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DEFORMATION RELIEF AS AN INDICATOR OF THE TEMPERATURE FLUCTUATIONS INFLUENCE ON THE FATIGUE DAMAGE ACCUMULATION

The article describes the methods and the preliminary results of the research directed on the investigation of temperature influence on D16AT aluminium alloy fatigue. The initial stage of fatigue has been studied by the analysis of the surface deformation relief. Test temperature regime corresponds to the aircraft structure temperature spectrum at the airfield. The level of cyclic stresses is about to those that arise when the airplane moves on airdrome surface.

Key words: *aluminium alloys, fatigue damage, elevated temperatures, deformation relief*

The actuality. Modern civil aircraft age is at least 30 years, during which 50-80 thousand flights are accompanied by repeated loading, caused by: lift force, pressure difference inside and outside the cabin, maneuvers, wind gusts, etc.

A substantial influence on the process of the fatigue damage accumulation is made by the aerodrome surface unevenness, which cause oscillations of the wing and other parts of aircraft. Requirements to analysis of the aircraft fatigue damage is recognized in corresponding regulatory documents [1–3].

A sufficient range of factors of additional external action contribute to the acceleration of the process of fatigue damage accumulation.

One of such factors is the fluctuation of ambient temperature which leads to temperature changes of structural members and corresponding changes of thermal-activated process.

By now a lot of experimental evidence have been accumulated [4–9 and others] (table 1), related to the temperature influence on the metal fatigue.

Table 1

Materials and temperature regimes of tests

Material	Research temperature regime	Source
Titanium alloy (ПТ7М)	20°С; 350°С	[4]
Titanium alloy (ВТ18У)	20°С; 350°С; 550°С	[4]
Titanium alloy (ВТ3-1)	20°С; 250°С; 450°С	[4]
Aluminum alloy (2024-T4)	Room-temperature; 180 °C	[5]
Steel (18%Cr-Nb)	Room-temperature; 500°C; 600°C; 700°C	[6]
Copper (M1)	196°С; 540°С	[7]
Bronze (БрБ-2)	20°С; 70°С	[7]
RR58 (aged alloy Al-2.5% Cu)	20-300°C	[8]
Powder metallurgy processed, supersolvus heat treated Udimet 720 and ME3	650°C - 704°C	[9]

The main interest of scientists is drawn by loading conditions, in which structures are subjected to extreme high and extreme low temperatures, which is obvious by reason of the evident effects of such regimes on the metal fatigue. At the same time, the effect of small temperature fluctuations, which include heating and cooling of aircraft while on the ground, have not been studied in the necessary degree.

It is obvious that evaluation of the effect of small temperature fluctuations on aircraft fatigue is a difficult task that requires a scientifically grounded methodology.

In this paper we consider the possibility of tool control of the process of fatigue damage at the temperatures corresponding to the heating of the aircraft structure while on the airfield. A main source of cyclic loading in this case is vibrations of the construction when moving on the runway.

Deformation relief as a fatigue damage indicator. As a result of cyclic loading systems of slip bands, extrusions, intrusions, features of grains rotating processes appear on the surface of some ductile poor metals and alloys. These structural signs of microplastic deformation form deformation relief of the surface, which, as numerical studies have shown, qualitatively and quantitatively reflect the accumulated fatigue damage of the surface layer. Deformation relief is being formed on the surface of the cladding layer of aluminum alloys under the stresses, which correspond to the aircraft components loading conditions in operation and under the full-scale testing.

The first slip bands can be observed under the mentioned loading conditions after a few thousands of loading cycles. With the increase of number of cycles the intensity of the deformation relief in two-dimensional and three-dimensional presentation increases as well.

Two-dimensional images, of the deformation relief, obtained by the light microscopy, demonstrate the increase of the surface area occupied by the features of microplastic deformation. Three-dimensional images, showing the increase of the extrusion and intrusion height and depth, can be obtained by means of contactless interference profilometry, or scanning electron microscopy.

Despite the monotonous character of the evolution of the quantitative indexes of deformation relief, there are certain limits of saturation, depending on the level of applied stress. Some grains have no features of the deformation relief due to their crystallographic orientation.

Stress concentration leads to primary formation of the relief near holes for rivets, at the adhesive/weld points, etc., that is, at places of potential failure.

The deformation relief of the surface has been observed at several scale levels. Light microscopy allows analysis of the deformation relief on meso - and macrolevel.

In the present paper the quantitative estimation of accumulated fatigue damage and comparison of processes of damage accumulation at 18-20 °C and in conditions of exposure to elevated temperatures was conducted by saturation of the deformation relief and fractal dimension of its clusters.

Methodology of the fatigue tests of D16AT alloy specimens at room and high temperatures. The specimens for the investigation of fatigue damage process were made of alloy D16AT. Aluminum alloys are the most common structural materials in the manufacture of aircraft. Despite the existing trend to use advanced composite materials, the airframe of modern Ukrainian aircraft An-140, An-148 manufactured using alloy D16AT. Analog for the D16AT alloy is widely used 2024T3, which in its composition and mechanical properties is very close to the D16AT alloy. The mechanical characteristics of materials and their chemical composition (without impurities) are shown in table 2 [9].

Table 2

The mechanical characteristics and the chemical composition of aluminum structural alloys D16 AT and 2024 T3

Alloys	Tensile strength, MPa	Yield stress, MPa	Elongation, %	Modulus of elasticity, MPa	Main components, (% of mass)
D16AT	440,0	290,0	18	71,0	Cu – 3,8-4,9; Mg – 1,2-1,8; Mn – 0,3-09
2024T3	435,0	290,0	12	73,2	Cu – 3,8-3,9; Mg – 1,2-1,8; Mn – 0,3-0,9

The presence of the cladding layer allows the monitoring the process of damage by visual characteristics of surface state.

Specimens for the determination of the main regularities of the deformation relief evolution under the combined action of elevated temperatures and cyclic loading have been made of alclad D16 alloy sheets. The dimensions of the specimens 10x150x1.0 mm. Thickness of cladding layer on each side close to 0.04 mm.

For compact specimens testing under cyclic bending a specially designed machine has been used (fig.1). Developed testing machine allows loading by cycles with any stress ratio.

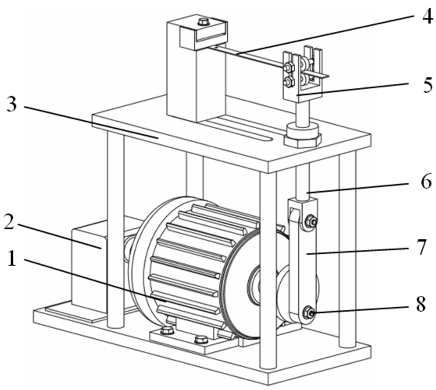


Fig. 1. Machine for the loading by cyclical cantilever bending: 1 – motor; 2 – cycles gage; 3 – element of the testing machine supporting frame; 4 – specimen for fatigue tests; 5 – movable grip of the testing machine; 6 – screw for the control of the stress ratio; 7 – rod; 8 – flywheel.

The amplitude of the deformations and the corresponding stress are determined by the eccentricity of the axis of the rod (7) mounting to the flywheel (8), or by the length of the working part of the sample. The asymmetry of the cycle can be set by a position of a slider (6).

The stress level in the working section of the specimen is determined by the formula [10]:

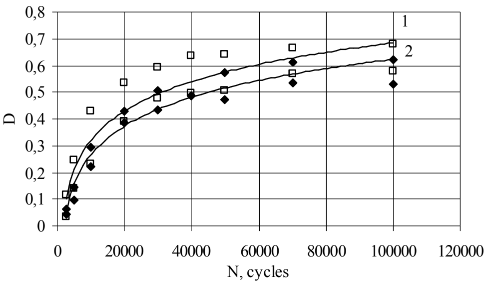
$$\sigma_{\max} = \frac{3E \cdot y \cdot x \cdot b}{2 \cdot l^3},$$

where E – modulus of elasticity; y – is the displacement at the point of force application of; x – the distance from the point of force application to the explored cross section; b - is the thickness of the sample; l – the working length of the sample.

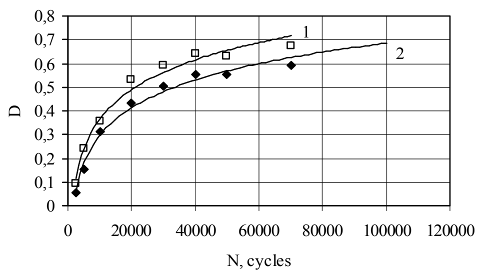
Monitoring of the deformation relief was performed using a stationary metallographic microscope MMP-4 equipped by digital camera. Magnification was 300^x. Digital photography of the deformation relief and assessment of the parameters of saturation and the fractal dimension of the clusters of the relief was carried out using a previously developed programs for the automated analysis of the surface deformation relief [11].

As a result of processing the following parameters have been identified: a) damage parameter *D*; b) fractal dimension of the deformation relief clusters *Dp/s*. The damage parameter *D* has been calculated as the ratio of the surface area with signs of microplastic deformation to the total surface area on the digital pictures of the site that is controlled. Fractal dimension *Dp/s* of the perimeter to the area ratio of the deformation relief clusters Dp/s was determined by the method of "box - counting".

Experimental results. The results of the experiments presented in the graphs of dependences of the damage parameter *D* on the number of loading cycles (fig.2) and fractal dimension *Dp/s* of the number of loading cycles (fig.3).



a



b

Fig.2.The evolution of the deformation relief saturation at the maximum stress of the cycle: 168 MPa (*a*) and 189 MPa (*b*): *1* – when the blowing hot air temperature 60°C, *2* – at room temperature

Each of the presented in fig. 2 graphs is based on the results of monitoring of the deformation relief of two samples. The samples tested at room temperature and 168 MPa stress failed after 172,6 and 168,9 thousands cycles of loading. The durability of samples tested at a temperature of 60° C and stress of 168 MPa was 142,9 and 141,9 thousands of loading cycles. The graphs presented in fig.2, b are based on the results of deformation relief monitoring of one sample each. A specimens of the second series of tests at room temperature and the stress of 189 MPa failed after 125,7 thousands of loading cycles. The durability of the specimen, tested at a temperature 60° C and stress 189 MPa was 118,1 thousand of loading cycles. The results of the determination of the fractal dimension evolution at room and elevated temperatures are shown in fig. 3 *a* and 3 *b*.

Each of dependencies shown in fig.3 is constructed by the results of tests of one sample. As it can be seen from the graphs of the fractal dimension *Dp/s* evolution, this parameter is not sensitive to the temperature change. Considering that the presented type of the fractal dimension reflects the change of the ratio of the perimeter and area of the deformation relief clusters, we can assume that the temperature change in the conducted tests conditions does not accelerate the formation of new clusters, i.e. does not contribute to the increase in the number of activated slip systems.

At the same time, saturation of the deformation relief, quantitatively described by a damage parameter *D* was sensitive to the temperature increase. It can inform about increasing of the height of the extrusions in the crystallites involved in the processes of microplastic deformation due to the ease of movement of dislocations under heating.

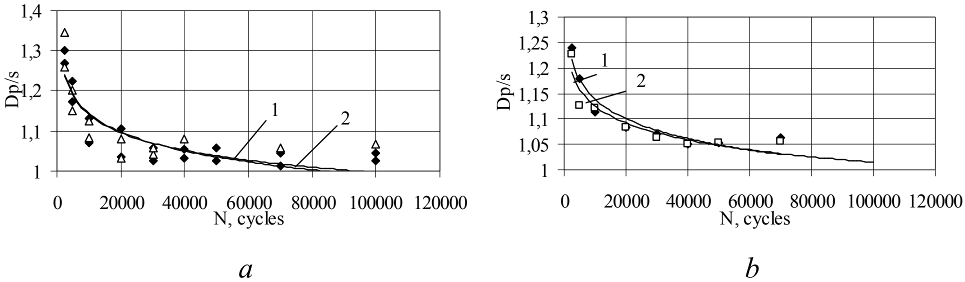


Fig.3. The change of fractal dimension *Dp/s* of deformation relief clusters at the maximum stresses of the cycle: 168 MPa (*a*) and 189 MPa (*b*): *1* – at the room temperature; *2* – at the blowing hot air temperature 60°C

Conclusions. The proposed technique allows a quantitative assessment of the impact of climatic fluctuations of temperature on the alclad aluminum alloys fatigue incubation period. The increase of the damage parameter value determined as the relative surface area with signs of microplastic deformation, with increase of the testing temperature from 20°C to 60°C is 13-16 % in the exhausting of 20% of the service life; 12.5% if the life exhausting is 40 %, and 10.5% at 60% durability of the specimens.

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ДЕФОРМАЦІЙНИЙ РЕЛЬЄФ ЯК ІНДИКАТОР ВПЛИВУ ТЕМПЕРАТУРНИХ ФЛУКТУАЦІЙ НА ПРОЦЕС НАКОПИЧЕННЯ ВТОМНИХ ПОШКОДЖЕНЬ

В статті представлена методика і попередні результати дослідження впливу флуктуацій температури на втому плакованого алюмінієвого сплаву Д16АТ. Інкубаційна стадія втоми досліджувалася шляхом аналізу деформаційного рельєфу поверхні. Температурний режим випробувань відповідає діапазону температур конструкції літака на аеродромі. Рівень циклічних напружень близький до напружень, які діють на літак при русі його по поверхні злітно-посадкової смуги.

Ключові слова: алюмінієві сплави, втомне пошкодження, підвищені температури, деформаційний рельєф

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