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DEFORMATION RELIEF AS AN INDICATOR OF REBINDER EFFECT

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Abstract. *The paper presents the results of a research directed on the creating the method of assessing the impact of surfactants on the fatigue of aluminum alloys. The possibility of the Rebinder effect investigation by the deformation relief of the surface, emerging and developing as a result of cyclic loading, is shown. Anti-corrosion and lubricating materials, widely used in aviation, are selected as surfactants. The effect of surfactants on the incubation stage of fatigue is established.*

Keywords: metal fatigue, Rebinder effect, surfactants.

1. Introduction

Influence of surface-active agents (surfactants) on the strength of the metal was first discovered in 1928 by Rebinder (Rebinder 1978) and later confirmed by numerous investigators. It was found that the effect of environment on the mechanical properties of metals at their deformation is observed not only in the form of conventional chemical corrosion. Adsorption of typical surface-active substances from the environment also affects the deformation and fracture of metals, and sometimes to a greater extent than in the case of a direct chemical transformation.

Effect of adsorption deformation facilitation or adsorption decrease in strength is primarily due to the fact that the surface-active agents, lowering the surface energy of the metal, contribute to the emergence of plastic shear.

Despite decades of research of Rebinder effect, the conclusions based on fatigue tests of various structure materials on the influence of surfactants, are contradictory. For example, in the work (Karpenko 1955) it was shown that lubricants and other surface-active mediums cause steel endurance adsorption reducing on 7–26 % relative to their endurance in the air. This is due to the adsorption of surface-active agents (surfactants) that are contained in lubricating oils and in connection with it due to the lowering of the surface energy, and respectively due to the relief of deformation and fracture of cyclically loaded details.

At the same time, in the works (Chaevsky, Shatinsky 1970; Nikols 1969; Romanov 1969; Vedenkin 1955) it was shown that the decrease in longevity may be due to other causes. A various surfactants in the form of organic acids, alcohols, resinous substances, asphalt, and so on are formed in the lubricants during manufacture. The synthetic additives added to oils and improved one or more of their properties at the same time, also contain various surfactants. However, the lubricating oil, even after short storage in the free access of air, enters a small amount of water. It was noted that the oil is markedly reduces the endurance of steel, and it was conjectured about the negative role of small amount of water in it (Stepurenko 1974).

Consequently, the fatigue resistance of steel in lubricating oil can be affected by both the adsorption and corrosion factors.

Many elements of aircraft structures operate in a medium of surfactants. Surfactants include the anti-corrosion materials, lubricants, special fluids. The surfactants also include the film-forming inhibited petroleum compounds.

The film-forming inhibited petroleum compounds are the means of a temporary corrosion protection on the basis of high-molecular film-forming petroleum products with additives of corrosion inhibitors and solvents. After coating on the metal and solvent evaporation the film-forming inhibited petroleum products form a films on the metal that act as protective materials.

Due to the high demands on the fatigue strength of aircraft structures it is obvious a necessity of assessment of the impact of film-forming inhibited petroleum products and other surfactants used in aviation, on the accumulation of fatigue damage.

In recent years in National Aviation University, the studies of the damage accumulation in the surface layer are conducted (Karuskevich et al. 2012). As an indicator of fatigue the deformation relief of a surface is considered.

It was proposed and tested in numerous experiments a new parameter of damage, which is calculated as the ratio of surface area with deformation relief features S_{rel} to the total surface area which is controlled S_{tot}:

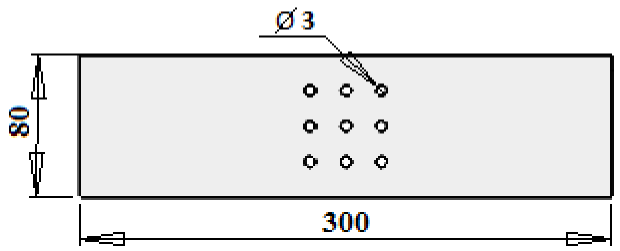
$$D = \frac{S_{rel}}{S_{tot}}.$$

The aim of the paper is to prove the possibility to reveal Rebinder effect by the analysis of the deformation relief on the surface of the metals covered by the anticorrosion surfactants.

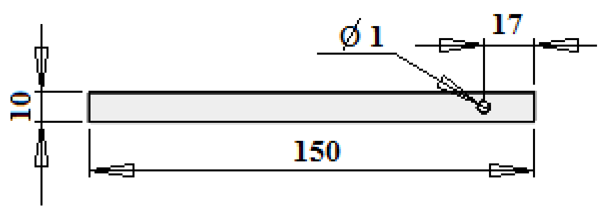
2. Experiments

Two types of cyclic loading have been carried out: a) axial tensile loading with a frequency 11 Hz and b) cantilever bending with a frequency of 25 Hz. In both cases, tests were conducted with the asymmetry coefficient *R=0.*

Specimens for fatigue tests were made of sheet alclad alloy D16AT (Fig. 1).



a



b

Fig. 1. Specimens for fatigue tests:
a – specimens for axial tension tests;
b – specimens for bending tests

Cyclic axial tensile tests were performed on a standard hydropulsation machine. Tests of compact samples for cyclic cantilever bending were performed on a machine developed at National Aviation University.

During the investigation of the effect of surfactants on the fatigue of structural aluminum alloys the next surfactants were used: Anti-corrosion film-forming compound DINITROL AV-25; Lubricant Ciatim-201; Aviation oil MS-20; 3 % oleic acid dissolved in Vaseline; Olive oil.

DINITROL AV-25 is water displacing anti-corrosion material with a high penetrating ability, which allows filling cracks and gaps of structural elements, forming a soft, waxy film. It is used to protect all applicable in the aviation industry metals and alloys. The material complies with technical requirements of the leading manufacturers of aircraft and standards: Airbus Industry TN 007 10138, Type I, Grade 2; AMS 3066; Boeing Material Specification BMS 3-226, Type I; I.P.T.N. NMS 3-26; McDonnel Douglas DMS 2150 and 2414; MBL-C-16 173 D; SAANN Aircraft STD 161454.

Ciatim-201 is low-viscosity petroleum oil, thickened by lithium stearate; it contains antioxidant additive.

MS-20 oil is aviation oil of selective treatment. It is made of paraffin and without paraffin oils with low sulfur content. Oleic acid $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$ (cis-9-octadecenoic acid) is monoun-saturated fatty acids. It is a colorless viscous liquid with melting point t_{melt}=13,4°C for the unstable beta version and t_{melt}=16,3°C for a stable alpha-modification, and boiling point t_{boil}=286°C.

Oleic acid is a traditional surfactant in the study of the Rebinder effect (Lichtman 1954).

Vaseline is used as a solvent of oleic acid. Vaseline is a mixture of mineral oil and solid paraffin hydrocarbons.

Olive oil is selected from the fact that it contains oleic acid. As for fatty acid composition it is a mixture of triglycerides of fatty acids with very high content of oleic acid esters.

The development of deformation relief was controlled by computerized optical method that allows quantifying the intensity of the relief by identifying previously proposed damage parameter *D* (Karuskevich et al. 2012). A typical image of the deformation relief at the stress concentrator – hole is shown in Fig. 2.

3. Experiment results

In the first stage the damage assessment was performed in conditions of axial cyclic tension. The experiments showed that the cracks can form in any of the rows of holes, which indicates a homogeneous state of stress along the length of the sample.

Determination of damage parameter *D* performed after 245,000 cycles of loading. At the same time a number of holes had fatigue cracks with length from 0.2 to 1.2 mm. For each of the tested samples the average value of parameter *D* for the plots treated with surfactant and not treated with was determined.

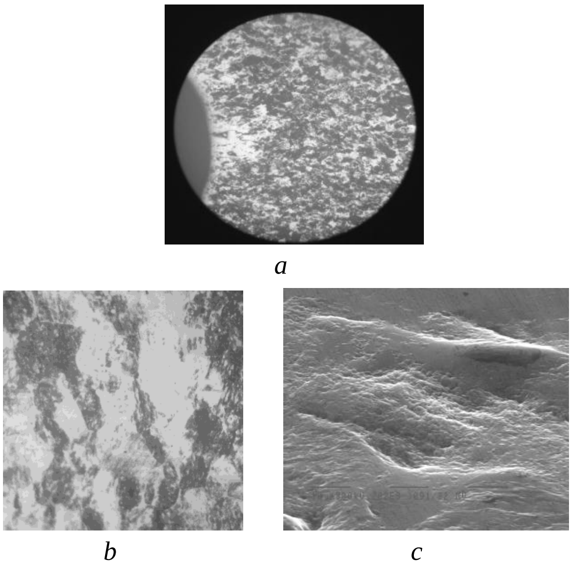


Fig. 2. Deformation relief of the surface of clad aluminum alloy D16AT:
a: Ч50 (optical microscopy);
b: Ч350 (optical microscopy);
c: Ч5000 (scanning microscopy)

A number of cracks by this time have been formed, thus the observed values of the damage parameter are the ultimate.

Taking into account that the considered cyclic operating time corresponds to the saturation stage of deformation relief and the formation of cracks at individual concentrators, the obtained values of the parameter *D* can be considered as ultimate for all monitored sites (Fig. 3).

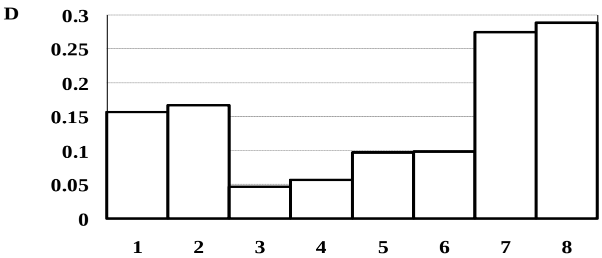


Fig. 3. Effect of surfactants on the value of damage parameter corresponding to the saturation stage:
1, 3 – treatment by composition DINITROL AV-25;
2, 4, 6 – without treatment;
5 – treatment by Ciatim-201;
7 – treatment by a 3 % solution of oleic acid in Vaseline;
8 – treatment by Vaseline

As it is seen from the presented diagrams the effect of surfactants is appeared in reaching the stage of saturation at lesser values of damage parameter. Taking into account that the saturation stage is completed by fatigue crack formation, we can draw conclusion about the effect of surfactants on the formation of fatigue cracks: a crack in the presence of surfactant is formed at a lower saturation of the deformation relief.

However, it should be noted that the difference of damage values between treated and not treated sites does not exceed 12.7 % at this stage. This determines the need for experiments in which the individual deterministic state would not be considered, but the accumulation of damage in its evolution would be.

The second phase of the study was aimed at establishing of the influence of surfactant on the evolution of the deformation relief and the corresponding damage. Compact specimens were studied under conditions of cyclic cantilevered bending. Samples were processed by the following surfactants: DINITROL AV-25, Ciatim-201, MC-20 oil, solutions containing oleic acid.

Fig. 4 compares the results of monitoring the deformation relief of samples surface coated with food olive oil in the area of stress concentrators and samples without surfactant.

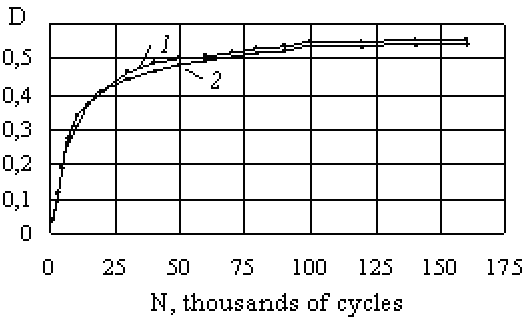


Fig. 4. Evolution of damage parameter D in the process of cyclic loading by the bending (σ = 235,0 MPa):
1 – without surfactant treatment;
2 – treatment with olive oil

As it is seen from Fig. 4 at a loading cycle maximum stress of 235,0 MPa the presence of olive oil has almost no effect on the development process of deformation relief.

Earlier studies by other authors have shown that the effect of surfactants on the deformation processes is determined by numerous factors: concentration of surfactant, properties of the material processed by surfactants, mode of loading.

In the present study the search of the most significant factors was carried out.

In this regard, let's consider the evolution of the deformation relief of the D16AT alloy samples surfaces treated with olive oil, at a somewhat lower level of cyclic stresses.

Fig. 5, *a* shows the evolution of relief at a maximum stress of the cycle 196,0 MPa.

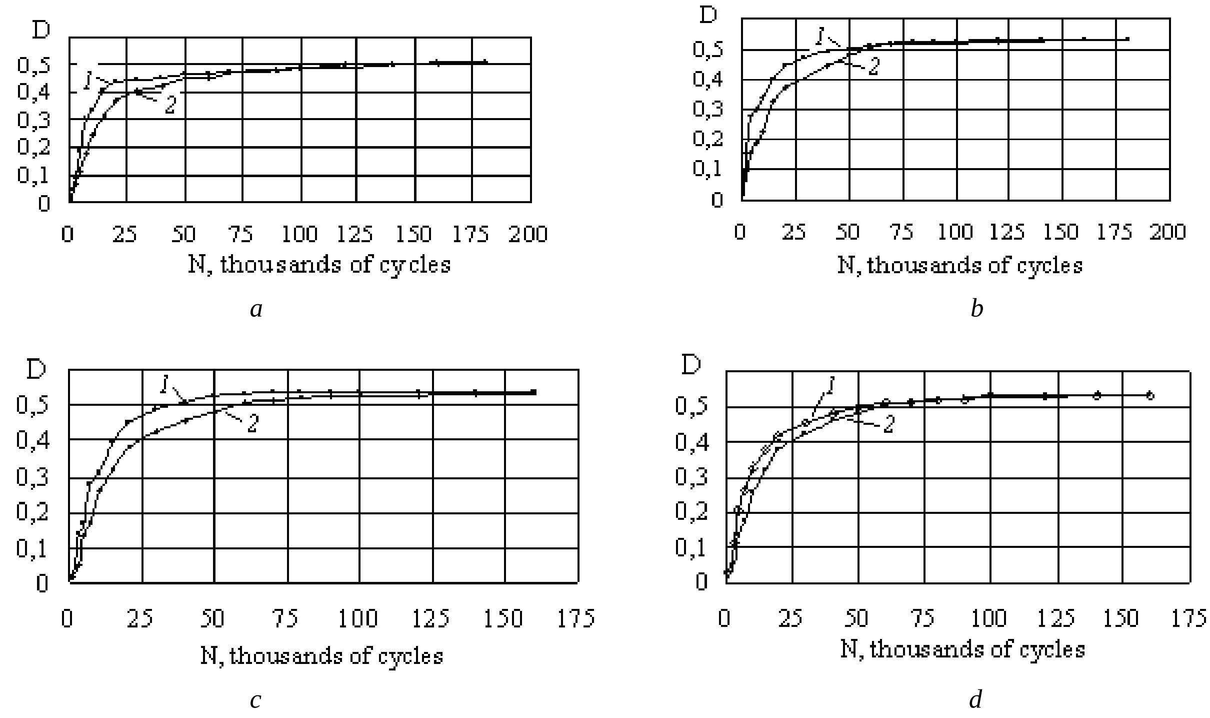


Fig. 5. Evolution of damage parameter D in the process of cyclic loading by bending (σ = 196,0 MPa):
1 (*a*) – treatment with olive oil;
1 (*b*) – treatment by DINITROL AV-25;
1 (*c*) – treatment MC-20;
1 (*d*) – treatment by Ciatim-201;
2 – without surfactant treatment

Presented data in Fig. 5, *b* indicate the presence of the influence of olive oil on the initial period of damage accumulation process, which appears in accelerating the development of deformation relief at the initial stage and the absence of such an effect when the state of saturation is reached.

Thus, it was shown that a decrease in the level of cyclic stress leads to the appearance of the Rebinder effect on the incubation stage of fatigue.

Fig. 5, *b* shows the effect of widely used in aviation anticorrosive coating DINITROL AV-25 on the development of the surface deformation relief. The maximum stress of cycle σ = 196,0 MPa. In this case, there is an acceleration of the damage process in comparison with the damage for the sample without surfactant. When the saturation stage is reached as well as in the above case, the processes of accumulation of damage do not reveal any visible differences.

As it is seen from Fig. 5, *c*, *d* the treatment by MC-20 and Ciatim-201 also influences the fatigue incubation period of aluminum alloy D16AT (σ = 196,0 MPa). At an early stage this effect is particularly expressive.

It can be assumed that the weakening of surfactant influence on the formation of deformation relief with further loading is due to the simultaneous action of different mechanisms of damage: the continuing growth of saturation and development of clusters of deformation relief, the appearance of cracks, and the stress relaxation on the shores of cracks.

4. Conclusions

It was established experimentally:

1. The presence of surfactant may contribute to the formation of fatigue cracks in the background of less-developed deformation relief.

2. Effective mean of investigation of the effect of surfactants on the fatigue of metals is to monitor the deformation relief, forming at the stress concentrators in the incubation stage of fatigue.

3. The approach provides the foundation of a new method of analysis and certification of surface-active substances used in the aviation industry by their effect on the accumulation of fatigue damage.

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Наведено результати дослідження методу оцінки впливу поверхнево-активних речовин на втому алюмінієвих сплавів. Показано можливість контролю ефекту Ребіндера по деформаційному рельєфу поверхні, який формується та розвивається в процесі циклічного навантажування. Як поверхнево-активні речовини обрано антикорозійні та мастильні матеріали, які широко використовують в авіації. Установлено вплив поверхнево-активних речовин на інкубаційну стадію втоми. Показано, що особливістю накопичення втомного пошкодження в середовищі поверхнево-активних речовин є суттєва чутливість процесу до параметрів режимів навантажування.

Ключові слова: втома металів, ефект Ребіндера, поверхнево-активні речовини.

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Приведены результаты исследований метода оценки влияния поверхностно-активных веществ на усталость алюминиевых сплавов. Показана возможность контроля эффекта Ребиндера по деформационному рельефу поверхности, который формируется и развивается в процессе циклического нагружения. В качестве поверхностно-активных веществ использованы антикоррозионные и смазочные материалы, широко применяемые в авиации. Установлено влияние поверхностно-активных веществ на инкубационную стадию усталости. Показано, что особенностью накопления усталостного повреждения в среде поверхностно-активных веществ является существенная чувствительность процесса к параметрам режимов нагружения.

Ключевые слова: поверхностно-активные вещества, усталость металлов, эффект Ребиндера.

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