COMPOSITE MATERIALS IN MILITARY AVIATION AND SELECTED PROBLEMS WITH IMPLEMENTATION

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Abstract: *In the work three groups of composite materials (laminates) today used and developed for aerospace industry were described. These are Fiber Reinforced Plastics (FRP), hybrid composites – Fiber Metal Laminates (FML) and Metal Matrix Composites (MMC). Their characteristics and implementation for examples in military aviation were also presented. From the point of operation for each group, it defined problems and risks, which are: cracks, delaminations and other mechanical degradations which have high influence on fatigue life of aviation structure. Further problems concern issues of connecting composite materials and related consequences of damage in connectors area. Other problems are methods of mechanical processing and manufacturing methods, which significantly increase costs of these materials.*

Keywords: *aviation, materials, laminates, exploitation problems*

1. INTRODUCTION

In recent years, the rising trend of using composite materials in aircraft constructions is observed. The reason is reduced weight of structures, while maintaining high strength properties. Presently, from composites there are produced load-bearing structures of gliders, motor gliders, ultralight category airplanes and Unmanned Aircraft Vehicles (UAV's). Moreover, composite materials allowed to build elements of passenger airplanes, such as vertical and horizontal stabilizers, wing structure and its plating, fuselages and other parts. In gyroplanes composites are used to produce blades, rotors and their fuselages. Furthermore, they are involved in constructing of power units in aircraft, such as: engine blades, tail airscrews and fans.

Fiber Reinforced Plastics composites with glass, carbon and aramid fibers, hybrid composites – Fiber Metal Laminates as well as laminates with metal and ceramic matrix are most commonly used in aircraft constructions. In the context of aircraft construction it is expected a lot from them not only from mechanical point, but also thermal one determined by high-speed movement and often ballistic in relation to military aircraft.

The subject of research in the publication are composites materials used in aviation. The purpose of the survey is to identify major problems connected with the materials which are applied in aviation structures.

2. FIBER REINFORCED PLASTICS MATERIALS – GLASS AND CARBON FIBERS REINFORCED PLASTIC IN MILITARY AVIATION

Composite materials used in military aviation are given high requirements, not only mechanical, but thermal, chemical, and often even ballistic as well. Fiber Reinforced Plastics composites fulfill these requirements perfectly.

They are lightweight, and very durable mechanically. Initially in the construction of aircraft they were used as a replacement for metal parts.

Today, clearly visible is an increasing trend in their application. Now it happens that there are over 90% [1] airframe structures and their participation in design of aircraft allows to reduce its weight up to 25%. As a result aircraft is able to carry more weapons and increase its range, what makes it more effective in combat missions.

Carbon and Glass Fibres Reinforced Plastic (CFRP and GFRP) are used commonly in modern military aviation. In the most modern fighter aircraft in the world the Lockheed Martin F-35 Lightning II. CFRP laminates were used in many elements of load-bearing structure of aircraft, such as: vertical stabilizer, tailplane, flaps and wings skin [2]. These items are about 40% of weight of aircraft and are responsible for aerodynamic lift creation and maintaining aircraft in the air. The fuselage also consists of CFRP laminate. Another advantage of the application of FRP in the F-35 is low detectability by radars, by joining them with very small tolerances of about 0.2 mm [3].

CFRP and GFRP laminates used in construction of aircraft apart from many advantages have some disadvantages. One of them being a major problem is so-called a brittle crack. It spreads rapidly and goes deeper into the structure. This process is often accompanied by delamination, or separation of adjacent reinforcement layers (laminas) [4]. In aircraft construction the phenomenon of brittle crack is very dangerous. During flight and activity of strong mechanical interaction on aircraft’s construction, this type of defect may cause damage to the structure with very serious consequences.

Another problem, at the stage of designing aircraft is mechanical treatment of composites. GFRP and CFRP laminates while drilling, grinding or other mechanical treatments are susceptible to local degradations [5]. Many difficulties focus on the effect of local delamination of setting while impacting of a cutting tool on the material. In this case, it is necessary to use appropriate tools, machines and cleaning equipment. Modern techniques of mechanical machining, such as cutting by Abrasive Water-Jet Machining (AWJM) and laser methods are being increasingly applied. They are considered as very adequate and effective. On the other hand, it is a very expensive solution.

Riveting is still one of the main joining methods of thin-walled aircraft structures. Such features as simplicity of implementation, possibility of connecting two different materials (e.g. metallic with non-metallic ones) and the fact that is it a well-known (reliable) method makes riveting so popular [6, 7].

Riveted connections aviation composite structures entail problems. One of them is initiation and propagation of mechanical damages. For example, the connection of rivet-nuts in the structure of aircraft was provided, which was built from GFRP composites. Two types of fiber orientation were established – $[0_2/90]_S$ (Fig. 1a) and $[-45_2/45]_S$ (Fig 1b). Bearing structure was joined by rivet-nuts connection and was made in accordance with a model – single lap. Connection was subjected to tensile tests. The result of the tests are the following images showing mechanical damages (Fig. 1).

In the rivet connection visible matrix cracks, delaminations and fibers break are defined. The propagation cracks are in accordance with the direction of the reinforcement (perpendicular orientation - Fig.1a, oblique orientation – Fig.1b) in relation to the load force. The cracks propagate from the connectors into the structure. Around the rivets in the back view (Fig.1b) there appear local delaminations by the pull-through. Fibers breakings are visible around and between rivet holes. They lead to the failure path. This type of composite damages applied in the aviation construction are very dangerous and can lead to a loss of lift force by aircraft.

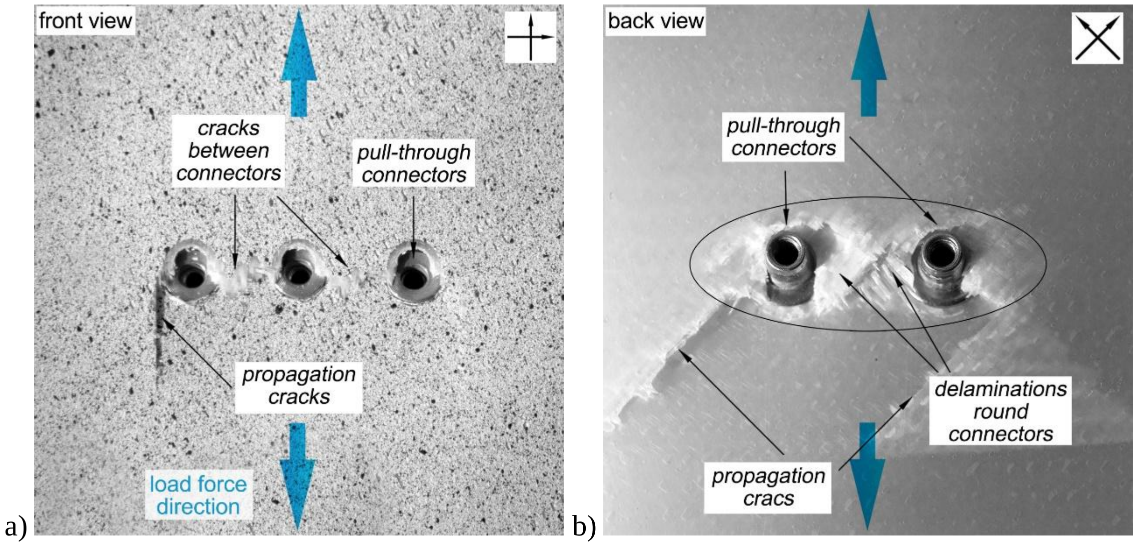

FIG. 1. Mechanical degradation in GFRP connection around the rivet area

3. ARAMID FIBERS REINFORCED PLASTIC AND HYBRID COMPOSITES

In modern air structures there is often used Aramid Fiber Reinforced Plastic (AFRP) for example Kevlar. It is one of the strongest synthetic fibers ever created. A common feature of the family of these products is high tensile strength with low specific weight. At the same weight it is five times stronger than steel. The material is outstanding for its excellent thermal strength , dimensional stability and low elongation at break. It is anti-corrosion and resistant to most chemicals. Kevlar fibers are: uninflammable, non-conducting wear resistant. With this unique combination of properties of this material it is used in many aviation constructions. In the design of aircraft, large module of Kevlar fibers in conjunction with its high impact resistance, allows designers to reduce the weight of many structural elements and to improve the mass-load characteristics.

An example of the application of composite materials type of Kevlar is the American helicopter Boeing AH-64 Apache. From Kevlar rotor blades (main and tail) were made. An interesting solution is so-called "Kevlar bath". Inside "Kevlar bath" the seats are embedded, where the crew is located. Its task is to protect against artillery shell up to 23 mm. Massive use of Kevlar in the construction of aircraft is rather negligible, due to high price. Mainly it is used as a material to reinforce elements of the heavily thermally and mechanically loaded.

In recent years, a lot of interest is given to Fiber Metal Laminates – FML. These are materials made of thin layers of metal sheets and fibers. The first study done on the wing of the aircraft S-11 and F-27 confirmed their increased mechanical properties, which have helped to conduct further research. As a result of the application of strengthened glue that connects the metal and fibres, the effect of cracks propagation was three times slower. The result of this point to the significant benefits that give possibility to use FML for the aircraft construction. Besides delaminations connected with cracks significantly decreased the propagation speed.

On the basis of this knowledge, and subsequent research there was created – GLARE (GLAss Reinforced/Glass-Reinforced Aluminum Laminates [8]) composite. It consists of 2 to 6 layers of aluminium (GLARE 1 i HS – 7475-T761; GLARE 2÷6 – 2024-T3), thickness of 0.2 to 0.5 mm. Between the layers of aluminium there are alternately layers of fibers and metal. S-glass fiber oriented of a thickness of 0.25 to 0.5 mm are connected by matrix of epoxy resin and combined with aluminium.

In view of its specific properties the GLARE became the subject of research in the context of military aviation. During the bullet hole caliber 16.5 mm, penetrating an obstacle with composite GALRE with the speed of 171 m/s there was observed only local destruction at the site of impact of the projectile and its area – see in Fig. 2 [9, 10].

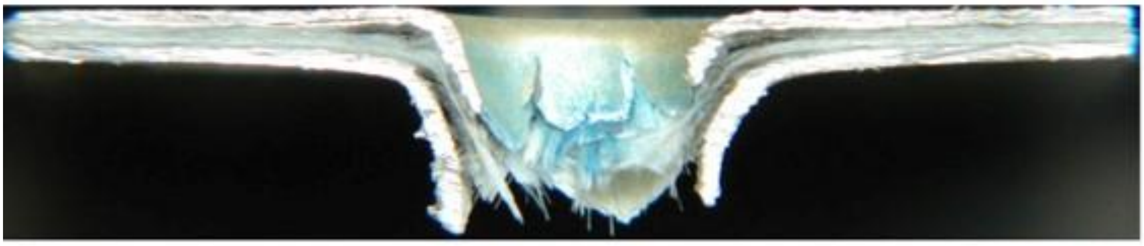

FIG. 2. Cross-section of bullet hole in GLARE [9, 10]

No occurrence of brittle cracks, very dangerous in aviation structures were noted. Besides tests for concentrated dynamic loads finished successfully. Deformation caused by point loads were plastics and visible visually.

GALRE material is characterized by low weight, high corrosion and fire resistance. Despite these and many other advantages of these materials have certain restrictions that limit their use for aviation. A significant impact on their use have adhesive (glued) connection applied between its layers. During using the connection in the GALRE composite can be adhesively and cohesively destroyed. The maximum cohesively strength between thin layers is about 100 MPa adhesive strength and typically lower and it indeed depends on the preparation of the combined surface for bonding. Even if there is applied an effective preparation of the surface for gluing, for example in the pickling form or anodizing of aluminium alloys, allowing high adhesive strength of the connection, local stresses in the adhesion layer order of 100 MPa should destroy it – cause delamination of laminar composite.

4. METAL MATRIX COMPOSITES MATERIALS IN MILITARY AVIATION MARKET

In modern air structures increased usage of Metal Matrix Composites (MMC) is observed [11]. Matrix of MMC composites were made from iron and its alloys, nickel alloys, non-ferrous metals and alloys, mainly: aluminum, magnesium, copper, silver, tin, lead, titanium, intermetals (NiAl, Ni3Al, Ti3Al, TiAl, MoSi2), and superalloys. MMC used in construction of military aircrafts should take into account the requirement to reduce density, which basically means using matrix of only light metals such as aluminium, magnesium, titanium or beryllium.

Example of using MMC is 5th generation aircraft Lockheed Martin F-22 Raptor. In its design many varieties of composite materials, reinforced dispersion composites based on aluminium alloys and titanium carried out by Automated Fiber Placement (AFP) [12] were used. Composites are dispersion reinforced were made from metal matrix, forced with very fine ceramic or metallic particle with a diameter of 0.01-0.1 μm to about 15% of the composite volume.

MMC composites from other types of composites can be distinguished by mechanism of strengthening. In the case of dispersion reinforcement occurs at the microscopic level (atomic or molecular) and is intended by the dispersed particles motion of dislocation in the matrix.

External load is transferred in the vast majority of the matrix, so reinforcement dispersion does not improve significantly the characteristics and strength of composite in elevated temperature. The impact of the reinforcement on the other hand, is pronounced at high temperatures, up to 80% of the melting temperature. Even a small participation of the particles dispersion significantly improves for example fatigue resistance compared with matrix of material. This is important especially in working under a heavy load at high temperatures, such as aircraft engine blades.

Another example of using metal composites such as MMC in military aviation is a heavy transport plane Boeing C-17 Globemaster III. In the construction of the aircraft manufacturer used MMC composite based on the alloy TiAl6V4 and continuous fibre made of silicon carbide. This material has been used in turbine aircraft engine – Fig. 3 [13].

FIG. 3. Pratt & Whitney PW2000 engine with fan blades from MMC [13]

MMC composite – B-Al is used in many military aviation projects. In this role the matrix is aluminum alloy and reinforcement are particles of boron. The advantage of this solution is high temperature resistance. It allows for safe operation up to 510°C, where the average composite can withstand just 190°C. This type of laminates were used on leading edges of main and tail rotor blades of helicopters: Sikorsky S-76D, Sikorsky S-92 or Sikorsky S-70 [14] and others.

Very high material expectations are set for hypersonics aircraft. They are undoubtedly the future of global aviation market. Assumption of the construction of this type of object is its very high speed, reaching a few numbers of the Mach speed. High stiffness, strength, and resistance to fracture and ability to work in high and very low (cryogenic) temperatures is desirable. In the case of work composite for a long period of time, in elevated temperature thermodynamic stability reinforcement becomes a critical parameter. Reactions between matrix and reinforcement during service in a progressive manner can degrade its mechanical properties. Such requirements are able to be met by the titanium matrix composites and Intermetalic Matrix Composite (IMC). They are applied in all four engines of a B-2 bomber. Cooling system, decreased exhausting gas stream from engines from 800°C to 400°C.

Such solution allows to detect and surveillance aircraft by missiles thermally homing on the target, making the design more secure during the war operations. On the other hand, this type of composites are very expensive.

CONCLUSION

Fibres Reinforced Plastic composites such as Carbon and Glass Fibres Reinforced Plastic (CFRP and GFRP) materials due to high mechanical properties and the relatively low price are the direction of the future development of materials used for military aviation industries. However, their using is connected with a number of operational issues, such as: mechanical degradations – delaminations and propagations cracks, using expensive tools and manufacture method, as well as problems with their merging.

Aramid Fibres Reinforced Plastic (AFRP) and GLARE composite are another direction of development of composite materials for aviation and have high mechanical-thermal properties. They show a high impact strength and ability to reduce cracks, dangerous for aircraft structures. The disadvantage, however, is a small adhesive and cohesive strength between laminas.

Metal composites are a class of materials with high thermal properties. They are appropriate material in highly loaded thermally and mechanically aircraft components, such as engine blades, or leading edges of wings. Their disadvantage yet is a very high cost.

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