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NAVAL AIR DEVELOPMENT CENTER

Johnsville, Warminster, Pennsylvania

REPORT NO. NADC-MA-6716 16 APRIL 1968

EVALUATION AND COMPARISON OF THE CORROSION SUSCEPTIBILITIES OF 7178 ALUMINUM PLATE MATERIAL OF VARIOUS TEMPERS

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WORK UNIT D - WORK ELEMENT 1

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John J. Deluccia, et al

Naval Air Development Center
Johnsville, Pennsylvania

15 April 1968

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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

Aero Materials Department

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Plate material of 7178 aluminum alloy in the -T651 and -T7651 tempers was evaluated for resistance to exfoliation and stress corrosion. Stress corrosion susceptibility was determined using tuning fork specimens stressed in the short transverse direction and exposed to alternate immersion in 3½% NaCl solution. Susceptibility to intergranular and exfoliation corrosion was determined by exposure in both acetic acid salt spray and NaCl-SO_2 environments. The -T651 temper was found to be acutely susceptible to intergranular corrosion and hence exfoliation and stress corrosion cracking. The -T7651 temper is less susceptible to intergranular attack and more resistant to exfoliation and stress corrosion cracking than the -T651 temper.

Reported by: J. J. DeLuccia
Chemical Metallurgy Branch

I. S. Shaffer
Chemical Metallurgy Branch

Approved by: S. J. Ketcham, Head
Chemical Metallurgy Branch

F. S. Williams, Superintendent
Metallurgical Division

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SUMMARY

INTRODUCTION

The high strength aluminum alloys used in naval aircraft are prone to exfoliation and stress corrosion cracking. Reference (a) authorized an investigation of special heat treatments to minimize this susceptibility. A comprehensive study of stress corrosion resistant tempers for 7075 has been reported (references b and c). The work has been extended in order to evaluate exfoliation resistant tempers for the 7178 alloy in the form of plate.

SUMMARY OF RESULTS

Salt fog corrosion tests, stress corrosion tests, as well as mechanical tests and electrical conductivity measurements were performed.

The 7178-T651 was very susceptible to intergranular corrosion and exfoliation, and to stress corrosion when stressed in the short transverse direction.

The 7178-T7651 although still somewhat susceptible to intergranular attack, is much less susceptible to exfoliation type of attack than the -T651. The stress corrosion specimens did not crack during the standard 30-day alternate immersion test in 3½% NaCl, although directional pitting occurred normal to the transverse direction. The increased susceptibility to pitting noted in earlier work with the 7075-T73 temper appears to be a characteristic of the 7178-T7651 also.

The -T76 heat treatment lowered the mechanical properties an average of 13%.

CONCLUSION

The -T7651 heat treatment for 7178 plate material is effective in improving the resistance of the alloy to exfoliation and stress corrosion cracking.

RECOMMENDATIONS

It is recommended that 7178-T7651 be used instead of 7178-T651 in existing aircraft, whenever corrosion has proceeded beyond allowable limits and replacement is required (provided the lower strength of the T7651 is within the design limits).

In new aircraft, or aircraft undergoing modernization, use of 7178-T7651 is recommended over the T651 temper when establishing design criteria.

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EXPERIMENTAL PROCEDURE

The 7178-T651 and 7178-T7651 were supplied as plates of ¼" thickness. Standard flat tensile specimens were used to determine the mechanical properties of the alloy tempers.

Electrical conductivity measurements were made on the various heat treatments of the 7178 alloy to establish a relationship between conductivity and corrosion susceptibility of the alloy such as was determined for the 7075 alloy.

Specimens representing the various tempers of 7178 aluminum were subjected to a salt fog acidified with acetic acid, described in reference (d)* and a salt fog acidified with SO_2 gas described in the Appendix. Cross sections of the specimens were microscopically examined and evaluated using the suggested procedure of reference (e). All tests were performed in triplicate.

For the stress corrosion tests tuning fork specimens, described in reference (f), were machined from the plate material so that the short transverse direction (¼" thickness) was parallel to the direction of the tensile component. The stress corrosion specimens were subjected to an alternate immersion test consisting of a 10-minute immersion in 3½% NaCl solution followed by a 50 minute drying period in air. Stressing of the tuning fork specimen is accomplished by drawing up a bolt that runs through the tines of the tuning fork. Equation 1 was used to determine the amount of closure (tine squeeze) associated with the imposed elastic stress.

The equation is derived from the experimentally determined strain-deflection relationship defined in reference (f) and a modulus of elasticity of 10.4×10^6 psi.

<u>Equation 1</u>:

$$S = 3.68 \times 10^3 \, y$$

where S = desired stress, ksi (in elastic region)
Y = deflection, inches at bolt hole

Three tuning fork specimens of each temper were stressed to 75% of their transverse yield strength and exposed to the alternate immersion test for 30 days.

Upon completion of the test, each specimen was macroscopically examined to 30X for areas of localized corrosion and cracking, then sectioned and mounted for microscopic measurement of corrosion and cracking.

* Reference (d) favored 95°F as the test temperature.

Corrosion potential measurements were also made in an electrolyte of 30% carbon tetrachloride, 70% methanol with 3 grams/liter of $CuCl_2$. Reference (g) describes the use of this test for 2219 aluminum alloy to differentiate between samples that are resistant to stress corrosion and those that are not.

RESULTS

The results of the various types of tests are given in Table 1. Behavior of each temper will be discussed separately.

A. -T651 Temper

Optimum mechanical properties are obtained on the 7178 aluminum alloys when they are heat treated to the T651 temper but this temper is very susceptible to intergranular corrosion, stress corrosion cracking and exfoliation. The T651 specimens exhibited an acute sensitivity to stress corrosion cracking in the short transverse direction. Tuning fork specimens stressed to 75% of the long transverse yield strength failed after one day exposure to alternate immersion in 3½% NaCl solution. Figure 1 shows the cross section of a 7178-T651 tuning fork specimen; numerous intergranular stress corrosion cracks are seen emanating from the tensile surface. Susceptibilities to intergranular corrosion and exfoliation were quite evident after exposure to the salt spray environments, one acidified to a pH of 3.5 by additions of acetic acid, the other involving introduction of SO_2 gas. Figure 2 depicts the exfoliation that resulted from both salt spray exposures.

B. -T7651 Temper

Tuning fork specimens of this temper did not crack after an exposure to alternate immersion in 3½% NaCl solution for 30 days, although directional pitting occurred normal to the transverse direction. Figure 3 shows the cross section of a 7178-T7651 tuning fork specimen with directional pitting. Figure 4 shows the type of attack resulting from both acetic acid and SO_2 salt spray environments. Note the increased severity of attack and incipient intergranular corrosion caused by the salt spray containing SO_2 as opposed to the acetic acid salt spray.

C. Potential Measurements

Corrosion potential values are given in Table 1. They are very similar to those reported in reference (g) for 2219 aluminum alloy. The

2219-T351 temper which is susceptible to stress corrosion had a potential of approximately -0.300 volts; the 2219-T851 which is resistant to stress corrosion had a potential around -1.0 volt. It is obvious that this test should be equally as sensitive for differentiating between the T651 and T7651 tempers of 7178.

D. Edge Effects

It is interesting to note that the degree of edge exfoliation on 7178-T651 plate specimens exposed to the salt spray environments was markedly affected according to whether the edge was sawed or sheared. Figure 5 depicts photomicrographs that show the attack caused by the SO_2 environment on a sheared edge and a saw cut edge of 7178-T651. The severe exfoliation of the sheared edge is further shown in Figure 6, a photomacrograph of the 7178-T651. The exfoliation of the sheared edge is truly excessive and much more severe than that exhibited by the saw cut edge.

DISCUSSION

The extreme susceptibility of 7178-T651 to intergranular corrosion resulted in an acute propensity to stress corrosion cracking as was expected. Although stress corrosion cracking could not be induced in the exfoliation resistant temper T7651 a slight susceptibility to intergranular corrosion was noted upon exposure to the SO_2 salt spray environment.

It is noted that a propensity, albeit slight, to intergranular corrosion may go undetected in conventional or acetic acid salt spray tests but will be revealed by the SO_2 salt spray test. *(Plates 5 and 6).

The accelerated exfoliation caused by the SO_2 salt spray environment at the sheared edge of the 7178-T651 plate material is not surprising since the shearing operation causes severe microstructural deformation so that the destruction along preferred microstructural paths such as grain boundaries would be accelerated.

The loss in mechanical properties from the -T651 to the -T7651 averaged 13%. The ultimate tensile value of 79 ksi for 7178-T7651 compares favorably with that of 7075-T651. This means that 7178-T7651 could be substituted for 7075-T651 without sacrifice of strength, but with improvement in resistance to stress corrosion and exfoliation over that of 7075-T651.

* In subsequent tests 120°F was used for the test temperature in the acetic acid salt spray and exfoliation attack was accelerated.

The results obtained with solution potential measurements in a carbon tetrachloride methanol electrolyte were very encouraging. A simple test such as this would be ideal for production control of heat treatment. Before this can be done however, a complete correlation of solution potential measurements with results of exfoliation and stress corrosion tests on 7178 is required. A cooperative program between the Aero Materials Department and the Alcoa Research Laboratory has been established to this end and the results obtained by the two laboratories will be compared. Hopefully, the two weeks acetic acid salt spray test for exfoliation and the 30 day alternate immersion test for stress corrosion could be replaced by a simple potential measurement requiring 15 - 30 minutes.

REFERENCES

(a) BUWEPS ltr RRMA-2 of 9 Aug 1962

(b) Report No. NAMC-AML-1562 of 11 Jan 1963

(c) Report No. NAEC-AML-1683 of 18 June 1963

(d) An Improved Exfoliation Test for Aluminum Alloys, B. W. Lifka and D. O. Sprowls, Corrosion Vol. 22, No. 1, 1966

(e) Report No. NAMC-AML-1362 of 13 Feb 1962

(f) Technical Report AFML-TR-65-258 of Oct 1965

(g) AFML-TR-67-329 R. L. Horst, E. H. Hollingsworth & W. King, A New Solution Potential Measurement for Predicting Stress Corrosion of 2219 Aluminum Alloy Products, Proceedings of AFML Symposium on Corrosion of Military and Aerospace Equipment, May 1967

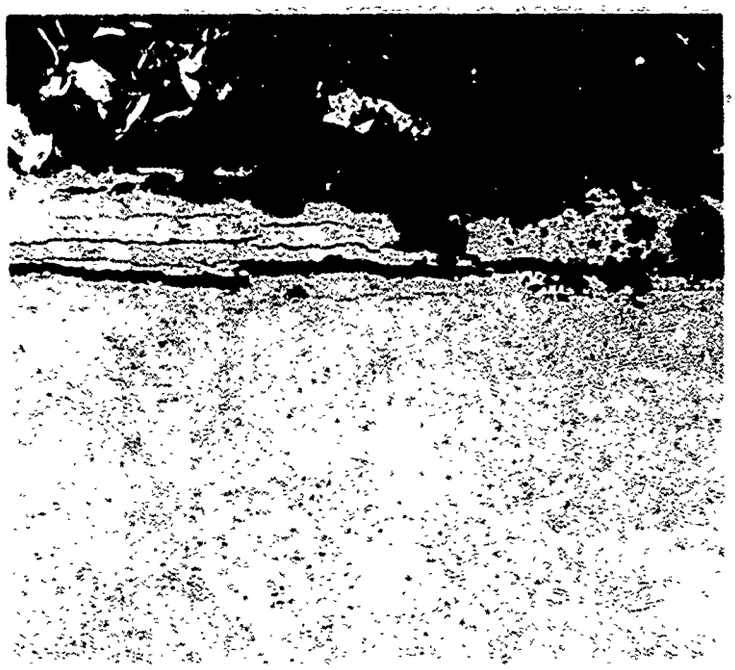
TABLE 1

SUMMARY OF RESULTS

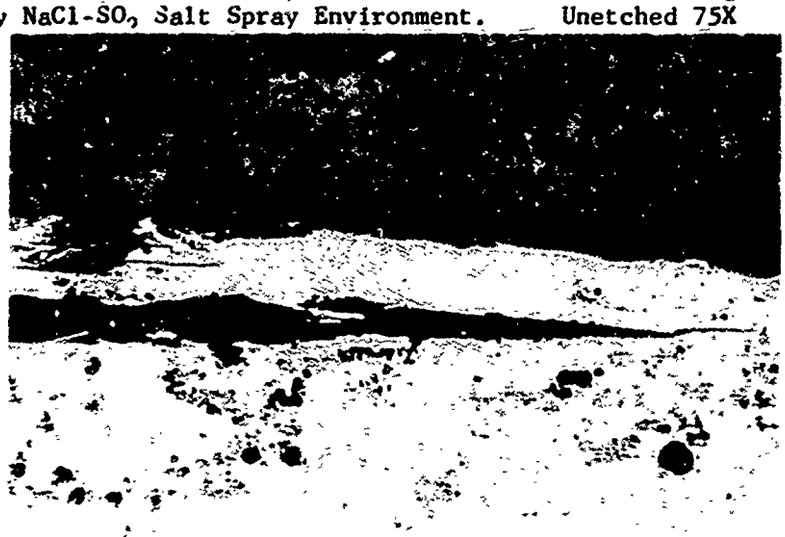
	7178-T651	7178-T7651
Longitudinal Yield Strength (ksi)	81.8	69.0
Longitudinal Tensile Strength (ksi)	89.1	78.9
Longitudinal Elongation (% in 2")	14.0	12.0
Transverse Yield Strength (ksi)	78.0	68.3
Transverse Tensile Strength (ksi)	91.0	79.4
Transverse Elongation (% in 2")	14.7	11.7
Electrical Conductivity (% IACS)	29.2	38.0
Exfoliation Test - 27 days		
Acetic Acid Salt Spray (pH 3.0)	Intergranular corrosion and exfoliation	Elongated pitting
$NaCl-SO_2$ (pH 1.5)	Severe intergranular corrosion and exfoliation	Severe pitting with slight intergranular attack
Stress Corrosion Test* - 30 days		
Time to Failure (days)	1	No cracking
Microscopic Examination	Numerous intergranular stress corrosion cracks normal to short transverse direction	Numerous elongated pits normal to short transverse direction
Potential vs. SCE in Carbon Tetrachloride and Methyl Alcohol	-0.35V	-1.04V

*Alternate immersion in 3½ NaCl, stressed to 75% of the transverse yield strength

FIGURE 1 - 7178-T651 Alternate Immersion Stress Corrosion Test. View: Short Transverse Cross Section of Tuning Fork Specimen. Unetched 100X



7178-T651 Plate Material Longitudinal Cross Section Showing Exfoliation Caused by NaCl-SO_2 Salt Spray Environment. Unetched 75X



7178-T651 Plate Material Longitudinal Cross Section Showing Exfoliation Caused by Acetic Acid Salt Spray Environment. Unetched 75X

FIGURE 2

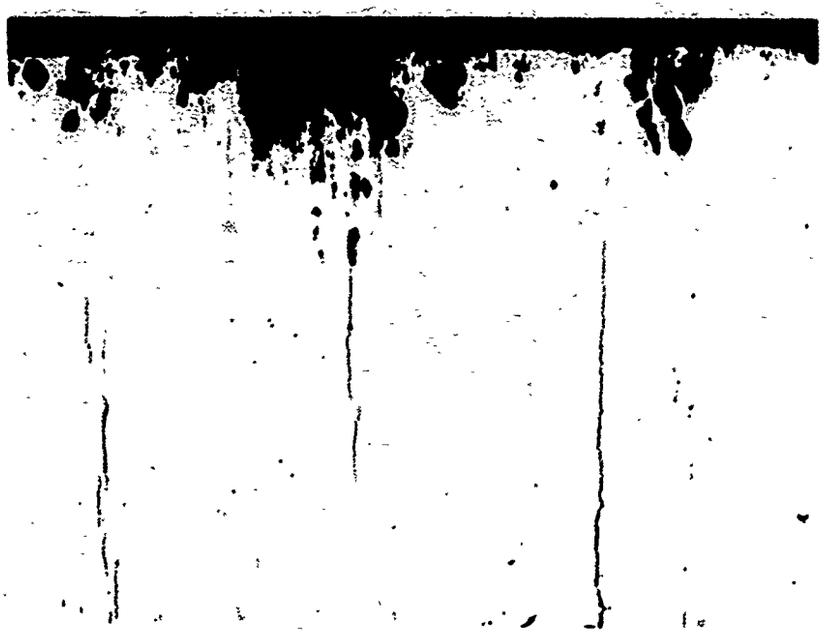
FIGURE 3 - 7178-T6511 Alternate Immersion Stress Corrosion Test
View: Short Transverse Cross Section of Tuning Fork Specimen
Unetched 75X

7178-T7651 Plate Material Longitudinal Cross Section Showing Attack Caused by SO_2 Salt Spray Environment. Unetched 75X

7178-T7651 Plate Material Longitudinal Cross Section Showing Attack Caused by Acetic Acid Salt Spray Environment. Unetched 75X

FIGURE 4

7178-T651 Plate Material Sheared Edge Exposed to SO_2 Salt Spray Environment. Unetched 75X



7178-T651 Plate Material Saw Cut Edge Exposed to SO_2 Salt Spray Environment. Unetched 75X

FIGURE 5

FIGURE 6 - Exfoliation at Sheared Edge of 7178-T651 Plate Material Exposed to SO_2 Salt Spray Environment. 5X

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13. ABSTRACT

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AERO MATERIALS DEPARTMENT
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APPENDIX

PROCEDURE OF $NaCl-SO_2$ TEST

5% Salt Spray - pH - 6.5 - 7.2
Tower Temperature - 100-110°F
Cabinet Temperature - 92-96°F

SO_2 gas injection - 14 hrs/wk (2 hrs/day)

Approximately 168 cc/min or 5 cubic ft/wk

CONDITIONS IN COLLECTION BOTTLE
(Tested Weekly)

(1) 168-336 mls/wk collection rate

(2) pH - 1.5

(3) Sp-gr - 1.02-1.04

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