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CORROSION EFFECT ON THE REMAINING LIFE OF AA2024-T351 COMPONENTS

UTICAJ KOROZIJE NA PREOSTALI VEK KOMPONENATA OD AA2024-T351

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Keywords

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- corrosion
- fatigue crack growth
- remaining life

Ključne reči

- legura aluminijuma 2024-T351
- korozija
- rast zamorne prsline
- preostali vek

Abstract

Remaining life calculation results are presented for the crucial aluminium alloy 2024-T351 components of the trainer aircraft. Calculations are based on data for fatigue crack growth (FCG) rate after 7 and 30 days of corrosion exposure, and without corrosion. The Shimadzu Servopulser E-type is used to determine the Paris law coefficients, i.e., the FCG rate.

Izvod

Predstavljeni su rezultati proračuna preostalog veka ključnih komponenata trenažnog aviona, od duraluminijuma 2024-T351. Proračuni su izvedeni na osnovu podataka o brzini rasta zamorne prsline posle izlaganja materijala korozionoj sredini 7 i 30 dana. Brzina rasta zamorne prsline, tj. parametri Parisovog zakona su određeni ispitivanjem na pulzatoru Shimadzu Servopulser E-type.

INTRODUCTION

Aluminium alloys 2024 and 7075 are two most common materials used for airplane and helicopter fuselage, as well as for wings and other components which require high ratio of static and dynamic strength with component weight.

For modern aircrafts made of AA2000-7000 increasingly stringent requirements are set in terms of safety and resistance to fracture, /1-4/. Specifically, corrosion damage and failure have attracted significant attention for many decades due to the strong effect on performance, /5/. It is also estimated that corrosion effect on aeronautical vehicles is responsible for 80 % of aging costs on one side, and causes 45 % of damage on the other side, significantly reducing operational safety. Different aspects of AA2024-T351 behaviour in a corrosion environment are presented in /6-9/.

The aim of this research is to determine the corrosion effect on the remaining life of components made of Al alloys 2024-T351. Toward this aim the results of fatigue tests performed on AA2024-T351 in three different states - as produced, and after 7 and 30 days of exposure to moisture, /5/, are used here as input data in form of the coefficients of the Paris law, defining the fatigue crack growth rate. Experimental results obtained previously are briefly presented in the following section.

EXPERIMENTAL PROCEDURE

Fatigue tests are performed at the Military Technical Institute in Belgrade, using the testing machine Shimadzu Servopulser E-type, with maximal force 100 kN, Fig. 1, on CT specimens, Fig. 2. Results are given in the form of fatigue crack growth rate (da/dN) vs. stress intensity factor range (ΔK), Fig. 3. The region II of the plot in Fig. 3 is represented by the Paris law:

$$\frac{da}{dN} = C(\Delta K)^m$$

where: C and m are constants.

Based on results presented in Fig. 4, the following Paris law constants are evaluated for the AA2024-T351 in three states:

- as produced: $m = 3.19$, $C = 2.04\cdot10^{-7}$,
- corroded after 7 days: $m = 2.80$, $C = 5.31\cdot10^{-7}$,
- corroded after 28 days: $m = 2.60$, $C = 1.40\cdot10^{-6}$.

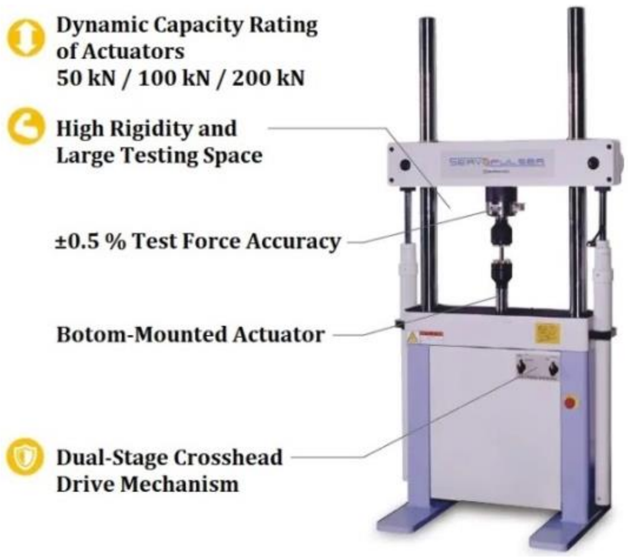

Figure 1. Shimadzu Servopulser E-type.

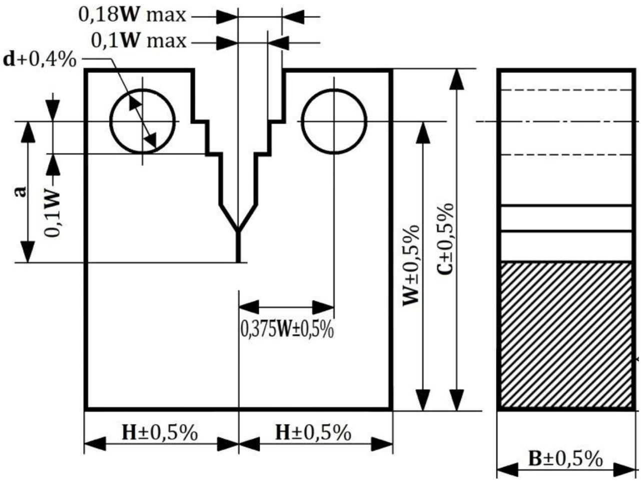

Figure 2. CT specimen, prepared for testing.

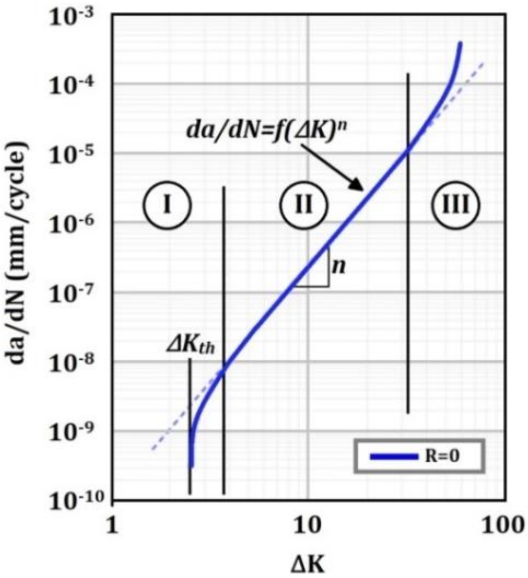

Figure 3. Fatigue crack growth curve.

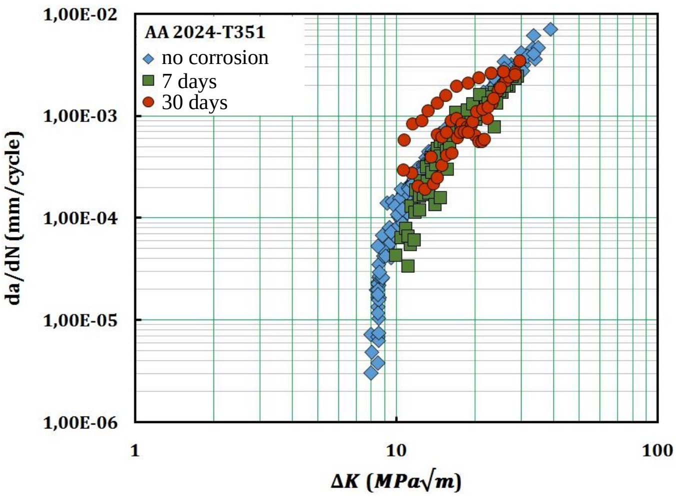

Figure 4. Fatigue crack growth curves for AA2024-T351.

REMAINING LIFE ESTIMATION FOR THE TRAINER AIRCRAFT

The remaining life is estimated for a small trainer aircraft, as shown in Fig. 5. The most stressed component, the lug connecting the wing and fuselage, was considered under the complex loading due to strong wind (1 in 1000 flights), manoeuvre (9), forced landing (90), and normal flight (900). If the worst case loads (strong wind) are taken with a coefficient 1, the maximal and minimal loads are given in Table 1.

Table 1. Loads in various conditions of flight.

Loading	Maximum (S_{max})	Minimum (S_{min})
Strong wind	1.0	-0.2998
Forced landing	0.80033	-0.2026
Manoeuvre	0.63114	-0.1116
Normal flight	0.45444	-0.0071
TOTAL	1.0	-0.2998

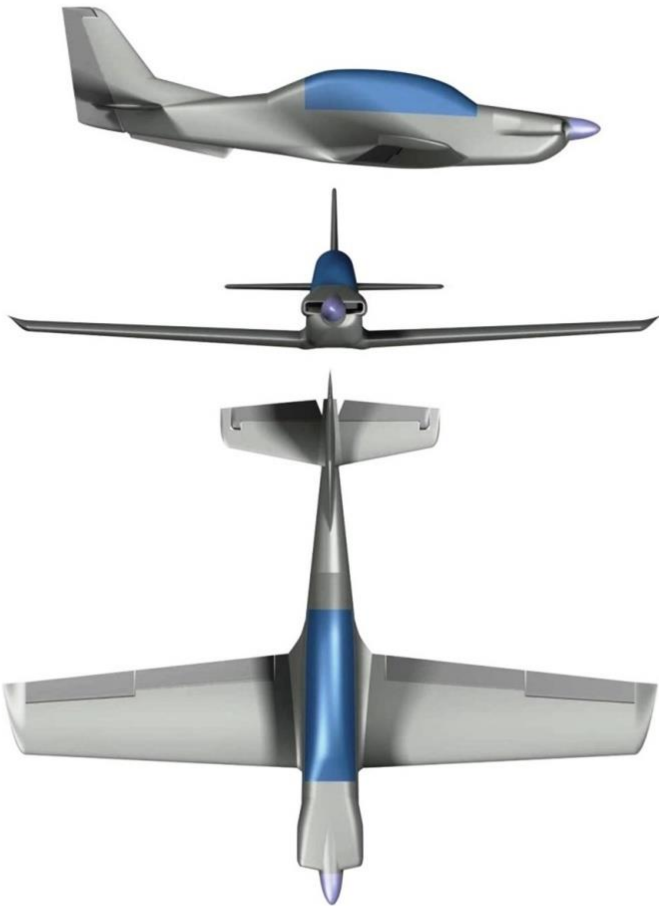

Figure 5. Small trainer aircraft model.

Taking into account the maximal loading with maximum airplane mass of 1210 kg, the following values of the forces can be obtained: F_{max} = 242.15 N, F_{min} = –72.6 N. Design life is estimated to be 20 years or 6000 hours of flight, /5/. A more advanced method for remaining life evaluation is based on FCG rate, as it is shown in the following text.

Here, the results of the remaining life are presented for the central plane beam, calculated for the critical area, lugs, Fig. 6. An edge crack is assumed with initial lengths 5, 10, or 15 mm. Loads are taken as three different stress ranges, 15, 20, and 25 MPa. As already mentioned, the material data is taken as without corrosion, as well as after 7 and 30 days of corrosion exposure. Critical crack length is taken as 70 mm, thus providing three sets of curves, given as plots in Figs. 7a-c.

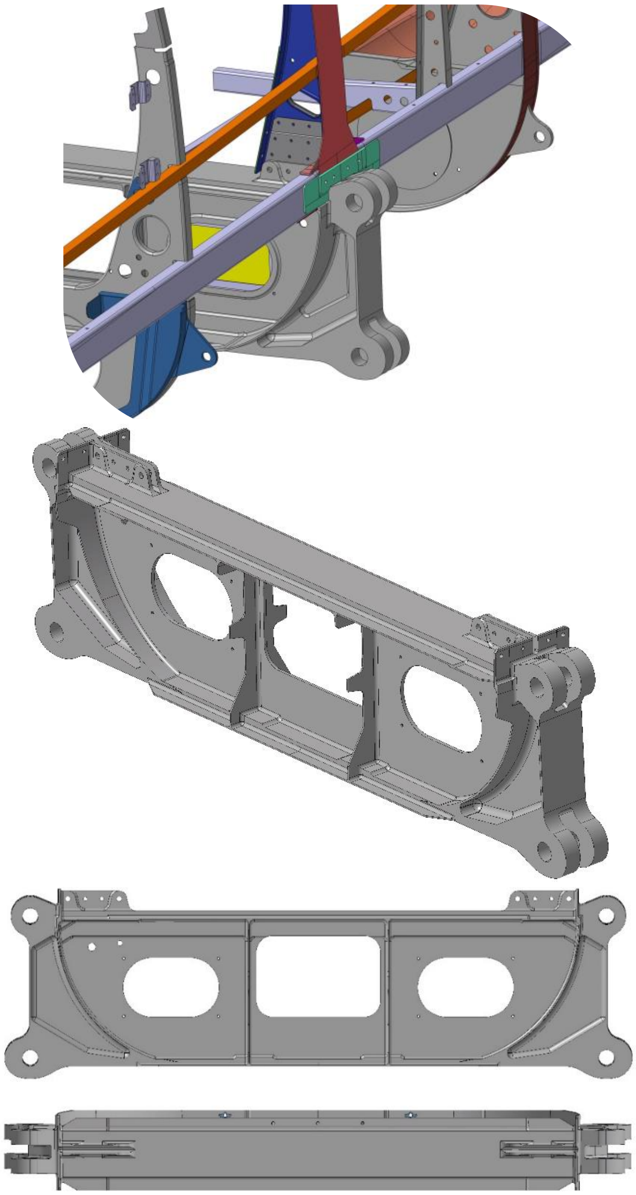

Figure 6. Central plane beam with lugs.

The Paris law was used for direct integration of the number of cycles needed for the crack to grow from initial to critical length, taking into account the expression for the range of stress intensity factor in the case of an edge crack:

$$\Delta K = Y\left(\frac{a}{W}\right)\Delta\sigma\sqrt{\pi a} \ ,$$

where: $Y(a/W)$ is the geometry parameter, depending on the crack length.

Calculation is performed at 5 mm increments of crack length, so that the remaining life is evaluated more precisely by changing the value of geometry parameter $Y(a/W)$ in:

$$N = \frac{2}{(m-2)C\left[Y\left(\frac{a}{W}\right)\Delta\sigma\right]^{m}\pi^{\frac{m}{2}}}\left(\frac{1}{a_0^{\frac{m-2}{2}}} - \frac{1}{a_{cr}^{\frac{m-2}{2}}}\right).$$

This procedure has been verified both analytically and numerically in a number of previously analysed problems, as described in /10-12/.

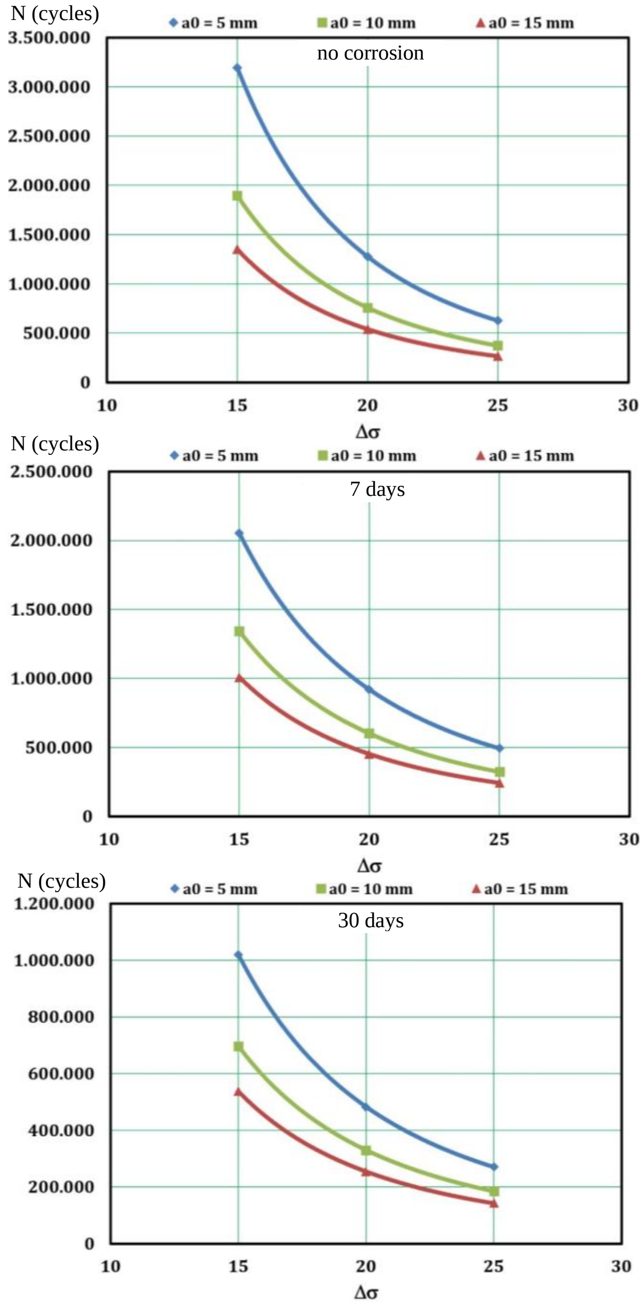

Figure 7. Remaining life vs. stress range: a) no corrosion; and corrosion for: b) 7 days; c) 30 days.

DISCUSSION

As one can see from Fig. 7a, the remaining life is significantly reduced with the increase of initial crack length (e.g. in the case of no corrosion and stress range 15 MPa, it is reduced 41 % for initial crack length of 10 mm, and 58 % for initial crack length of 15 mm). Also, significant reduction can be seen for the increase in stress range, e.g., in the case of no corrosion and the initial crack length of 5 mm, the reduction is 60 %, for 20 MPa compared to 15 MPa, and as high as 78 % for 25 MPa compared to 15 MPa. Finally, if the corrosion effect is analysed, it is significant as well (e.g. for the stress range of 15 MPa and 7 days corrosion, the reduction in the case of initial crack length of 5 mm is 36 %, while for 30 days corrosion, it is as high as 68 %).

CONCLUSIONS

Based on presented results we conclude the following:

- the remaining life is significantly reduced with an increase of initial crack length, stress range, and corrosion exposure,
- using the relatively simple engineering tool to evaluate the remaining life, one can get useful information on the behaviour of crucial components of an aircraft in various corrosion conditions, for different initial crack lengths, and different levels of the stress range.

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C. *Failure analysis* (V. Infante, M. Freitas and C. Azevedo). An Engineering Failure Analysis special issue is available.
D. *SHM and damage identification - prediction of structural response* (A. Katunin, H. Lopes and J. Bär)
E. *Structural integrity of steel/FRP & concrete composite structures* (X. Haohui, J. Correia, J. He, R. Liu and Z. Xiong)
F. *Structural integrity of 3D printed metal components* (M. Kepka and V. Chmelko)
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I. *Aerospace materials & manufacturing: emerging materials, manufacturing, and repair techniques* (M. Elboujdaini and G. Olson)
M. *Fatigue and structural integrity* (L. Reis, J. Correia and F. Berto)
N. *Hydrogen embrittlement of metals: problems and solutions* (TC21 *Hydrogen embrittlement and transport* of the ESIS, M. Djukić, F. Cheng, M. Koyama, T. Depover, A. Alvaro, and E. Martinez-Paneda). The tentative programme is already available.
O. *Fluid-structure interaction and integrity of mechanical and biological structures* (J. Xavier and M. Brito)
P. *Environmentally assisted degradation and fracture of materials: advanced characterization and modelling* (ESIS TC10, R. Mostert, C.M. Charalampidou, M. Zheludkevich, J. Toribio, H. Nykyforchyn, and N. Alexopoulos)

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