Analysis of applicability of polymer, composite materials as components of aeronautical structures

V N Moskvitin, V I Makarov, D S Leonovich

Irkutsk National Research Technical University, 83, Lermontov St., Irkutsk, 664074, Russia
Irkutsk Aviation Plant (IAP), an affiliate of Irkut Corporation, Department 372

Abstract. The paper considers the problems of using composite materials to create power units of modern passenger planes. It gives examples of crash situations involving planes of the leading companies, describes some technological aspects in the production of composite parts.

1. Introduction

The volume of polymer, composite materials growing annually as components of aviation structures is first of all caused by two main advantages of these composite materials:

- minimization of weight at maximum strength and rigidity;
- opportunity of advance setting of strength characteristics and properties of a composite material according to nature and actions of forces and loadings in a particular aviation structure.

The application of polymer composites and carbon fiber in particular for the production of bearing wing components in the form of wing box panels is caused by positive relation of rigidity and strength to the weight of a piece. Therefore, for wing aspect ratio >10 the wing box panels from carbon fiber with E>100 GPA are made [1, 2, 4]. It is considered that carbon fiber, “black” wing box in this case has the winning advantage in terms of rigidity and strength at significantly smaller weight compared to traditional wing boxes from aluminum-based alloys.

It shall be noted that the designers of such aviation structures and technologies particularly rely on the advantages of a “black” wing in terms of rigidity and strength compared to traditional wing metal. However, this requires the analysis of the current situation, which the given paper is devoted to.

It is known that the joint use of composites and standard aluminum or titanium alloys will inevitably lead to joint assembly of parts diverse in their properties. Thus, traditional riveting and the corresponding opening of holes immediately resulted in extremely formidable disadvantages – microchips and micro-cracks in composites in jointly opened holes of metal alloy parts. This fostered the attempts to overcome this disadvantage menacing with sharp drop of fatigue strength of such combined compounds.

For example, the works [3, 5] suggest using a complex technology of unilateral fastener in the form of combined rivets containing a composite material to fight against the above problem. It shall be noted that this disadvantage will definitely show itself in practice. Thus, on 08.03.2014 the Boeing Company reported on micro-cracks in composite panels of a wing box of some of its 787 Dreamliner planes. The reason was a crucial mistake in the production technology of a wing box and its assembly. It is clear that the same radical disadvantages became the reason of incidents with this plane in operation. For example, mass drop fuel leak from a wing box was detected on the B787 plane on 13.01.2013 in Narita Airport located in Tokyo. On 21.06.2013 the B787 plane had to land urgently in New York Airport (New Jersey)
due to the same loss of fuel from a wing box. These are all data on incidents with the B787 plane taken from the Internet. As result, the Boeing Company had to suspend and pull out of service the whole range of Dreamliner B787 [6, 10].

Thus, the rigidity and strength of a “black” wing has such organic defects, which are quite difficult to overcome. We can ask a question here – what is the difference between a usual wing box from traditional, wing metal and a composite “black” wing box? Most likely it is the fact that besides the same strength and rigidity the material of a usual wing box has such characteristics of metals as viscosity, plasticity and fluidity. Moreover, it is plasticity, i.e. the ability to receive residual deformation under loading without discontinuance, has the greatest influence on durability and fatigue strength. It is the plasticity that does not allow creating the critical number of dislocations in crystallites of metals and alloys in a stress concentrator zone for the formation of primary microcrack, but forces them not to concentrate, but “scatter” along the crystal lattice in the direction of the load action. Only when their total quantity in a lattice exceeds a certain limit, their concentration and formation of primary microcracks begins. For this reason we can take a thin plate (0.5-1.0 mm), for example from a usual alloy like D16m and bend it for a long time until it breaks. It is impossible to do with the same plate from carbon fiber. It will sustain much less bends and will eventually break similar to fragile one. This happens due to the fact that internal, atomic and molecular structure of composite materials has nothing in common with metals and alloys. Usually composite materials on the basis of fiber glasses or carbon fibers are destructed following the mechanism of the so-called quasi-fragility [7, 8].

2. Results

There is another disadvantage of composite materials. Riveting of prepreg structures with a binding agent cannot guarantee lack of micropores, capture of micro- and nanosized air bubbles in the glued mass, which later serve as concentrators of loading or even absorbers of water, which in sub-zero temperatures will simply begin to destroy a structure from within. This is impossible with metal structure [9].

Thus, relying purely on strength and rigidity the designers of polymer composite materials for aviation structures completely forgot about viscosity, plasticity and fluidity, without which long operation of any high-loaded structure is absolutely impossible.

What does such enthusiasm for composites lead to? It is clear from the analysis of plane accidents. Thus, on 12 August 1985 the Boeing 747 crashed near Tokyo. The reason was a full separation and destruction of a fin made of composites. The accident with A-300B4 on 12 November 2001 over New York. The reason – destruction of a fin made of composites. The problem disappeared as soon as the manufacturers refused to produce vertical stabilizers from composites [10].

It is worth mentioning technological features of fabrication operation from composite materials in comparison with standard materials:

- composite materials are received from different components such as carbon fibers and fabrics, resins and curing agents, softeners, etc., which serves the factor of instability and accident, increases the cost of a composite material (1 kg costs more than 400 dollars); they require continuous control using unique equipment at all production stages;
- traditional materials on the basis of aluminum with beryllium, titanium with high strength properties are characterized by stability and quality confirmed by the certificate of a metallurgical enterprise (1 kg costs 3-10 dollars, which is 100 times less than a composite material);
- high requirements to production spaces of composites in terms of pollution, air, temperature, humidity; almost all processes are connected with harmful emissions (products of chemical reactions, noxious dust of machining, etc.) and require personal protective equipment and strong aspiration systems;
- there are no special requirements to the processing of traditional materials;
- complete production cycle of parts from composite materials includes a variety of technological processes: production of fibers and fabrics, fabric cutting, laying by form,
preparation of glues, infusorial treatment, vacuum compaction, autoclave thermal treatment at 180 degrees, milling, cleaning and finally control throughout the entire production cycle;
• for metal parts the production cycle includes much less operations: milling, cleaning, shaping and hardening, anticorrosion coating, selective control of separate parts in a batch; it shall be noted that the majority of processes related to the production of parts from composite materials are rigidly bound to chemical reactions, which define the actual time of their production, therefore there is almost no reserve for productivity increase;
• equipment for the production of composites is characterized by greater complexity and cost of foreign production, complex, high accuracy equipment, big nomenclature and requires a large number for the production of one piece;
• production from standard materials requires special milling machines with CNC, press, peen forming and strengthening domestic equipment; in mass production of long panels of plane wings it is possible and necessary to create specialized workshops for complete production cycle of these parts, which will considerably increase the efficiency of such production;
• non-recoverable losses of initial materials in the production of composite parts may reach 3-5% (spacing, cutting, milling, etc.); besides there are problems of their utilization in terms of ecology;
• for aluminum alloy parts all chips, cuttings and scrap are sent to metallurgical plants for processing to new workpieces;
• assembly of knots and units from composite materials imply only titanium elements of frames, titanium fasteners, which increases the cost of a product and complicates the assembly processes;
• traditional materials have no special requirements to assembly of knots and units, and the assembly technology is completely tested.

On the MS-21 plane it is planned to make a wing box and plumage, i.e. vertical and horizontal stabilizers, separate elements of winged section and fuselage from composite materials, and in general by weight up to 37% of all parts. But will it result in the long-term perspective to incidents and even accidents similar to the ones mentioned above? In this case it is still possible to use such technologies fully or partially but to redesign this product taking into account, for example, import substitution, especially since the production of this plane is not in complete series yet.

3. Conclusion
In general, following the results of even such small analysis it is possible to draw a conclusion on further application of composite materials in aircraft industry:
• to change properties of polymer composite materials thus ensuring not only their rigidity and strength, but also such qualities necessary for durability and fatigue strength as viscosity, plasticity and fluidity; only the complete set of these somewhat contradictory properties of composites will guarantee operational reliability of aviation structures;
• to create new, high-strength metal alloys with small specific weight and high strength factor, for example, beryllium aluminate alloys where beryllium with its low specific weight and high modulus of elasticity serves the main component, or to use titanium beryllide alloys.

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