MATERIAL-SCIENCE ASPECTS OF FORMATION AND EVOLUTION OF DAMAGES WHICH DEFINE THE RESOURCE EXPLOITATION OF ALUMINUM STRUCTURES OF AIRPLANES

МАТЕРИАЛНО-НАУЧНИ АСПЕКТИ НА ФОРМИРАНЕТО И ЕВОЛЮЦИЯТА НА ВРЕДИ, КОИТО ОПРЕДЕЛЯТ ИЗПОЛЗВАНЕТО НА РЕСУРСИТЕ НА АЛУМИНИЕВИТЕ СТРУКТУРИ НА САМОЛЕТИТЕ

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Abstract
The work is devoted to the study of evolution of flaws in aluminium alloys of Al-Zn-Mg-Cu, Al-Cu-Mg-Mn alloying systems and to the determination of their connection with structural factors of the material such as the size and composition of intermetallic phases conditioned by heat treatment tempers, and also to the study of the effect of big number of physical factors on the long-term behaviour of structural elements of aluminium alloys, and to the determination of the rate of formation of corrosion damages in structural elements of the aircraft wing

KEYWORDS: *ALUMINIUM ALLOYS, CORROSION DAMAGES, INTERMETALLIC PHASES, COPPER, HEAT TREATMENT, MICROSTRUCTURE, CORROSION RESISTANCE, GRAIN BOUNDARIES, REGRESSION ANALYSIS*

Introduction

the study of evolution of flaws in aluminium alloys of Al-Zn-Mg-Cu**,** Al-Cu-Mg-Mn alloying systems and to the determination of their connection with structural factors of the material such as the size and composition of intermetallic phases conditioned by heat treatment tempers, and also to the study of the effect of big number of physical factors on the long-term behaviour of structural elements of aluminium alloys, and to the determination of the rate of formation of corrosion damages in structural elements of the aircraft wing. The work is aimed at securing the long-term safe operation of airplanes.

The issue of evolution of flaws and metal-science aspects of their formation was examined for В93Т1, В93пчТ1, 1933Т3 forging aluminium alloys of Al-Zn-Mg-Cu alloying system which is applied in the aircraft primary structural elements where we face large concentration and localization of stresses that can lead to their very rapid failure. In this case, origination and propagation of a failure can occur even without the previous effect of corrosion. Susceptible areas are strictly regulated and they are first of all subject to monitoring during scheduled inspection of the airplane. Using the techniques of electronic microscopy and X-ray chemical microanalysis, it was determined that during industrial heat treatment of В93 alloy using T1 temper: quenching 450-465^{o}C and two-stage phase ageing 115^{o}-125^{o}C (6-10 hours), 165^{o}-175^{o}C (4-8 hours), chains of the phase with increased content of copper precipitated at the grain boundaries during quenching simultaneously with strengthening phases. The size of some links of the chains reached 1-5 mcm. Their presence stipulates for concentration of stresses which contribute to corrosion cracking. Precipitation of inclusions of intermetallic phases containing copper at the grain boundaries does not correspond to the statements of developers of the alloy.

It was proved that change of heat treatment temper to coagulation ageing (T3 temper: quenching 450-465^{o}C and two-stage ageing 115^{o}-125^{o}C (6-10 hours), 180^{o}-190^{o}C (6-10 hours)) contributed to higher corrosion resistance of В93пчТ3 alloy compared to В93Т1 alloy, that was conditioned by much smaller content of copper in precipitation of intermetallic phases after quenching, formation of strengthening phases after ageing which did not contain copper, higher fragmentation of particles of intermetallic phases, which precipitated during quenching.

During coagulation ageing of 1933Т3 alloy, which differed from В93пчТ3 alloy with the zirconium admixture, precipitation of particles of strengthening phases occurred mainly at the stage of coagulation ageing. At the grain boundaries we observed particles of $MgZn_2$, $Al_2Zn_3Mg_3$, Mg_2Si phases connected with the matrix in a coherent way. Precipitation of particles of intermetallic phases with copper content at the grain boundaries did not occur, that obviously stipulated for the highest corrosion resistance of the alloy. Such differences in the structure of alloys, conditioned by heat treatment, contributed to evolution of flaws during transition from В93Т1 alloy to 1933Т3 alloy and the increase of corrosion resistance, yield and plasticity while maintaining high strength.

Application of X-ray microanalysis techniques allowed to determine the presence of coarse inclusions of insoluble phases with the length of 10 to 300 mcm in the grain body of all three alloys, which presence contributes to the development of fatigue failure during long-term operation.

Monitoring of flaws which contributed to premature failure of parts showed that В93Т1 alloy had low resistance to alternate and static loads, and was susceptible to corrosion cracking even under the absence of aggressive environments. 1933Т3 alloy appeared to be the most resistant to static, dynamic and alternate loads, and not susceptible to corrosion cracking.

Further examination of the issue of evolution of flaws and their monitoring in service was continued for wing upper and lower panel skins which are the most responsible structural elements of the airplane though they are much less loaded if compared to structural elements produced of forging alloys. For the upper panels, which are in compressed state during the flight, we apply В95Т1 high-strength alloy of Al-Zn-Mg-Cu alloying system, quenched and aged to the maximum strength. And for the lower panels, which experience tensile loads during the flight, we apply Д16Т long-life alloy of Al-Cu-Mg-Mn alloying system. The skins are produced of long extruded or rolled products: sheets or plates, in which the direction of elongated grains is perpendicular to the acting loads (the area of action of the load coincides with the transversal-longitudinal area of fibres in the material). Taking into account the design features: considerable length of joints, big number of fastener holes and areas of permanent condensation in the torsion boxes of the wing centre section (closed cavities), the most probable areas of origin of corrosion damage are the grain boundaries located in problem areas perpendicular to the direction of application of loads. A critical factor which determines the life of skins is thinning of their crosscut due to corrosion damage. Stated features of evolution of flaws and also relatively easy access to damaged areas change the strategic approach to enhancement of durability of these structural elements. An emphasis is made on the increase of latent period of formation of corrosion damage and fatigue cracks that is achieved at the first stage by applying protective coatings and restoring them after certain interval of operation. However, this effective method does not ensure 100% guarantee from appearance of corrosion spots in the metal matrix, that is why there is another and not less important way to delay the appearance of critical flaws called scheduled maintenance which ensures detection and elimination of flaws on external and internal surfaces of the wing. In this case, a critical condition is to provide the optimum amount of scheduled maintenance which from one side would ensure an accident-free operation and from the other side would minimize capital expenditures.

The paper addresses the main operating factors which influence the origin and growth of flaws on the surface of the aircraft wing skins, and determines characteristic areas which are susceptible to corrosion. The largest amount of statistical data is accumulated for two versions of An-24 and An-26 airplanes that allowed evaluating the damage growth rate in the centres of corrosion which appeared on upper and lower panel skins of B95T1 and Д16T alloys respectively. As a criterion there was taken the change of the maximum depth of damage on flawed surface areas which appeared in the interval between two successive inspections of panels, it means not considering the latent period of damage formation. It was shown that linear relation exists between the geometrical parameters of corrosion flaw and the time. The rate of corrosion is determined by the tangent of the angle of slope of the straight line.

Basing on the results of statistical analysis of a huge amount of data from inspections performed in certain climatic zones such as the size of corrosion damage, accumulated life, service life, intensity of flights, number of overhauls, etc., it was determined that climatic conditions and inspection intervals had the maximum effect on the corrosion damage growth rate (unlike the total time of operation).

Using the method of regression analysis, there were obtained the equations of regression which determined the corrosion damage growth rate for different climatic zones, and there was determined the maximum damageability of the aircraft wing skins during one year of operation: this data is shown below.

Lower panel skins of Д16T alloy:
Moderate climate - $y=(0.12\pm0.015)\ x_1$;
Continental climate - $y=(0.23\pm0.042)x_1$;
industrial zones - $y=(0.33\pm0.035)x_1$;
maritime climate - $y=(0.34\pm0.045)x_1$;
mixed operating conditions - $y=(0.28\pm0.037)x_1$;
humid tropics - $y=(0.47\pm0.056)x_1$.
where x_1 is the life between overhauls.
Upper panel skins of B95T1 alloy:
moderate climate - $y=(0.12\pm0.028)x_1$;
maritime and industrial zones - $y=(0.27\pm0.014)x_1$;
mixed tropical and moderate climate - $y=(0.37\pm0.025)x_1$;
humid tropical climate -
$y=(0.51\pm0.022)x_1 + (0.00024\pm0.00018)x_2$
- where x_1 is the life between overhauls; x_2 is the intensity of flights.

There by, the increase of the time between overhauls by 1 year leads to the increase of the maximum depth of corrosion damage on the lower panel skins of the wing centre section by ~0.12 mm in moderate climate zones; by ~0.23 mm in continental climate zones; by ~0.33 mm in industrial zones; by ~0.34 mm in maritime climate zones; by ~0.28 mm under mixed operating conditions; by ~0.47 mm in humid tropics zones.

Using the similar procedure, there was determined the depth of corrosion damage of the external surface of the wing upper panel skins of B95T1 alloy. In this case we shall expect the increase in depth by ~0.12 mm in moderate climate zones; by ~0.27 mm in the zones of influence of maritime and industrial environments; by ~0.37 mm in the zones of mixed tropical and moderate climate; by ~0.58 mm in the zones of humid tropics with the intensity of flights of 300 flights/year.

Basing on the obtained results of the analysis, technical documentation was developed for ultrasonic inspection of the thickness of lower panels of the wing centre section of An-24 and An-26 airplanes and there were issued the recommendations for timely detection of damages of different structural elements. This will make it possible to operate these airplanes without disassembly of panels during not less than 10 years after preliminary inspection and despite the climatic zone where the airplane is based.

The results of corrosion growth rate analysis for different structural elements of the wing were used to adjust the inspection intervals and to determine the optimum time for renovation of anticorrosion protection of the analyzed area and group of airplanes, as well as other areas, groups and types of airplanes for which this area and group can be considered a prototype.

General scheme of acquisition and analysis of corrosion damage data based on service experience of the available aircraft fleet allows solving both the problems of its continued airworthiness, and the problems of reliable anticorrosion protection of newly designed aircraft based on available data.

Research of the microstructure of industrial aluminium alloys in terms of susceptibility to corrosion cracking is taken into account when evaluating the life of a separate element and that of the entire structure, and it is also used for successful selection of materials with required set of features for existing and future aircraft structures.

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