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Comparative Analysis of Innovative Materials Application in Aircraft Building of Different Countries

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Abstract
The article identifies the causes and factors proving the urgent need for the use of innovative materials in aircraft production.The authors have considered various types of materials applied in aircraft building and have identified the most advanced and durable ones. Besides, they have performed a comparative analysis of the materials used in aircraft production in different countries.The production advantages and disadvantages of such materials are also reviewed in the article. The authors of the article have considered the most prospective substances used for producing aircraft parts and have analyzed both domestic and foreign experience in the use of innovative materials.

Keywords: materials, aircraft, aircraft building, composite materials (composites)

INTRODUCTION

Nowadays, aircraft building in civil aviation is one of the most prospective industries.Within a short period of time, it has become possible to ensure import substitution in aviation, to organize state-of-the-art manufacture, to commercialize unique technology and to conclude contracts with the leading aircraft building countries.
Russia is rapidly winning the global market of civil aviation aircraft.
The developed countries do not only create new aircraft models but also design a wide range of innovative equipment for them, namely: technologically advanced control systems, state-of-the-art high quality engines and modern lightweight composite bodies [19-20].

Areas of innovative materials application

As for Russia, aircrafts of different directivity– short-haul and medium-haul aircrafts– have been designed recently. Sukhoi Superjet 100 and MC-21 with the state-of-the-art engine PD-14 are among them. Composite materials are widely applied in these aircrafts (Figure 1).

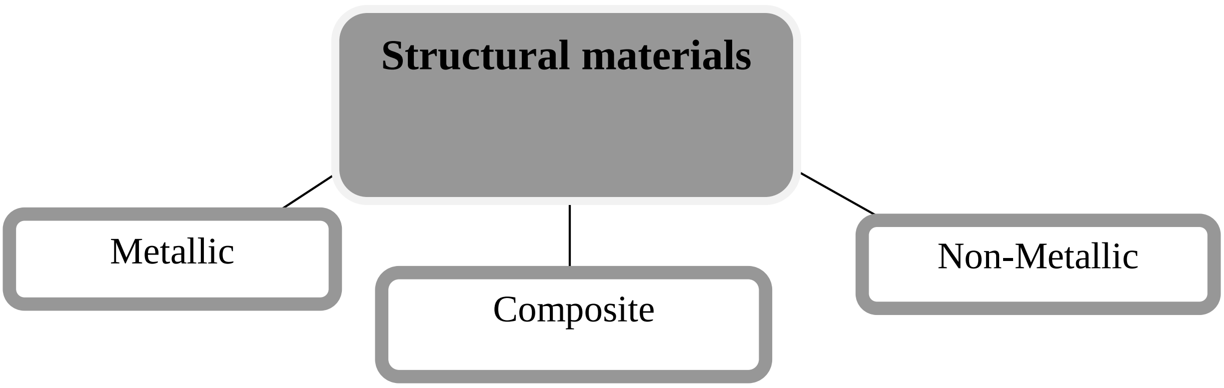

Figure 1. Types of structural materials.

Due to the use of up-to-date aluminum alloys, polymeric composite materials, and a combination of non-metallic materials (paints and coatings, glues), the increase of aircraft parts useful life (by 1.5-2 times), intermaintenance period, as well as of the level of fire-safety, is guaranteed [3].
For the purpose of decreasing the aircraft take-off weight, the need for lightweight and high-quality innovative materials for aviation is preserved.

Materials are selected with regard to the following characteristics:

- Maximum permissible stress.
- Fatigue of material in service.
- Crack growth behavior.
- Corrosion resistance.
- Heat resistance.
- Availability and manufacturability.

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Composite materials meet most of the above characteristics (see Figure 2).

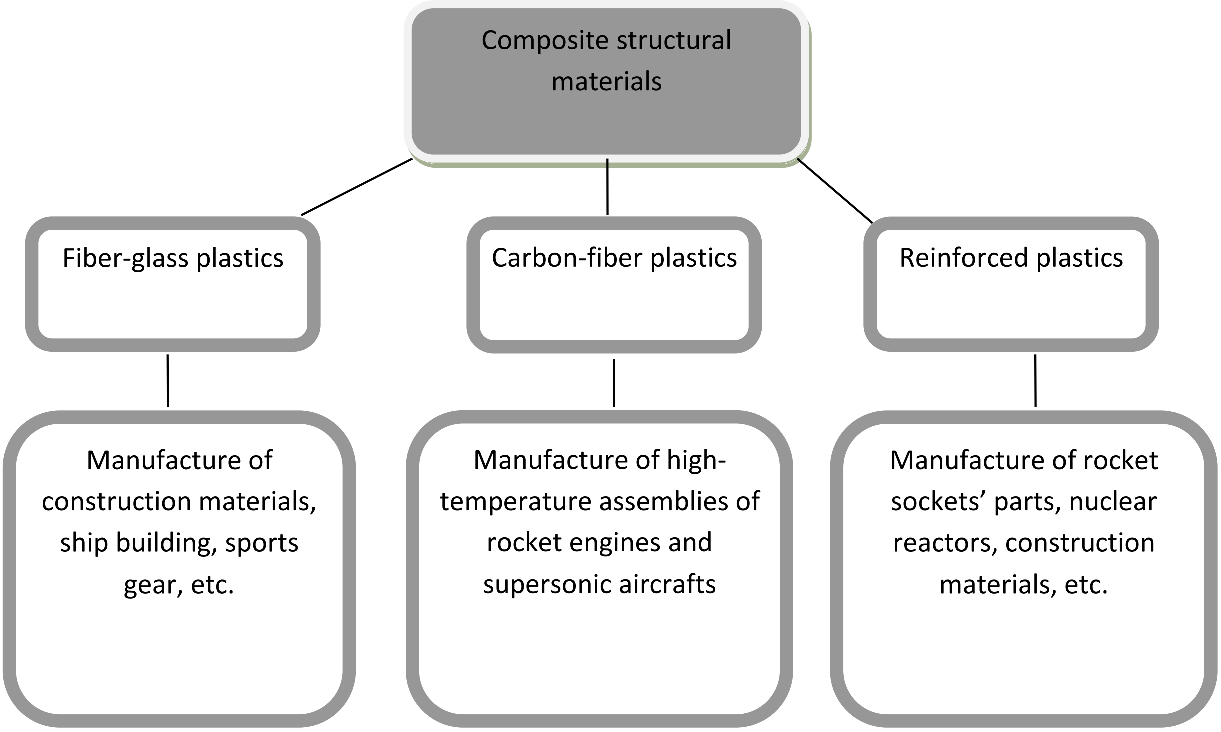

Figure 2. Applications of composite structural materials.

The society is currently experiencing a polymeric renaissance: composites are used in aerospace industry and in many other industrial processes.

Composites, as a rule, constitute two macroscopically and functionally different materials used within one structural unit. These two components function as a reinforcing material and a matrix (or a matrix material).

In the classical sense of the term, artificial composites have already been used by our ancestors: they are clay mixed with straw and concrete used as construction materials. These substances were predecessors of today's composite materials.

The first composite used in aircraft building was developed in late 1930s by Aero Research Aerolite. It was a phenolic-impregnated unidirectional tape [4].

The following types of composite materials are popular today:

1. Solid monolithic composite structures.

Solid monolithic structures are structures in which the rigidity is accomplished on the account of simultaneous engagement of longitudinal stiffeners (mail beams, stringers) and transversal stiffeners (main frame, ribs) – see Figure 3.

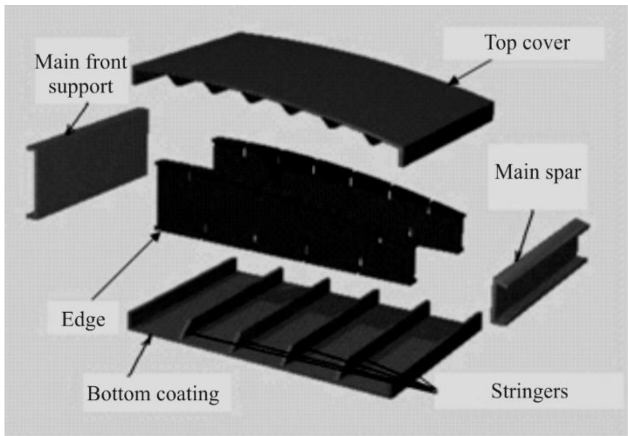

Figure 3. Monolithic structure pattern

Advantages of composite monolithic structures [5]:

- reduces maintenance costs
- enhances damage and shock resistance
- absence of damages caused by humidity

Disadvantages of composite monolithic structures:

- lower ratio of the relative rigidity weight than in a multi-layer structure (see below)
- require the use of supplementary bending and torsion rigidity elements

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2. Multi-layer composite materials.
The most common multi-layer composite material is conventional plywood.Closed-cell foamed plastic or cell-shaped material with no supplementary stiffeners are most frequently used for multi-layer structures of relatively small thickness, intended for exterior and interior finishing, as well as for the material interleaved between them and to which they are attached (glued) (see Figure 4).

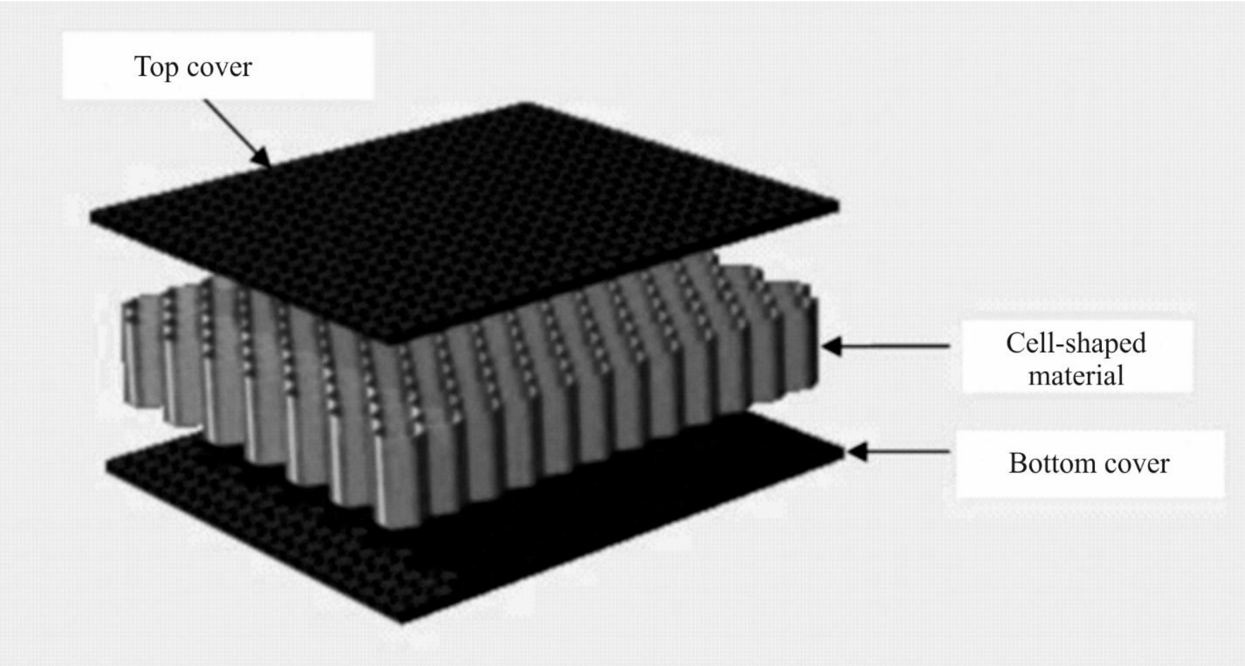

Figure 4. Basic structure of multi-layer materials.

Advantages of multi-layer composite materials:
- maximum structure rigidity at the lowest weight
- high torsional rigidity
- excellent heat insulation
- perfect damping properties

Disadvantages:
- subject to moisture absorption and, as a result, to destruction
- -have lower impact resistance than that of solid structures
- higher production costs[4]

3. Reinforcing basis composites.
Such composites include two main components – the reinforcing material itself and a filler material.

REINFORCEMENT MATERIAL
The reinforcement (or “building”) material is one of the main components of the composite material ensuring mechanical strength of the structure and rigidity.
Well known reinforced concrete, widely used in construction, in which rebars are used as a reinforcing material, can serve as an example. The most common form of reinforcing material is long continuous filaments (continuous filament), staple fiber threads (chopped fiber) or needles (whiskers). Nano-technologies are also used: tubes and plates, disk formats. Fiber can be used both in combination with the filler material (matrix resin), and without it.

Examples of reinforcement materials [6]:
- **-**Carbon fiber, graphite fiber (HS, IM, HM; UHM)
- Glass fiber (“E”, “S”)
- Aramid polyamide fiber (aramid, kevlar, Nomex, Twaron, etc.)
- Ceramic fiber (silica, aluminum oxide, silicon aluminum-silicon-boron, silicon carbide)
- Mineral-based reinforcement fiber (basalt fiber) [6]

Most common forms of reinforcement fibers:
- Strands, slivers (bundles, sliver): typically from 30 to 100 thousand threads of untwisted (twisted) compound fibers which are dried or impregnated with a liquid matrix in the course of finished-product manufacture. Such materials are mainly used in smaller machine building.
- Conventional two-dimensional fabrics: textiles manufactured using the ordinary weaving process, which are used in large volumes, in both dry and

resin matrix impregnated state ("prepreg"). As a rule, approximately 1000-12000 elementary twisted threads (yarns) or untwisted fiber bundles (tow) are used for manufacturing fabrics. Non-standard multiple-thread filamentary strands are used in aerospace industry.

- One-directional tapes (or unidirectional tapes). Unbraided, side-by-side arranged straight fiber lines of linen yarn, which are used in dry condition, fixed transversal thin threads of synthetic fiber or matrix resin.
- Two-directional and multidirectional tapes (of fabrics) (or multi-axial biaxial fabrics). As a rule, unbraided. Fabrics are superimposed in a criss-cross manner in different directions which form transversal dry thin synthetic fiber threads sewed together or are used without matrix resin.

The most common material is "biaxial" fabric (Biax). It is laid at 45^{o} +/-, - 45° / 90 °/ + 45°/90°/0° or other directions are also applied.

The obtained fabric is fixed in sewing bundles.

- Three-dimensional fabrics. Special type of fabric having more superimposed layers of fabric. Their planes are perpendicular to the plane of the braided bundling.They are used in building lightweight and ultra-lightweight aircrafts by theunusually named companies "PARABEAM" and "PARAGLAS".

After this fabric is impregnated and solidified we obtained a laminar structure finished product. Thus, in addition to light weight we also obtain persistence (flexural rigidity) of the bearing structure[7].

FILLING MATERIALS

As a rule, they are filling material solid particles in composite structures intended for adhesion, filling the cavity, increasing the viscosity of the liquid resin which is used for ensuring gap filling density.

Types of filling materials:

- Microspheres of polyester, urea-formaldehyde, phenol resins (glass microballoons, phenol microballoons).
- Milled fiber materials (milled carbon fiber, staple fiber, ceramic staple fiber).
- Gelatinizing agents (Colloidal Silicon Dioxide).
- Pigment (color powders, paste) [8].

COMPARATIVE ANALYSIS OF INNOVATIVE MATERIALS APPLICATION IN AIRCRAFT BUILDING OF DIFFERENT COUNTRIES

It should be noted that not only composite materials are of great "innovative" popularity. Titanium appears to replace the conventional aluminum and its alloys [7].

Titanium is one of the main metals used in aircraft building. Nowadays, 50% of globally produced titanium is used for the needs of aerospace industry and the volumes are only growing [19-20].The increasing application of titanium in the aircraft building industry contributes to the solution of the structure weight reduction problem. The wide application of composite materials (CM) in aircraft building cannot do without titanium, as it is better combined with composite materials than aluminum and increases aircraft useful life by 60%. In addition to high strength, the thermal strain mitigating property is added. This property increases the stability of the structures [8].

Figure 5 illustrates the volumes and aircraft elements where such innovative materials as titanium and composites are applied.

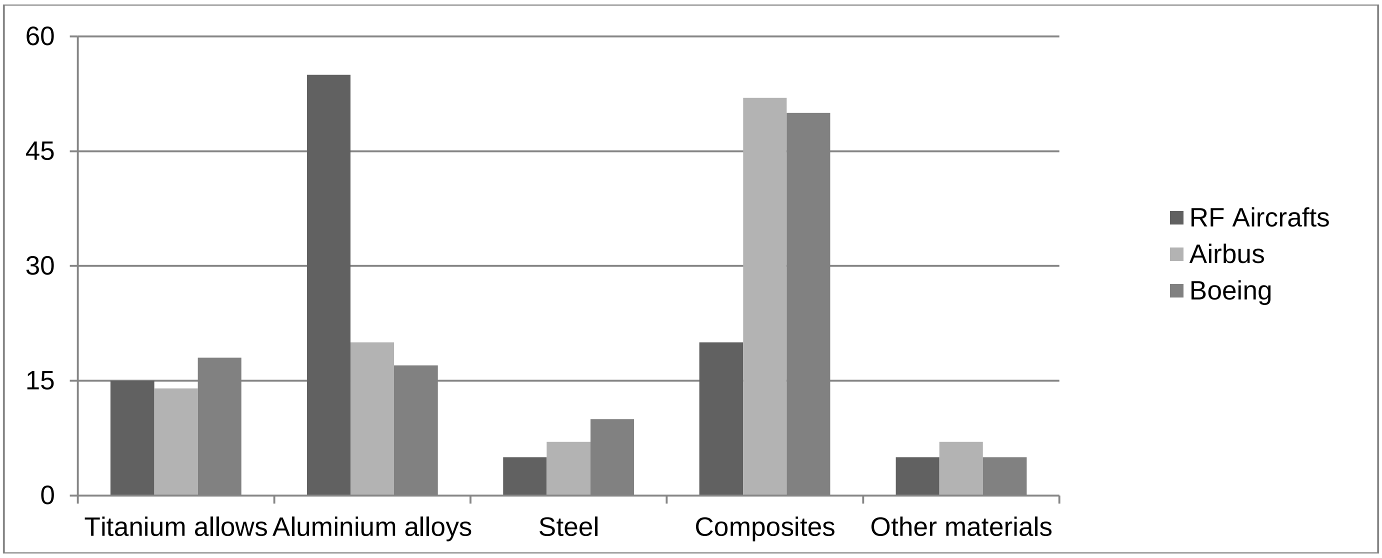

Figure 5. Application of titanium alloys in aircraft structures as compared to other materials, per cent [9].

As it is clear from Figures 6, 7 and 8 below, American corporation Boeing and European company Airbus have achieved the greatest implementation of innovative materials in the global market of state-of-the-art aircraft models. Boeing

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B-787 uses 65% of innovative materials, Airbus A-350 – 66%, while Russian Sukhoi Superjet and MC-21 – 56.5% each [1-2, 10-11].

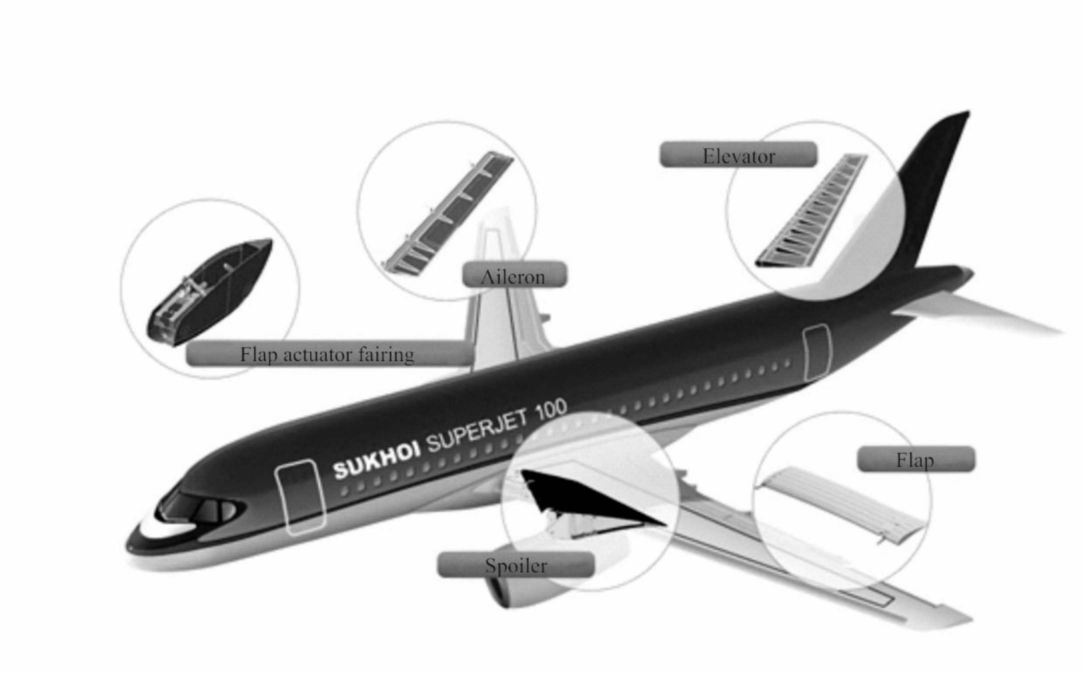

Figure 6. Aircraft elements where innovative composite materials are applied – Superjet 1000, Russia.

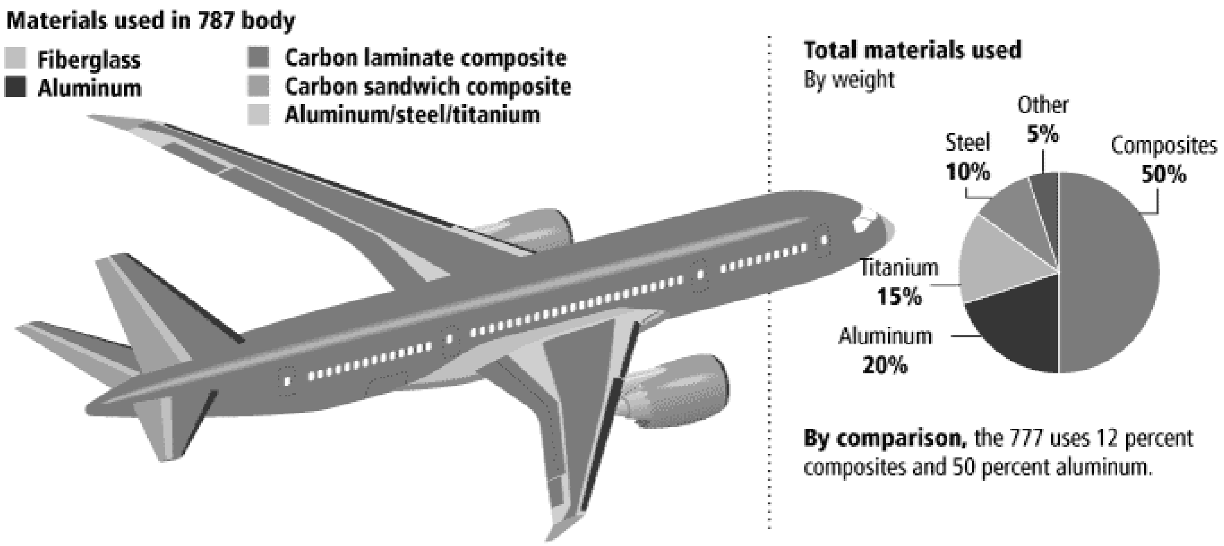

Figure 7. Application of innovative materials in Boeing aircraft.

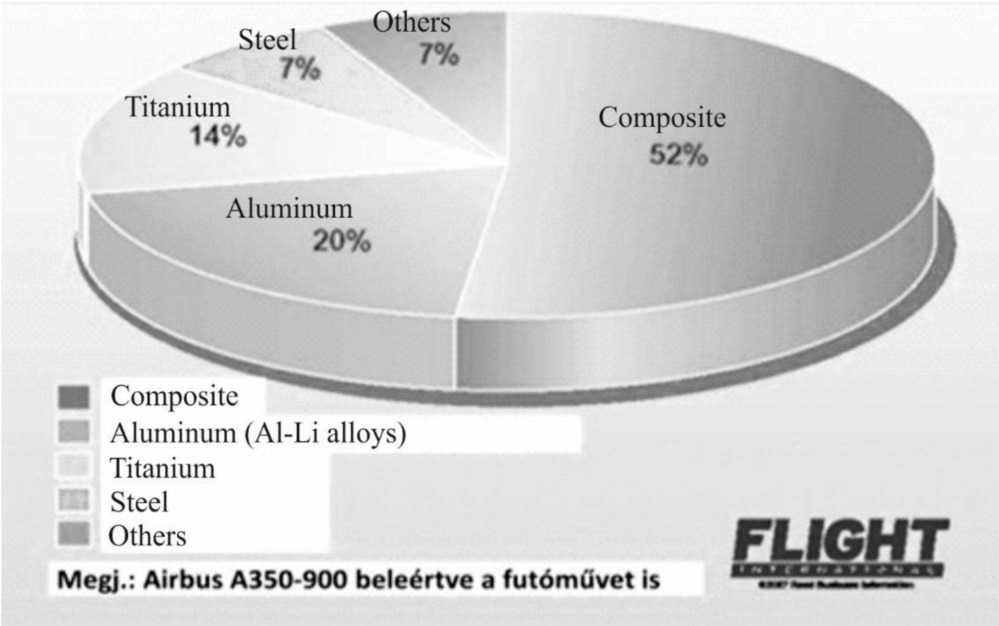

Figure 8. Application of aviation materials in Airbus A350 design.

Modern aircrafts and helicopters are designed with due regard for special requirements set to flight safety and quite strict operating conditions: repetitive maximum loads, augmented flight modes in all-weather conditions, abrupt temperature jumps, and aerodynamic nature of force impact [1-2].

The integrated property of aircraft materials is determined by the parameters united into several groups: cost effectiveness, maintainability and testability, etc. The weight performance is mainly determined by stability characteristics, specific stability. The most important of them are weight performance and maintainability (inter alia, operating maintainability).

Aircraft reliability can be evaluated by such material characteristics as: counteraction to low-cycle fatigue, speed of material fatigue crack growth, counteraction to stress-corrosion cracking and other types of corrosion. There exists so called Rehbinder effect which was discovered in 1928 [14].

It considers the level of solid bodies' properties modification due to physical and chemical effect. Rehbinder effect makes itself evident in case of metal contact with liquid medium. The safety of the structures is determined by metal action against earlier existing crack propagation and the resistance to its occurrence.

Other success factors are also important, such as domestic aircraft building government support at the international level, launching high-tech aircraft to the domestic market, as well as governmental support in mastering the latest aircraft building technology [13, 19-20].

The mitigation of aviation environmental impact, comfort and aircraft volume minimization are of significant importance for today's advancing civil aviation, and for long-haul civilian aircrafts and versatile helicopters in particular [12].

The solution of these issues might be deemed possible due to a new setup and selection of construction and multifunctional substances which were based on the notion of the integrated quality of aircraft materials [13].

A great number of composite materials are used when modern aircrafts are designed and created. And that is understandable: the passenger flow is growing, flight ticket prices go down, airlines try to reduce operating costs, inter alia, by reducing aircraft weight. According to today's experts' evaluation, the polymer market capacity for aircraft building comes to 8.17 bln USD.

Nowadays, polymers are more actively used for the production of regional jets.

In smaller 2-, 4-seat aircrafts and helicopters, the share of using composite materials may reach 80% of the overall aircraft weight. In larger aircraft building, for the most "composited" wide-body jet-liner Airbus A-350, this share comes to 66%. This factor is determined, firstly, by the production costs of such an aircraft, and, secondly,by its aviation properties [14-15].

Therefore, nearly all similar type aircraft producers of the world have shifted to using composites for a long time now. This also refers to Austrian aircraft producer "Diamond", German "Extra", "Extrime". Special attention should be paid tomilitary aviation, where the share of polymer use is currently much lower [16].

CONCLUSIONS

Therefore, the practice has revealed the following advantages of using composite materials [17-18]:

- Significant weight saving
- Anisotropy
- Corrosion and atmospheric effects resistance
- Long service life, fatigue resistance
- Vibration resistance
- Structural simplicity
- Formalliberty, esthetic design
- Shape and temperate extension for containment
- Low "tooling" costs
- Reduction of radar reflectance
- Low operating costs

- Significant weight saving: the application of composite material polymer matrix in addition to weight reduction by 20 to 50 per cent can be achieved with the use of conventional metal (aluminum, titanium and steel alloys) as compared to the same force and rigidity.This happens to extremely high strength of reinforcement fiber composite materials and a high module of elasticity; however, their density (specific weight) is much lower than that of metals.
- Anisotropy: the term implies that the specific structure of mechanical properties, unlike that of metals, varies both, in plane and space direction.
- Corrosion and weather effects resistance: resistance to high humidity, rain, salty water, alkalinity, acid medium, UV and IR-radiation, naturally occurring fungi bacteria. Epoxy resin matrices are resistant to extreme weather conditions and infections.
- Long service life, fatigue resistance: epoxy composite reinforced fibers have a very long (almost unlimited) service life as, due to structural inhomogeneity, due to peak loads and long-term fluctuating loads metals fatigue is not accumulated.
- Suppression of oscillations: various structural components influence aircraft oscillations during the flight. Composite materials suppress oscillations in a more efficient way that metals do.
- Structural simplicity: this implies that, when compared with conventional metal construction elements, a significantly lower number of fasteners are required, which decreases the weight of the structure and extends its average service life.
- Formal liberty, esthetic design: composite materials are very soft before solidification and can be turned into complex three-dimensional shapes.
- Size stability and moderate expansion: composite structures most frequently use non-metallic reinforcement thread (carbon and graphite fiber in particular). The thermal expansion coefficient is very low here which is typical for the majority of aircrafts: within the range of from -65 °C to +100 °C.
- Low expenditures: production startup is less capital intensive, as composite structures do not require expensive, complicated processes, up-to-date machines and other specific tooling for the production thereof.
- Reduction of the radar reflectance: this function constitutes an apparent advantage for its military purpose – the radar wave is absorbed due to combined coating application. In the given case this property is currently more widely used for unmanned aircrafts.
- Low operating costs: as composite materials are not subject to corrosion and tear their maintenance is carried out in case of mechanical defects only.

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