Оцінювання негативних побічних ефектів, спричинених антикорозійними профілактичними речовинами / Михайло Віталійович Карускевич, Татьяна Петрівна Маслак, О Линник, Василь Миколайович Олексюк // Вісник ТНТУ, — Т. : ТНТУ, 2015. — Том 79. — № 3. — С. 39-46. — (Механіка та матеріалознавство).

УДК 620.179.6(045)

М. Карускевич, докт. техн. наук; Т. Маслак, канд. техн. наук; О. Линник; В. Олексюк

Національний авіаційний університет

ОЦІНЮВАННЯ НЕГАТИВНИХ ПОБІЧНИХ ЕФЕКТІВ, СПРИЧИНЕНИХ АНТИКОРОЗІЙНИМИ ПРОФІЛАКТИЧНИМИ РЕЧОВИНАМИ

Резюме. *Представлено вимоги до процедури оцінювання негативних побічних ефектів, спричинених застосуванням антикорозійних сполук або інших поверхнево-активних речовин, які застосовуються в авіації. Показано, що негативний вплив на втому конструкцій літака має бути проаналізований на різних стадіях втоми та на різних масштабних рівнях. Розглянуто три аспекти загальної методології: вплив поверхнево-активних речовин на стадії зародження втомних тріщин, відомий як ефект Ребіндера; вплив поверхнево-активних речовин на швидкість розповсюдження втомних тріщин; зменшення втомної довговічності заклепкових з'єднань як результат зменшення сил тертя між листами обшивки. Показано, що всі ці підходи можуть бути об'єднані в одну загальну методологію сертифікації антикорозійних сполук.*

Ключові слова*: конструкція літака, втома, корозія, профілактичні покриття.*

M. Karuskevich, T. Maslak, O. Lynnyk, V. Oleksiuk

ESTIMATION OF NEGATIVE SIDE EFFECTS CAUSED BY THE CORROSION PREVENTIVE COMPOUNDS

Summary *The paper presents requirements to procedure of examination of negative side effects caused by the corrosion preventive compounds or any surfactants used in aviation. It is shown that the negative influence on the fatigue of aircraft components should be analyzed on different stages of fatigue and at different scale level. Three aspects of the general methodology are discussed: influence of surfactants on initial stage of fatigue, known as the Rebinder effect, influence of the surfactants on crack propagation, and reduction of fatigue life of riveted joints as result of the reduction of friction between the sheets of skin. It is shown that all three approaches must be combined in one generalized methodology for the certification of corrosion preventive compounds.*

Key words: *aircraft structures, fatigue, corrosion, preventive compounds*

Introduction. Despite the progress in the development of new constructional materials and improvement of the maintenance procedure, corrosion continues to be a widespread and costly issue for airplanes. Due to the increase of the planes service life the issue gets more evident and dangerous.

The use of Corrosion Preventive Compounds (CPCs) reduces the risk of the unexpected failure caused by corrosion damage, but the questions arise about probability of CPCs possible side negative effects on aircraft components' fatigue.

The wide range of CPCs on the market makes the problem of the CPCs universal testing more and more important, but relevant published information has very limited character.

Aircraft fatigue phenomenon currently is analyzed at different scale level and at the different stages of fatigue. Thus the same approaches should be used for the analysis of the side effects of CPCs application.

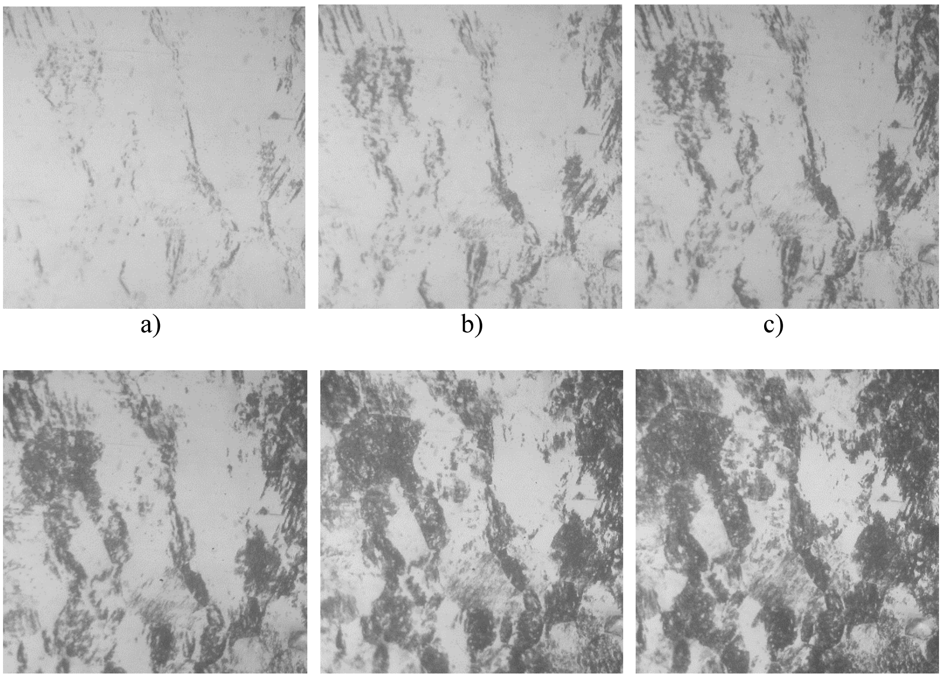
The interaction of CPCs with metal components will be discussed below in terms of: a) CPCs influence on dislocation processes at the initial stage of fatigue (Rebinder effect); b) CPCs influence on crack propagation; c) CPCs influence on the redistribution of forces in aircraft rivets components.

How to reveal Rebinder effect in the CPCs environment. Rebinder effect [1] is known as the decrease in mechanical properties which sometimes accompanies the absorption from solution of such surface active agents as the long-chain fatty acids, alcohols and amines. The surface-active agents, lowering the surface energy of the metal, contribute to the emergence of plastic shear.

If the metal fatigue is considered, the Rebinder effect manifests change of correspondent dislocation structure of the surface layer as well as acceleration or deceleration of the damage accumulation process.

At National Aviation University the methodology of fatigue damage assessment based on quantitative analysis of the surface deformation relief has been developed [2]. The deformation relief have been observed and analysed on the surface of alclad aluminium alloys D16AT, V95, 2024T3, 7075T6. The methodology relies on the possibility to measure intensity of the deformation relief (damage parameter *D*) by the computer aided light microscopy technique.

The evolution of the relief intensity with the indicated damage parameters *D* is presented in Fig.1.



a) b) c)

d) e) f)

Figure 1. Evolution of the deformation relief under fatigue under the σ_{max}=147 MPa; R=0; 400^x: a) 15200 cycles, *D*=0,042; b) 30000 cycles, *D*=0,136; c) 47300 cycles, *D*=0,208; d) 100000 cycles, *D*=0,296; e) 258000 cycles, *D*=0,427; f) 711000 cycles, *D*=0,543

Рисунок 1. Еволюція деформаційного рельєфу при втомному пошкодженні при σ_{max}=147 MPa; R=0; 400^x: a) 15200 циклів, *D*=0,042; b) 30000 циклів, *D*=0,136; c) 47300 циклів, *D*=0,208; d) 100000 циклів, *D*=0,296; e) 258000 циклів, *D*=0,427; f) 711000 циклів, *D*=0,543

Despite the existence of some other advanced methods of nondestructive inspection of the metal surface, for example atomic force microscopy, scan microscopy, non-contact interference profilometry, the two dimensional images of the deformation relief and the correspondent damage parameter D are considered as primary characteristics of surface damage under fatigue. It was proved that the evolution of deformation relief is sensitive to the stress amplitude, stress ratio, sequence of loading, etc. so it can serve as reliable indicator of accumulated fatigue damage for components made of alclad aluminium alloys and for fatigue sensors.

Thus, to reveal influence of the CPCs or any surfactants on initial stage of fatigue the monitoring of the damage relief of the component covered by the CPC should be conducted. The strain-stress state of the specimen under the laboratory loading must be as close to the operational condition as possible.

How to reveal CPC influence on fatigue crack. Damage tolerance concept in aviation industry assumes the origin and propagation of fatigue cracks. That's why there is strong necessity to know all factors that affect cracks. Analysis of researches in which aviation materials and components, treated by CPCs were tested, proves the probable harmful effect on fatigue crack propagation rate. For example, the paper [3] presents the results of crack growth measurements conducted on aluminum alloy 2024-T351 samples, in normal laboratory air, distilled water and an oily film CPCs commonly used in the aerospace industry.

Samples subjected to medium under high stress fatigue in the CPCs environment exhibit an increase in crack growth rate of the order of 20%, compared to about 7% increase in distilled water. The influence of the environment is mainly seen as a change in the Paris coefficient C, with negligible change in the Paris exponent "n". Authors of the paper consider some mechanisms by which the presence of CPCs increases crack propagation rates and recognize as necessary the further researches covering a wider spectrum of load levels, stress ratios, frequencies and materials.

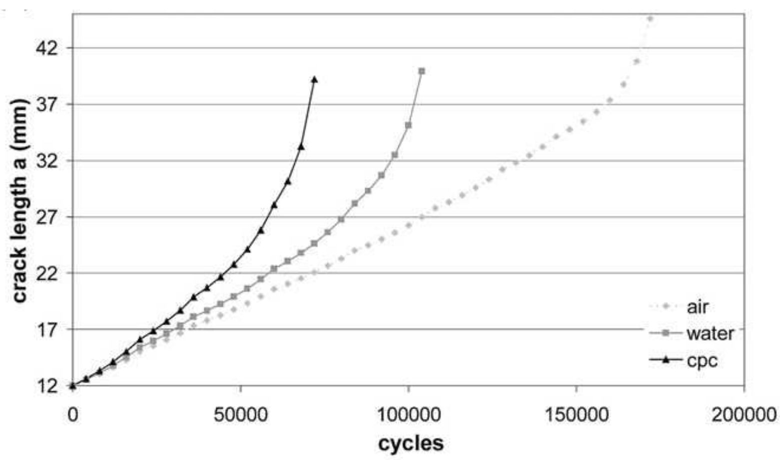


Figure 2. Fatigue crack propagation rate in different environments [3]

Рисунок 2. Швидкість розповсюдження втомної тріщини в різних середовищах [3]

The test technique used by authors of the paper [3] in our opinion might be improved to make the impact of PCPs more evident and argued.

It is well known that number of cycles to crack initiation is a random value. As the damage accumulated before the start of the crack influences the rate of the further damage and fracture, the impact of the CPCs might be hidden or not evident. In our opinion it is more efficient to input CPC on the stable phase of crack growth. To prove this procedure concept the special experiment has been conducted. We have tested specimens of D-16AT alloy (analogue of 2024 T3) shown in Fig. 3.

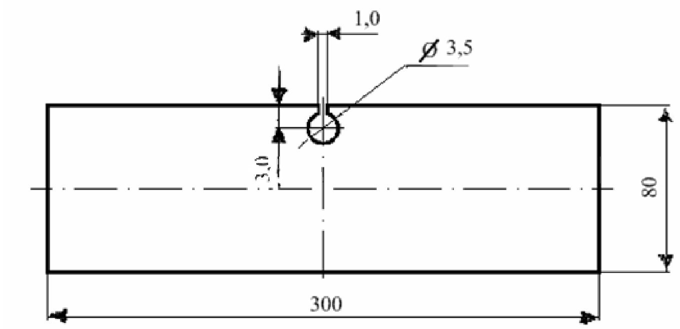


Figure 3. Specimen for fatigue crack growth measurements

Рисунок 3. Зразок для вимірювання росту втомної тріщини

The specimens have been tested under the maximum stress 100 MPa and stress ratio R=0. The frequency of loading is 11 Hz. The hydraulic machine MUP-20 was used for the loading.

At the first stage of test the specimens without surfactants covering have been tested. Results of the crack propagation are presented in Fig.4. No changes of the crack rate are observed.

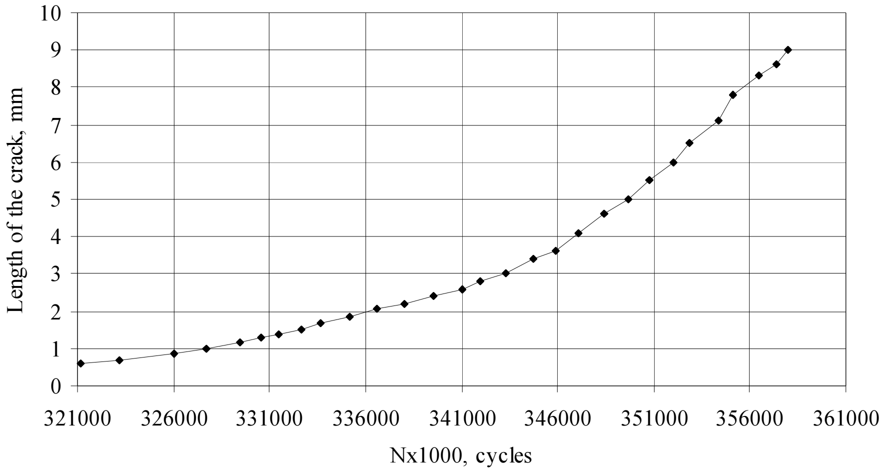


Figure 4. Fatigue crack growth in the specimen without surfactant treatment

Рисунок 4. Ріст втомної тріщини в зразку без покриття поверхнево-активною речовиною

Let’s consider then the results of the examination of the CPC DINITROL AV25 influence on crack propagation (fig.5).

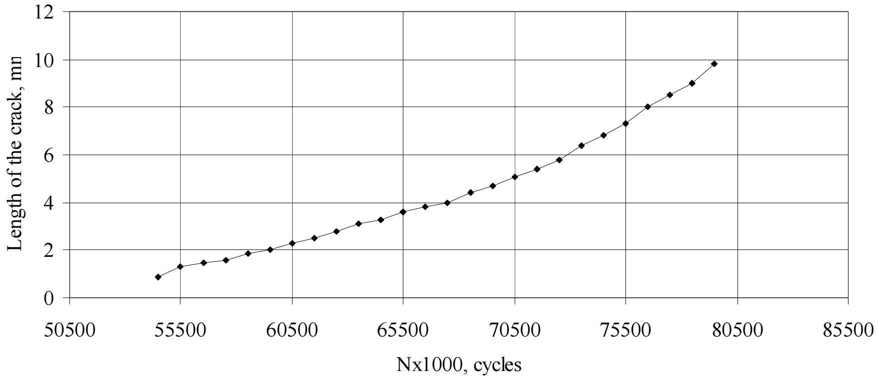


Figure 5. Crack growth before (crack length < 2.0 mm) and after (crack length > 2.0 mm) the covering by DINITROL AV25

Рисунок 5. Ріст втомної тріщини до (довжина тріщини < 2.0 мм) та після (довжина тріщини > 2.0 мм) нанесення DINITROL AV25

The CPC was applied at the process of crack growth, when the crack reached 2 mm length. The number of cycles was 127200 and the rate of growth was correspondent to the stable propagation stage.

As it is seen from the Fig. 6 the application of DINITROL AV25 has no negative effect in the described conditions of the loading.

This result unfortunately can not be extended to all surfactants. The following test has proved the necessity of examining. The solution of oleic acid, $CH_3(CH_2)_7CH$ in glycerine has been applied as a standard surfactant .

As it is seen in Fig. 6, after the covering of the 2.0 mm crack by the glycerine solution of the oleic acid at 120700 cycles of loading, the rate of the crack propagation considerably increases, thus the negative effect is evident.

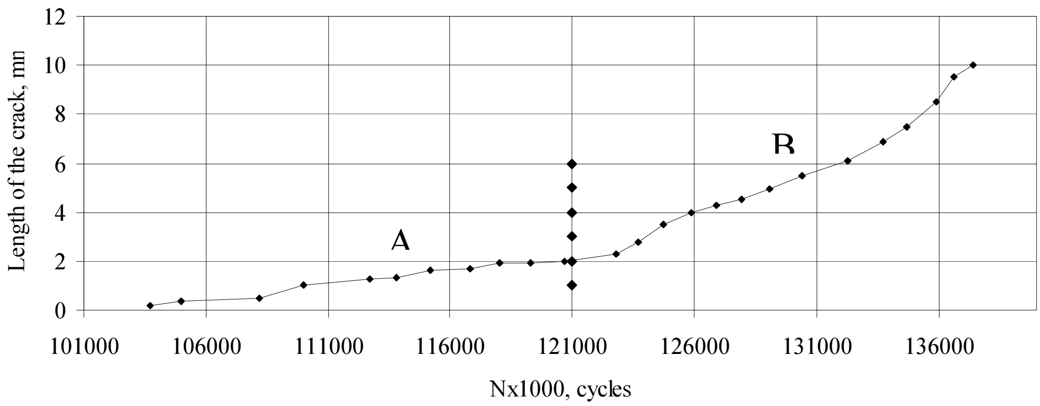


Figure 6. Fatigue crack propagation before (area A) and after (area B) the covering by the oleic solution

Рисунок 6. Розповсюдження втомної тріщини до (ділянка А) та після (ділянка В) нанесення олеїнового розчину

Thus, the proposed procedure allows examination of the surfactants' side negative influence on fatigue fracture process and might be used under certification test of CPCs.

How to reveal CPC influence on the redistribution of forces between riveted components. Some tests performed in different countries have demonstrated the negative effect of the CPCs on the fatigue of the riveted structural components. Similar tests have been carried out at the National Aviation University in Kiev in the 1980th and in the Great Britain [4], Holland [5], Australia [6].

In the research [7] the specimens were subjected to constant amplitude fatigue testing. Two CPCs used to prevent aircraft corrosion were applied. The results showed that the application of CPCs reduced the fatigue life of single lap joints. The greatest reduction occurred when the joints were tested at intermediate load levels and at the upper bound of the low load levels; a reduction factor of two or more was found. At high and low load levels, less reduction in fatigue life was observed.

Some possible mechanisms of the phenomena have been discussed. A major factor in this drop of fatigue life could be the reduction of friction due to the lubricating properties of the compounds. The reduction in friction between connected sheets would cause more load to be transferred through the rivets. Such a change in load transfer mechanism would explain the changes observed in the fatigue of the joints. The change in friction determined by high penetrating property of CPC.

The examining of the friction reduction effect can be performed by special tests simulating rivet joints. The drawing on fig.7 shows how to simulate rivet joint and measure friction between sheets of metal.

The presented specimen simulates two rows lap splice. Instead of circular holes for rivets the openings were made so that to provide mutual displacement of the sheets and instead of rivets the bolts are installed. The force of axial drawing-up of bolts is controlled by special calibrated torque wrench spanner so that the axial load corresponds to that produced by the rivet.

The model of the rivet joint is subjected to the slow loading with registration of the force correspondent to the displacement of the sheets from initial mutual position. In fact measured force is a force of friction dependent on the characteristics of CPC penetrated into the crevice between the sheets.

By this simple test it becomes possible to find out the CPC which causes the negative effect on the fatigue strength of riveted joints.

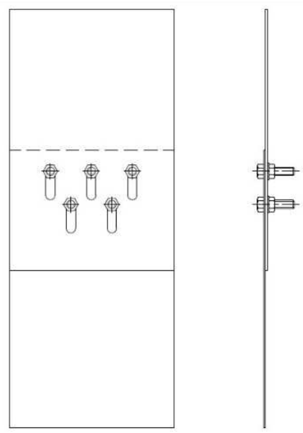


Figure 7. Simulation of riveted joint to measure friction between sheets of aircraft skin.

Рисунок 7. Схематичне зображення заклепкового з’єднання для вимірювання тертя в листах обшивки літака

At the first stage of research three series of test have been conducted. In the first test the model of rivet joint without treatment was subjected to the loading. In the second test the model was loaded after treatment by DINITROL AV-25, in the third test the model was treated by well known greasing Ciatim-201.

The results are presented in the Table 1.

Table 1.

Results of the friction measurement in riveted joint

Treatment	Number of test					Average value
	1	*2*	*3*	*4*	*5*	
No treatment	4.93	5.11	4.57	6.76	8.24	5.922
DINITROL AV 25	4.58	3.01	2.82	2.82	2.83	3.212
Ciatim-201	3.91	4.63	3.52	3.83	3.80	3.938

As it is seen from the table the method proposed allows investigation of the friction in the model of rivet joint when the different surfactant penetrate into the gap between the sheets of metals.

As the friction is one of the main factors that influences the redistribution of the forces between the components of joint, by the measurement of friction it is possible to select appropriate covering.

Conclusions. As the corrosion remains to be one of the most dangerous damage of the aircraft, the new generations of CPCs are expected to be under inventions and implementations.

The chemical composition of some CPCs allows their classification as surfactants. Interaction of surfactants with metal components can lead to the negative side effects both at the stages of crack initiation and propagation, thus the examination of the CPCs influence on fatigue becomes actual. Another factor that becomes harmful in some conditions is the lubricating property of the CPCs, which together with easy penetration into the crevices can change the friction between the joined by rivets components and influence fatigue strength.

For alloys covered by the aluminium layer the influence on initial fatigue stage can be revealed by the analysis of surface deformation relief as an indicator of accumulated fatigue damage.

For the examining of the CPCs influence on crack propagation the CPCs should be used directly under the loading. It allows investigator to ignore fatigue scatter.

To reveal CPCs influence on the fatigue properties of riveted joints instead of numerous fatigue tests the measurements of the forces of friction in the CPCs environments can by conducted.

Altogether these three procedures allow correct preliminary selecting of the corrosion preventive compound for aircraft structures.

References

1. Karpenko, G.V. The Rebinder effect in corrosive and weak surface-active media / G.V.Karpenko, E.M.Gutman, I.I.Vasilenko//Fiziko-Khimicheskaya Mikhanika Materialov. – 1967. – V.3, № 5. – P. 523 – 532.
2. Karuskevich, M. Extrusion/intrusion structures as quantitative indicators of accumulated fatigue damage / O. Karuskevich, T. Maslak, S. Schepak. // International Journal of Fatigue. – 2012. – № 39. – P. 116 – 121.
3. Craig Purry, Alan Fien, Krishnakumar Shankar. The effect of corrosion preventative compound on fatigue crack growth properties of 2024-T351 aluminium alloys International Journal of Fatigue 25 (2003) 1175 – 1180.
4. O'Neill PH, Smith RJ. A short study of the effect of a penetrant oil on the fatigue life of a riveted joint. Farnborough, UK: Royal Aircraft Establishment, pp. 1305, 1973.
5. Schijve J, Jacobs FA, Tromp PJ. Effect on anticorrosion penetrant on the fatigue life in flight simulation tests of various riveted joints. NLR TR 77103. Amsterdam: National Aerospace Laboratory, 1977.

6. Dhamari RDA. The effects of water displacing corrosion preventatives on the fatigue behaviour of mechanically fastened aluminium joints. PhD thesis: Aerospace, Civil & Mechanical Engineering, Australian Defence Force Academy, UNSW, 2005.
7. Aditya Jaya, Ung Hing Tiong, Reza Mohammed, Cees Bil, Graham Clark. The influence of corrosion treatments on fatigue of aircraft structural joints, 27th international congress of the aeronautical sciences, 19 – 24 September 2010, Nice, France, pp.1 – 8.

Отримано 27.08.2015