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NEGATIVE SIDE EFFECTS OF CORROSION PREVENTIVE COMPOUNDS ON AIRCRAFT FATIGUE AND CRITERIA FOR THEIR SELECTION

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Summary. *The necessity and possibility to reveal probable negative side effects of Corrosion Preventive Compounds on fatigue of aircraft structural members is shown. Three mechanisms of the side effects are considered: a) redistribution of loads on the riveted components due to the reduction of friction; b) influence on fatigue crack propagation; c) influence on fatigue crack nucleation. Experimental methods to reveal negative side effects are proposed.*
Key words: *corrosion preventive compounds, fatigue, aircraft structures.*

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Introduction. Despite the significant achievements in the aircraft design, manufacturing and maintenance, as well as developments of new protective materials, corrosion still remains one of the mostly frequent defects. It takes approximately 25% of all operational defects with huge required cost for repair.

One of the efficient ways to prevent or block corrosion is application of Corrosion Preventive Compounds. These materials deserve special attention prior application because some researches reveal their influence on fatigue of primary structure components.

CPC are liquids able to prevent initiation of corrosion damage and even suppress existing corrosion process. This type of protection refers to the post-production additional treatment, with can be renewed after certain period if necessary. The number of CPC on the market grows but the special requirements to the aircraft safety form the special requirements to the CPC. Some unique and very much attractive properties of the CPC look rather controversial while discussing aircraft fatigue.

As it is known the metal fatigue is a progressive stage process, comprising: a) stage of the fatigue crack nucleation; b) fatigue crack propagation.

Real aircraft structures, for example riveted joints of the skin are complex multi components designs. Covering by CPC leads to their penetration into the gaps between the sheets of skin, change of friction force between the sheets and consequent redistribution of loads on components. Thus, one can expect the more severe conditions for the resistance of the structure to fatigue.

Another aspect of the problem is probable chemical interaction of the CPCs with metal on the stage of the crack nucleation and propagation. The phenomenon of the plastic deformation easing by the action of surfactants called Rebinder's effect [1], can lead to the acceleration of the slip process with formation of extrusion/intrusion structure and the initial crack. The composition of known CPC may have the surfactant components, thus the chance for the Rebinder's effect exists.

The stable crack propagation stage must be considered while discussing side effects of the CPC application and it is not only Rebinder's effect. Some published results of the fatigue

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crack monitoring in the presence of CPC point out the clearly expressed negative effect, but the mechanisms are still need study.

Thus, general methodology for the CPC selection with respect to mentioned effects still absent and apparently the systematic studies of the CPC influence on the fatigue of aircraft structure are demanded currently.

Investigation of the Corrosion Preventive Compounds influence on fatigue crack nucleation. Currently used CPC are categorized as follows [2]: 1) Water Displacing Soft Film (WDSF): a) LPS-2; b)CRC 3-36; c) CRC Protector 100; d) Mobilarma 245; e) WD40; f) Boeshield T-9; g) Ardrox 3961; h) Ardrox 3107; 2) Water Displacing Hard Film (WDHF) – AV-8; 3) Non Water Displacing Soft Film (NWDSF): a) Fluid Film NAS; b) LPS-3 Heavy-Duty Inhibitor; 4) Non Water Displacing Hard Film (NWDHF): a) Dinol AV-30; b) ZipChem ZC-029; c) Dinol AV-40; d) LPS Procyon; e) Ardrox 3322. Apparently, the suggested influence on the fatigue depends on the CPC composition and correspondent properties.

Compositions of CPC can not be described in details because of the proprietary limitations for this information. Nevertheless, it is commonly known that CPCs may contain: a) oil, grease or resin to form covering film; b) a volatile, low surface-tension, carrier solvent; c) a nonvolatile hydrophobic additive; d) corrosion inhibitors, first of all e.g. sulphonates.

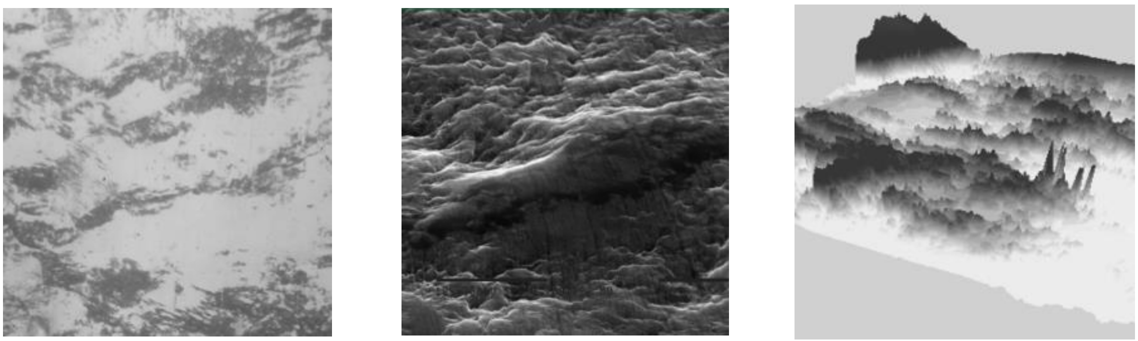
Oils and greases refer to the surfactant, thus CPC containing oil also should be considered as surfactant, so that the influence on the process of plastic deformation at the micro scale level is expected.

First time the influence of surfactants on metal fatigue was observed by P. Rebinder in 1928 [1] and since explored by many scientists. The Rehbinder's effect in material science is the reduction in the strength of a material by a surface active molecular film (surfactants).

The raw of surfactants is very wide. No sense to investigate influence of all surfactants on fatigue damage accumulation, but CPCs selected for the aircraft structure protection requires special attention.

Accumulated fatigue damage at the stage of crack nucleation currently is inspected by different methods. The approach developed at National Aviation University is based on the direct observation of surface deformation relief under fatigue. The methodology of the fatigue damage assessment based on the quantitative analysis of surface extrusion/intrusion structure described in the paper [3].

Deformation relief, as it was shown by light microscopy, scan microscopy and profilometry is a complex of surface intrusions, extrusions and persistent slip bands (Figure 1) observed on some ductile metals, for example pure aluminum covering industrial aluminum alloys, like a D16AT (analogue of 2024T3), or aluminum-zinc alloy used to cover V-95 (analogue of 7075T6).



a) b) c)

Figure 1. Deformation relief images: a) light microscopy, 300$^{\times}$, b) scan microscopy, 5000$^{\times}$, c) noncontact interferometry

Being indicator of accumulated fatigue damage, deformation relief can be used for the assessment of negative effect on fatigue caused by CPC [4]. The correspondent approach leads to the reduction of the number of specimens required to reveal mentioned effect by common way, i. e. by testing of specimens in statistical aspect.

Influence of CPC on fatigue crack propagation. Damage tolerant method for aircraft primary structures means that the structures are designed to sustain cracks without failure. To ensure safety the structure must be inspectable and damage could be detected in scheduled inspections.

Some experimental data show negative CPC influence on the aircraft fatigue crack propagation. In the work [5] the negative effect is revealed by the comparison of fatigue crack of 2024-T351 specimens in the air, distilled water and in the selected CPC, used in aviation. It was found that the rate of crack propagation in the distilled water 7% bigger than in air, and in CPC 20% bigger than in air (Figure 2).

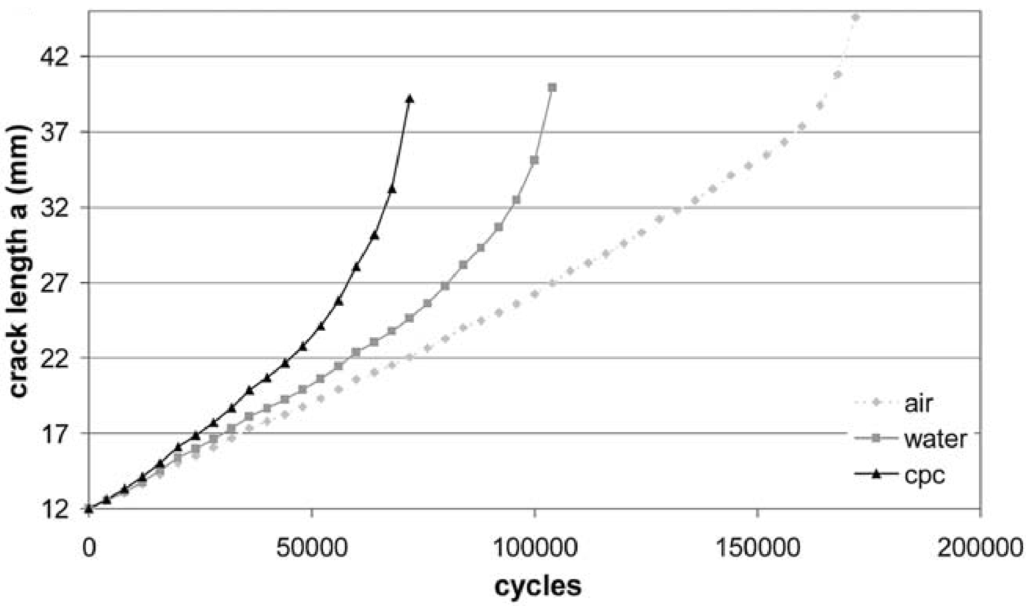


Figure 2. Influence of surrounding on the fatigue crack propagation rate [7]

Analysis of the Paris' equation:

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

where *a* – crack length; *N* – number of cycles; *ΔK* – range of stress intensity factor, shows that coefficient *C* changes in the greatest extend, whilst the *n* change is not sufficient. The mechanism of the influence is not explored in details yet, but it is clear that the crack tip spot deserves main attention.

The crack propagation analysis in the process of CPC selection must be the mandatory procedure. It should be taking into account also the influence of the load spectra on the effect of CPC on the plastic zone at the crack tip, thus the Variable amplitude loading program is preferable.

CPC influence on riveted joints fatigue. Riveted aluminum alloys structures are found to varying degrees on virtually all aircraft. The rivets are used to connect skin and stringers, skin panels, skin and frames, etc. The moisture penetrating into the gaps between structural components leads to the different types of corrosion, more frequently to the crevice corrosion.

Good penetration properties of CPCs provide removal of moisture from crevices, protecting by this way the structure against corrosion. At the same time good penetration of CPC may result in the bad consequence, influencing friction between the sheets of skin, or components of primary structure. There were some attempts to study this effect before CPC implementation [6]. In the work [7] the fatigue life of riveted joints decreased by a factor of two after treatment by CPC.

This effect can be explained by the reduction of friction between the components. The data concerning mentioned effect may also be found in papers [8, 9].

The influence of CPC on friction and correspondent reduction of fatigue life on our opinion can be explored by the simulation of riveted joints with special re-usable specimens, providing possibility to measure friction (Figure 3). The proposed design provides mutual displacement of sheets due to the special shape of holes for the bolts installed instead of rivets. Friction force is measured as a force at of the mutual displacement beginning.

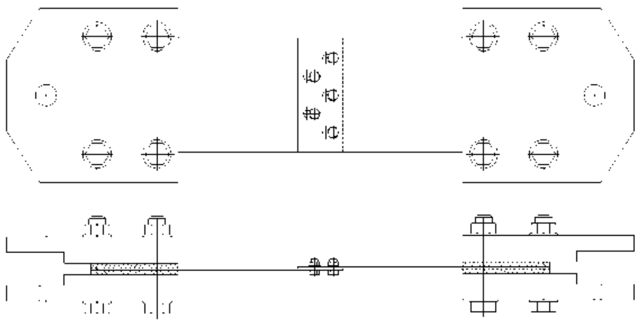


Figure 3. Re-usable specimen for measurement friction at the presence of CPC between the sheets of skin

Results of the friction between the sheets of riveted specimens are shown in Figure 4–5. The presented results do not reveal the effect of CPC Ardrox-AV25 harmful effect, moreover the presence of Ardrox-AV25 has led to the increase of friction.

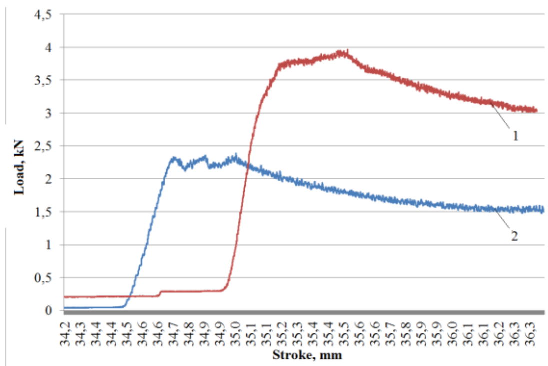


Figure 4. Friction force between the sheets in specimen treated by CPC Ardrox-AV25 (1) and without treatment (2)

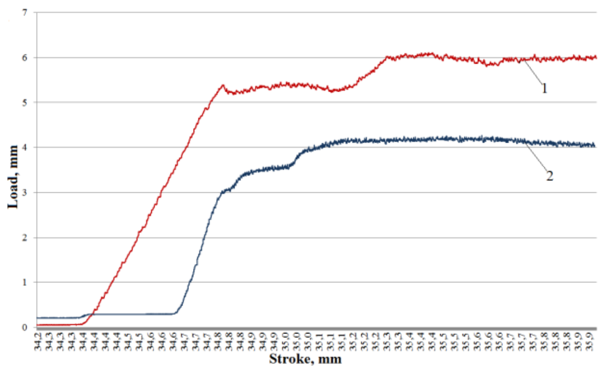


Figure 5. Friction force between the sheets in specimen without treatment (1) and treated by grease ЦИАТИМ-201 (2)

At the same time the presence of grease resulted with the sufficient reduction of friction and expected redistribution of forces between the components of the riveted joint. Thus, the application of any substance proposed for the structure treatment requires special study.

Conclusions. Application of Corrosion Preventive Compounds for protection aircraft primary structure can lead to the reduction of aircraft fatigue life. For the prevention of negative side effects the special complex procedure of the CPC selection is under development.

The components of this procedure are: a) investigation of CPC influence on fatigue crack nucleation, which can be performed on the base of analysis of the surface deformation relief under the action of CPC; b) investigation of CPC Influence of CPC on fatigue crack propagation based on the monitoring of crack propagation at the conditions as much as possible close to the constructional and operational details; c) investigation of CPC influence on riveted joints fatigue, based on the influence of CPC on friction between the sheets of skin panel and correlation between the friction between the sheets of skin panels and fatigue of the joints.

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НЕГАТИВНІ ПОБІЧНІ ЕФЕКТИ ЗАСТОСУВАННЯ АНТИКОРОЗІЙНИХ ПРОФІЛАКТИЧНИХ СПОЛУК НА ВТОМУ ЛІТАКА ТА КРИТЕРІЇ ЇХ ВІДБОРУ

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Резюме. *Не зважаючи на значні досягнення в проектуванні літаків, їх виробництві та обслуговуванні, а також в розробленні нових захисних матеріалів, корозія залишається одним із найрозповсюдженіших дефектів. Доля корозійних пошкоджень складає приблизно 25% експлуатаційних дефектів, а відповідні витрати на ремонт дуже значні. Одним з найефективніших шляхів попередження або уповільнення корозії є застосування профілактичних антикорозійних сполук. Ці матеріали заслуговують спеціальної уваги при їх упровадженні тому що, як показали деякі дослідження, їх застосування може мати негативний вплив на втому елементів авіаційних конструкцій. Наведено дані про вплив плівкоутворюючих антикорозійних сполук на процес руйнування зразків конструкційних алюмінієвих сплавів та заклепкових авіаційних конструктивних елементів. Для попередження негативних побічних ефектів запропонована та розробляється спеціальна комплексна процедура, яка поєднує методи визначення впливу плівкоутворюючих сполук на втому авіаційних конструкцій.*

Компонентами цієї процедури є: а) дослідження впливу профілактичних антикорозійних сполук на зародження втомних тріщин, яке може бути виконане на основі аналізу поверхневого деформаційного рельєфу, що формується в умовах дії профілактичних антикорозійних сполук; б) дослідження впливу профілактичних антикорозійних сполук на розповсюдження втомних тріщин, яке базується на моніторингу тріщин в умовах, максимально наближених до реальних умов роботи елементів конструкції; в) дослідження впливу профілактичних антикорозійних сполук на втому заклепкових з'єднань, яке базується на ефекті впливу профілактичних антикорозійних сполук на сили тертя між листами обшивки та кореляційній залежності втоми елементів заклепкових з'єднань від сил тертя в з'єднанні.

Ключові слова: *антикорозійні покриття, втома, авіаційні конструкції.*

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