Perspectives for use of composite and polymer materials in aircraft construction

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Abstract. One of the main indicators characterizing the quality of modern products are reliability indicators. The detection and development of effective measures to combat corrosion of aviation materials and structures is one of the most important areas of ensuring safety, high operational reliability and efficiency of modern aviation technology. It is one of the modern trends in the development of aviation at this stage of development of aircraft construction. This article discusses the technological aspects of the development of the use of composite materials in aircraft construction at the present stage of society development. The aircraft industry is one of the high-tech industries where modern polymer and composite materials play a decisive role. In this regard, the development of composite and polymer materials is the future of all the world aviation.

1. Rationale
The development of modern technology requires new structural materials that are superior in strength, elasticity and other properties to traditional ones. Polymeric materials like plastics, elastomers, fibers (first of all the filled ones) are the most interesting and promising among them. Structural polymer materials are increasingly used in modern mechanical engineering, and they are used in cases where no other material meets the ever-increasing requirements of new technology. Currently, polymers and materials based on them have seriously replaced such basic structural materials like reinforced concrete, metal, wood. The possibilities of polymeric materials are extremely wide due to the variety of polymers and fillers, the inexhaustible variability of the mixtures of composites based on them and the methods of their modification. For a long time, the main technological method for obtaining polymer composites has been mechanical mixing of a filler and a polymer matrix. Polymerization filling is a chemical grafting of a catalyst or initiator to the surface of the filler. The subsequent polymerization or copolymerization of monomers on these surfaces may open a new page in the chemistry and technology of composites. The development of the technology of composite polymer materials is currently determined by scientific research in the field of polymer materials science, since the problem of the interaction of fillers and matrices is very multifaceted. Modern people encounter polymer materials not only in technology, but also in everyday practice, therefore, knowledge of the basic properties of these
materials and the ability to use them correctly are gradually becoming necessary for an ever wider circle of people [1].

2. Ensuring the reliability of the aircraft

The problem of reliability of products (especially of such highly important ones as aircraft) is now generally recognized by everyone. In order to ensure the reliability of new products amount of money that reaches of up to 80-90% of all costs for a technical project are invested to the means of product reliability. And the timing of launching of a product into serial production due to its adjustment to the specified values of reliability indicators can increase by 3-5 times or more. The current standards regulate a unified procedure for the development, production and operation of created products. This procedure consists of three main stages: product development, mass production, operation of the product. The peculiarity of resolving issues of reliability lies in the fact that these issues must be resolved at each of the listed stages, since it is impossible to change the level of reliability of a manufactured product (as opposed to change of its appearance). The level of product reliability can be determined only after its operation or after conducting of special tests. And after that if it is necessary it is possible to make adjustments to the design, production or operational documentation and manufacture a new product with a higher level of reliability [2,3].

The main features of these three stages are considered below from the point of reliability. After receiving of an assignment for product development, the collection and study of data on load ranges and external influences at different stages of product operation is carried out. The actually achieved level of operational reliability of the product and its units (which are selected as prototypes) are studied. Products taken out of service due to failures or full depletion of the resource are of a special concern. Based on this information, the requirements for individual elements of the product are specified and the selection of materials is made taking into account their strength characteristics, processing properties, production capabilities and cost. After that, a comprehensive program is developed to achieve the desired level of product reliability with the specification of the work performed for individual units and the product as a whole at each stage of product creation. Product reliability is built into during design and construction. It depends on the design of the product and its assemblies, the materials and technologies used, methods of protection from external influences, lubrication systems, adaptability to repair and maintenance, etc.

Any unit can be designed in an infinite number of ways, calculating the reliability of the structure for static loads. However, at present, there are few calculations that allow predicting the behaviour of a structure in real operating conditions, taking into account the dynamics and statistical nature of external influences. Therefore, the design is based on the use of structures that have been used in the products that have passed the operation. Usually, during creation of new types of products, up to 50 or more percent of units and assemblies made according to previously developed schemes and tested in serial operation are used. This, on the one hand, speeds up and cheapens the process of launching a product into a series, but, on the other hand, slows down the progress of technology development [4]. For newly designed components and assemblies, a complex of advanced measures is carried out for their manufacture and testing at simulating installations, stands and special flying laboratories.

During the manufacture of a product, the reliability inherent in its design must be ensured, i.e. the manufacturing technology determines how much the potential of the design can be realized. It is known that up to 80% of product failures occur due to the fault of manufacturers. The failure of any technical product always occurs suddenly i.e. that it is impossible to accurately predict the time of its occurrence. Therefore, from the point of mathematics, failures are always simulated by random events. However, this random event can be predetermined either by gross errors at the stage of development, manufacture or operation of the product, or it can occur due to an unfavourable combination of many different factors. And as already noted, it is impossible to predict the time of failure in the first and second cases, it is customary to call failures that arise due to gross errors as predetermined. During classification of failures, it is necessary to distinguish between the classification carried out for the correct application of the mathematical apparatus of the theory of reliability, and the classification carried out for its application in engineering analysis.
From the point of engineering analysis of failure causes identification, the following classification is adopted:

- On the location of the failure (for example, during flight or on the ground);
- According to their consequences (for example, a flight accident, non-fulfillment of a flight mission or without consequences);
- On reasons of occurrence (structural, production, operational due to external or accidental reasons, operational due to errors of ground technical personnel, operational due to errors of flight personnel, etc.);
- According to the method of elimination (for example, restoration on place of operation, restoration in repair organizations, write-off). Depending on the period of operation of the product, the following failures are distinguished: failures that occur during the initial period (break-in failures), failures that occur during the period of normal operation and failures that occur during the period of natural aging of construction materials.

In addition, failures are divided into functioning failures, in which the product stops performing its functions, and parametric failures, in which the values of some parameters of the product have reached the specified tolerances, but the product itself could still perform its functions. This determines the special danger of failures of functioning, in contrast to parametric failures. In this regard, an important task is the development of diagnostic methods that make it possible to convert functioning failures into parametric ones [5,6].

While the aircraft have been subjected to operating loads of a small level, they have been made of medium-strength materials, had large safety factors and small resources, static calculations and existing technologies ensured the reliability of the products. However, the transition to high-strength materials to ensure a higher efficiency of the product showed that such materials are much more sensitive to any changes in external influences, both during operation and during manufacture.

Thus, an important task of creating technological systems for the production of aircraft is to identify the least reliable elements of technological systems and their improvement.

3. Influence and methods of corrosion prevention at the aircraft

The problem of assessing the effect of corrosive damage to the airframe of an aircraft (AC) on airworthiness is a rather complex scientific and technical problem, which requires a systematic approach. At the aircraft design stage, an analysis of the airframe structure is carried out in terms of corrosion conditions, a forecast of the sizes and types of possible corrosion damage, an assessment of the permissible dimensions based on strength conditions, and the formation of a corrosion control and prevention program. During aircraft operation, the methods of combating airframe corrosion are based on an analysis of the parameters of operational corrosion damage, clarification of their effect on the strength characteristics of the airframe structure, and adjustments to the start and frequency of inspections. In the world practice, the leading aviation companies, during formation of their aircraft maintenance strategy, develop measures to fight against corrosion damage, which are reflected in the corrosion control and prevention program, the zone inspection program, and the program for aging aircraft. The corrosion control and prevention program is developed at an early stage of aircraft operation in order to ensure the aircraft airworthiness under the conditions of corrosion as a result of deterioration of the technical condition due to chemical interactions or the impact of the external environment [7]. For long-term operating aircraft, upon reaching a certain service life, the aging aircraft program comes into force, within which additional procedures are provided to ensure the safety of aircraft operation.

Corrosion damages of aircraft are very different and depend on the conditions, terrain and nature of operation, where the aerodromes are based (rural or industrial area, areas of high moisture and high precipitation) where the equipment is located; on the conditions in which parts and assemblies are operated inside the aircraft structure; on duration of operation; quality of care of equipment and parts, etc.
Mostly corrosion occurs on the skins of aircraft based on aerodromes located near areas with high moisture and at the coastal areas.

The atmosphere in these places is affected by industrial gases (SO2; NO2; NH3; HCL), coal dust, salt particles, etc. Riveted joints, backfilling points, bolt heads, metallization points, etc. are especially susceptible to corrosion. Corrosion damages on the surfaces of aircraft skins are mainly of a point nature and sometimes are accompanied by other corrosion damages.

Corrosion damages are also observed on the outer surfaces of the skin, especially made of the pressed panels (they are not clad), which are exposed to the exhaust fumes. The upper surfaces of aircraft and helicopter skins are in better conditions than the lower ones. This is due to the fact that moisture settled after rain or condensate after planting, evaporates relatively quickly [8]. This is facilitated by air temperature and wind. The lower surfaces, are moistened almost constantly due to the insignificant distance from the ground and due to the evaporation of moisture from the soil.

In terms of corrosion, the internal surfaces of a aircraft, parts inside structures, work in more severe conditions than surface ones, which are explained by the long retention of moisture inside products and parts, components and assemblies. Moisture gets on the inner surfaces during precipitation or when washing equipment through the existing non-densities in the joints of the skins, it also condenses from the air after the aircraft lands due to a sharp temperature drop.

In more unfavourable conditions are the inner surfaces of the skin and parts of the inner set under the floor of the pressurized cabins.

Condensed moisture lingers here for a long time, it gets contaminated and becomes corrosive. Water pollution under the floor of a pressurized cabin occurs most of all due to insufficient tightness of floors and butt joints of toilets and faulty communication of bathrooms. These fluids are very dangerous, especially in relation to aluminium alloys and their additions. Moisture and condensation are also retained for a long time on the lower and internal surfaces in the event of an unsuccessful location or clogging of the drainage holes to drain moisture from the structural elements, as well as in the absence of possibility of ventilation and blowing of the underground space with warm air [9].

The occurrence of corrosion in the underground part of passenger and cargo cabins of aircraft is also assisted by gaps and slots and butt joints formed at the joints of stiffeners (stringers, frames, etc.) from the inner surface of the airframe skin, where moisture and condensate remain for a long time. The development of corrosion occurs especially rapidly in gaps and crevices formed during the contact of parts made of dissimilar alloys and metals, for example, from aluminium and magnesium alloys, aluminium alloys and steel, etc. Due to these and other reasons, a large area of corrosion can develop in the underfloor space of passenger cabins where there is no proper protection.

Niches for storage batteries are in severe corrosion conditions. It is explained by the possible ingress (for various reasons) of very aggressive working fluids used in batteries (acid, alkali) on the walls and parts of the niche.

The most common methods of protection of metals and alloys from corrosion is the creation of protective coatings on their surfaces. They can be divided into the following groups by the type of materials that make up protective coatings:

- metal (galvanic);
- inorganic non-metallic (oxide, phosphate, etc.), organic (paint and varnish).

The use of paint and varnish coatings in combination with inorganic coatings is the most widespread among the all types of corrosion protection coatings. The use of paint and varnish coatings is the most affordable way to protect metal and non-metal products from corrosion and destruction. They differ very favourably from other protective coatings due to their relatively low cost and simplicity of their production technology [10].
4. Technological aspects of the development of the use of polymer and composite materials in aircraft construction at the current stage

To ensure the safety of flights, the structure of the aircraft must be sufficiently robust during the entire service life of the aircraft.

The strength of a structure is understood as its ability to perceive without destruction the loads acting during operation. The rigidity of a structure is characterized by its ability to deform under the influence of external loads. In aviation technology, due to the peculiarities of operation, high requirements are imposed on materials. The materials used for the construction of aircraft must provide the required strength and rigidity of the structure, must have weather resistance [11,12]. Herewith the material shall provide the possibility of manufacturing a product of complex shape and, if possible, without additional fasteners that increase the mass of the aircraft.

Composite materials, due to their qualities (high specific strength, the ability to control the structure and shaping of products of almost any geometry, ease of combination with different materials), have found wide application in aircraft construction.

The development of aircraft construction is associated with a continuous struggle to reduce the weight of the structure. Reducing the weight of the structure can be achieved by a rational choice of materials and power circuits, the use of rational technological processes, as well as by clarifying the loads on the structure.

During selection of materials for load-bearing structural elements, take into account its mechanical and thermo physical characteristics, specific gravity, corrosion resistance, cost and scarcity of raw materials, as well as the possibility of processing the material with modern production processes [13].

The choice of material also depends on the size and shape of the structural element and the conditions in which it operates under load. These conditions are characterized by the following:

- value, direction and duration of the load;
- maximum temperature;
- type of load (constant, smoothly changing, shock, cyclic);
- presence of stress concentration, etc.

The specific strength and stiffness of composite materials is higher in comparison to traditional metal structural materials. It is determined by the properties of the filler (reinforcing fiber). The names of many composite materials include the types of fillers and binders: carbon fiber reinforced plastics, fiberglass plastics, organoplastics and other materials. The first word characterizes the type of fillers: carbon, glass, as well as other fibers and fabrics, and the second - the types of binder: plastics based on various resins or special adhesives.

The main feature of creating a structure from composite materials, in comparison to the traditionally used metals, is that the product design process begins with the creation of the material itself. In this case, the properties of the material are formed during the production of a specific structure.

It is expected that widespread use of composite materials will contribute to:

- reducing the weight of the airframe up to 15%;
- improvement of the fuel efficiency;
- increasing of the resource;
- decreasing of operational costs up to 10% and maintenance costs up to 30% (since fewer inspections of the structure are required) due to the higher corrosion resistance and a longer service life of composite materials compared to metals;
- decreasing of the number of parts in a structure and, accordingly, decreasing of labour intensity and assembly cost. But there is also a weak point of polymer composites - an impact resistance. After the impact, microcracks are formed in the parts made of composite material, which, under cyclic loads, lead to delamination of the material. In order to make polymer composites more resistant to the impact a special compositions of binders are developed and thermoplastics are
introduced into the composition of thermosetting matrices, or thermoplastic matrices are used. If a composite part breaks, it must be completely replaced with a new one [14]. There are repair technologies, but they are not very reliable, and in aviation, repairs are rarely used: after it, a part can rarely be qualified. A complex diagnostics is required in order to monitor the appearance of cracks. For example, fiber optic sensors are embedded in a composite: this solution allows timely determination of the integrity of the material structure in online mode.

In addition, carbon plastics (unlike metal) can be burned and release poisonous substances during burning. People can suffocate with smoke, therefore, plastics with low flammability are used in interiors. These plastics include special additives (flame retardants).

5. Findings
Thus, it can be concluded that work in the promising direction of the development of the use of composite and polymer materials in aircraft construction is continued. New types of composites are being developed and introduced. With the widespread use of such materials (including materials corresponding to advanced world ideas), new samples of aviation equipment are created. Measures aimed on development of the industry, training of specialists, etc. are taken.

Aviation equipment built with the use of composites is already being mass-produced and new samples are also being prepared. Many things remain to be done, and all of these are associated with various difficulties. However, the work is continued and there are causes for optimism. Composite materials have become firmly established in practice, and now everything is done to develop this direction. This direction directly affects the success of other industries. The leading place in the world in the development of composite materials and their use in the construction of aircraft (especially for military purposes) belongs to the United States, where the pace of work in this area is constantly growing. Research is coordinated (in relation to aircraft structures) by the US Air Force and NASA Materials Laboratory. The Materials Laboratory evaluates the effectiveness of the application of composite materials to the design of military aircraft. Currently, under contracts with the Air Force and programs funded by large aircraft manufacturers, a large number of structural elements of aircraft and helicopters from composite materials are produced and tested [5].

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