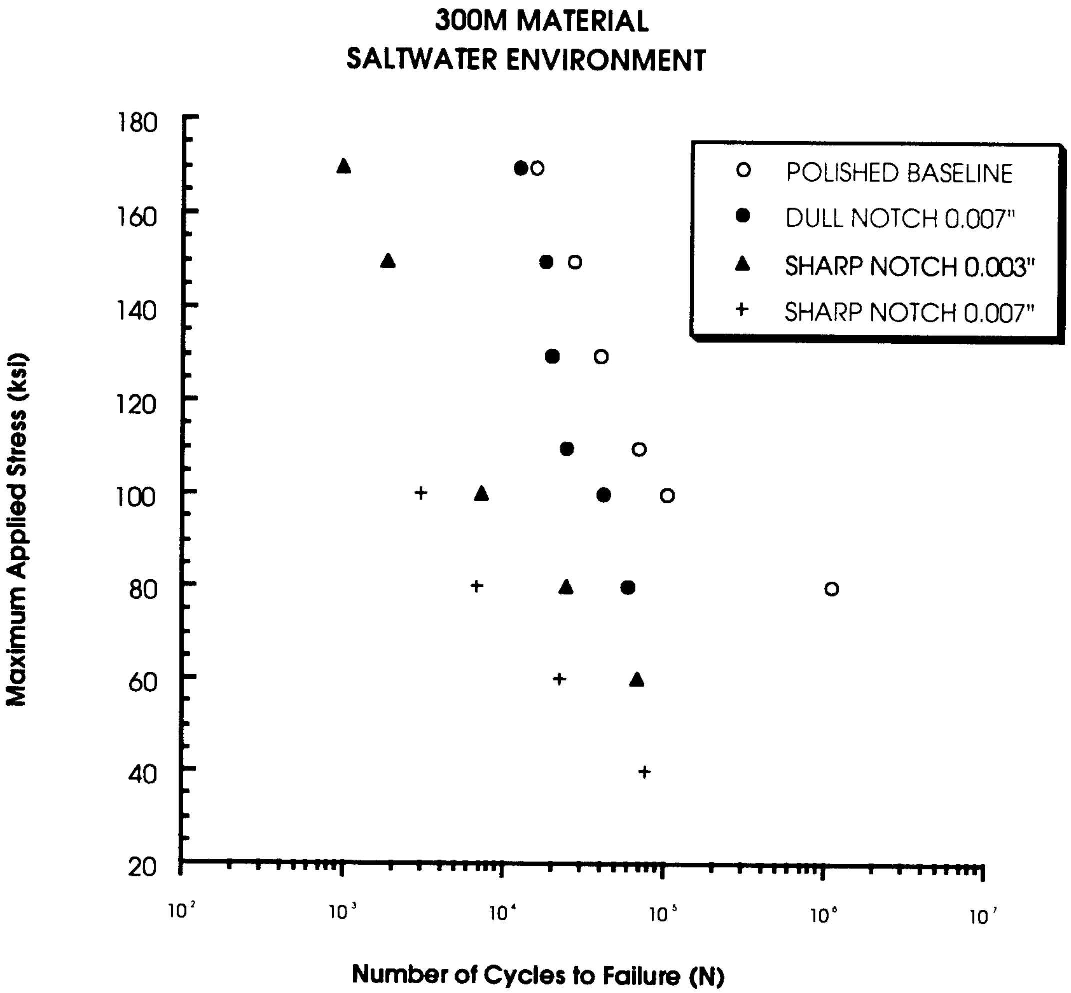


Figure A-11
300M SUMMARY CHART

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