Keywords: military aviation; materials; properties; structure

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MATERIALS USED IN THE COMBAT AVIATION CONSTRUCTION

Summary. In this work, an attempt was made to apply laser surface technology for enhancement of the properties and strengthening the material with addition of ceramic phases in the form of silicon and tungsten carbide particles, leading to a remarkable increase in hardness. Thanks to rapid cooling caused by heat being transferred to the cold substrate, an advantageous, fine-grained structure develops, showing higher gradient morphology; furthermore, the surface layers obtained with laser alloying offer greater heat-resistance and anti-corrosion properties, as well as high wear resistance in addition to the aforementioned hardness, which increases by as much as 15% for the AlSi9Cu4 alloy compared with the alloy after standard heat treatment. Such an increase in the values of the mechanical properties makes it possible to use the investigated alloy in applications including, e.g., recyclable thermally exposed surfaces, such as pistons in internal combustion engines, which enables further decrease in the weight and the thermal expansion with simultaneous increase in the strength, reduction in fuel consumption, and increase in carrying load, speed, and range, which generates the need for further research into the area.

1. INTRODUCTION

In the early days of aviation, wooden or metal elements of the structure were covered with canvas, leather, or even paper. Before the beginning of World War II, the English company Fairey Aviation Co. Ltd. built the Fairey Swordfish torpedo-bomber aircraft (Swordfish). Although its design certainly did not constitute a breakthrough, it was the most frequently used Royal Navy torpedo-bomber plane during the Second World War. Airplanes of this type participated in destroying the German battleship Bismarck. The plane had a metal construction and was covered with canvas. Only the body with a lattice structure in the front part was covered with a metal sheet. The used materials should not only improve the performance of airships but also their safety and contribute to risk reduction [1-3].

The most popular fighter of the World War II (at least in European skies) – the Supermarine Spitfire – was a very modern plane. It had a shell structure, which was completely metallic, making it stronger and lighter than the structure used in another type of fighter aircraft, the Hawker Hurricane. This airframe, manufactured by Hawker Aircraft Ltd., was already technologically obsolete at the time of production. Its body construction was based on a steel pipe truss and the use of traditional mechanical connections, such as those used in manufacturing biplanes. The wings and the rear part of the body were covered with canvas. It was only from the beginning of 1939 that the wings were covered with aluminium sheet.

The design of the Polish RWD-25 fighter aircraft from 1939 assumed, in turn, that this single-engine, one-seater, low-wing airplane would have a welded steel tube body, covered with a metal sheet in the front part, with plywood in the middle part, and with canvas on wooden slats in the back part. Moreover, the use of wood for the construction of a two-blade propeller was proposed [4] in another Polish design of fighter aircraft, the PZL 45 Sokół, developed at the State Aircraft Company (Państwowe Zakłady Lotnicze) in 1936-1939.

Later, quite a significant advancement in aircraft construction technologies occurred, which manifested itself above all in the large-scale use of composites. In the 1940s, layered panels with a light honeycomb core (Fig. 1) were used for the first time in military aircraft. This allowed constructors to reduce the weight of the aircraft, which led to a reduction in fuel consumption and an increase in the range of the aircraft. Moreover, those materials could also, with appropriate internal design, fulfil the role of absorbing radar waves (Fig. 2).

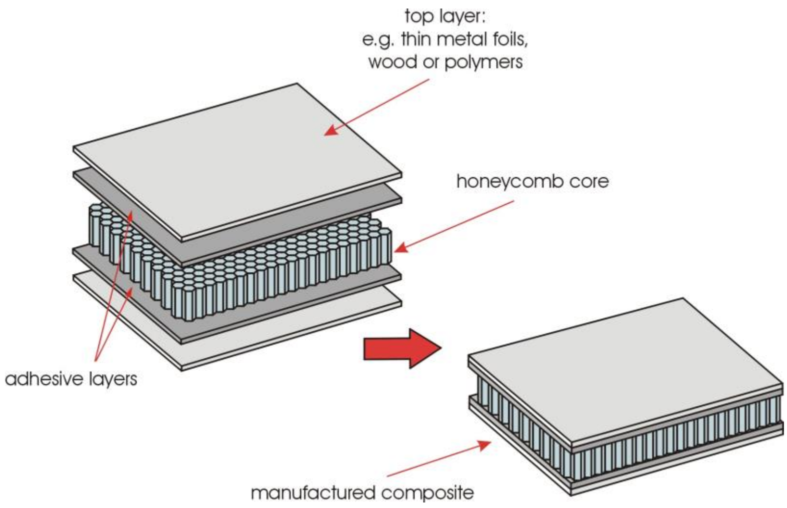


Fig. 1. Layers of the structure of a lightweight composite with a honeycomb core used on aircraft plating [5]

2. METAL-BASED CONTEMPORARY MATERIALS

Nowadays, aircraft design involves much more demanding and complex constructions. Using conventional materials is out of the question.

Designed in the late 1950s and the early 1960s, the American strategic reconnaissance aircraft had a structure based on titanium, which constitutes 85% of the mass, with the remaining 15% being composite materials. So far, owing to the high costs of obtaining pure titanium and its treatment in aircraft, titanium has been used only for the construction of the body cover in the areas of the outlet nozzle and the leading edges of the wings. In places particularly exposed to high temperatures (e.g. the cockpit enclosure during high velocity supersonic flight in the area of the so-called thermal barrier temperature of 300°C), non-fibrous asbestos was used [6].

The construction of the multi-purpose Lockheed Martin F-16 Fighting Falcon, which is on duty in the Polish Air Force, uses predominantly aluminium (78.4%), steel (11%), titanium (0.8%), composite materials (3%), glass fibres (6.8%), and other materials.

Currently, composites with ceramic matrix (Fig. 3), *CMC* (*ceramic matrix composites*), are some of the most widely used composites in aviation. They are composites with a brittle ceramic matrix (e.g. aluminium oxide – Al_2O_3 corundum or SiC – silicon carbide). Ceramic matrix composites exhibit good resistance to oxidation and alkali corrosion as well as low dielectric constant. For these reasons, they are used for the construction of low-pressure turbine blades on the Lockheed Martin F-35 Lightning II aircraft or the outlet nozzle on the McDonnell Douglas AV-8B Harrier II aircraft [7].

Metal matrix composites (MMCs) are obtained by inserting into the metal or alloy a second component (metal, ceramic or intermetallic phases), called the reinforcing phase, in the form of particles (Fig. 4). This strengthening allows to increase the strength, hardness, stiffness and abrasion resistance of composite materials. The particles used for strengthening [8] are as follows:

- carbides (*TiC*, *SiC*, and *ZrC*),
- oxides (Al_2O_3, TiO_2, *MgO*, and ZrO_2),
- nitrides (*BN*, Si_3N4, *TiN*, and *ZrN*),

- borides (*TiB_2, ZrB_2,* and *SiB_2*), and
- fragmented intermetallic phase particles (*Ni_3Al, NiAl, Fe_3Al, FeAl, Ti_3Al, and TiAl*).

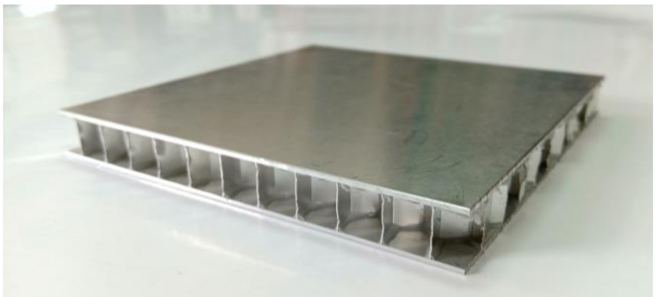


Fig. 2. A sample of radar absorbing honeycomb material [the authors own work]

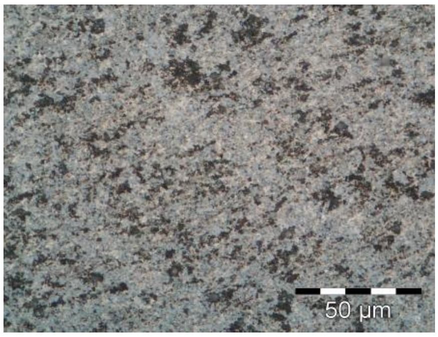


Fig. 3. Ceramic Matrix Composite F1200, with aluminium oxide matrix reinforced B_4C [the authors own work]

Fig. 5 presents the effect of the composite reinforcement type on the strength properties of the composite. It is also worth noting that the size of the reinforcement particles plays a very important role – the smaller their size, the higher the effect on increasing the strength properties of the composite.

Currently, the advanced state of technical knowledge also allows the construction of aircraft made only of polymer, ceramic, and metal composites (such as Beechcraft *Starship* and the Northrop Grumman B-2 Spirit bomber). Its construction required the use of titanium alloys and composite materials based on epoxy and ceramic resins. Materials absorbing electromagnetic waves (RAM - *radar absorbent material*) were also used, and the surface was covered with *ferrite paint* [9]. Application of ceramic and metal composites with matrix from intermetallic phases (intermetallic phase is a solid phase with crystal lattice and properties intermediate between solid and chemical compounds, exemplified by Fe_3C – cementite, or carbon in steel in the form of iron carbide; in the intermetallic chain, there is a predominance of metal bonding) in four B-2 bomber engines in combination with a special exhaust gas cooling system, which allows the temperature to drop from the typical level (around 800°C) to just 400°C, makes it impossible to trace the aircraft with detectors. When using metal composites in aviation, one should take into account the requirement of reduced density, which practically means using only light metals (aluminium, magnesium, titanium, and beryllium) as a matrix. The construction of the fifth-generation fighter F-22 Raptor includes dispersion- and continuous reinforced composites based on aluminium and titanium alloys made with the AFP (*Automated Fibre Placement*) method in addition to polymer composites made with the RTM (*Resin Transfer Moulding*) technique. It is also possible to substantially reduce the time needed for manufacturing high-performance carbon composite parts by utilising compression resin transfer moulding (CRTM), thus ensuring a further decrease in production costs [10, 11].

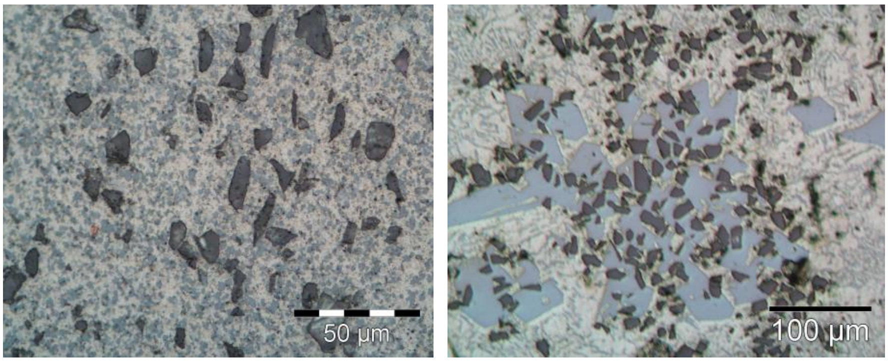


Fig. 4. Examples of Metal Matrix Composites a) ASCM alloy+SiC9%; b) AlSi25+SiC20% [the authors own work]

The Lockheed F-22 Raptor is an example of an airframe design, where high-temperature BMI (bismaleimide) composites were used. In general, polymer composites, treated with the HIP (Hot Isostatic Pressing) technology, constitute 24% of the aircraft's weight.

Another innovative commercially used composite material is produced by the 3M company, specializing in the production of titanium composites. This unique material uses vacuum deposition of the TiA16V4 alloy on silicon carbide (SiC) fibers. Fiber-reinforced Ti/SiC composites have already been used in the production of the following:

- plane chassis, e.g., Boeing C-17 “Globemaster III” and
- turbine blades of a new generation engine (composite TiA16V4/SiCfl – for the Pratt & Whitney JT9D engine).

The same company uses the precise casting technology to manufacture aircraft parts made of composites based on aluminium alloys reinforced with 20% SiCp[1]:

- gyro housing and housing of a photo camera made of the F3B.20S composite, matrix: cast aluminium alloy A357, reinforcing: 20%SiC [8], and
- part of the aerodynamic brake of the aircraft in F-16 from the composite A356/20SiC.

The main advantage of composites with a metal matrix as compared to corresponding organic composites is the maximum working temperature, e.g., the B-Al composite (the matrix is aluminium alloy and the reinforcement are boron particles) can work at temperatures up to 510°C, whereas the organic equivalent, the B- Ep composite can only work up to 190°C (for example in the rudder of the McDonnell Douglas KC-10 Extender, used in the US Air Force as a flying tanker). In addition, metal composites such as Graphite-Al, Graphite-Mg, and Graphite-Cu can work at much higher temperatures, thanks to the reinforcement of metallic fibres (main rotor and tail rotor blades, fuselage fairing along its bottom edge accommodating fuel tanks in helicopters Sikorsky S-76D, Sikorsky S-92A, Sikorsky UH-60 / S-70 Black Hawk [13, 14].

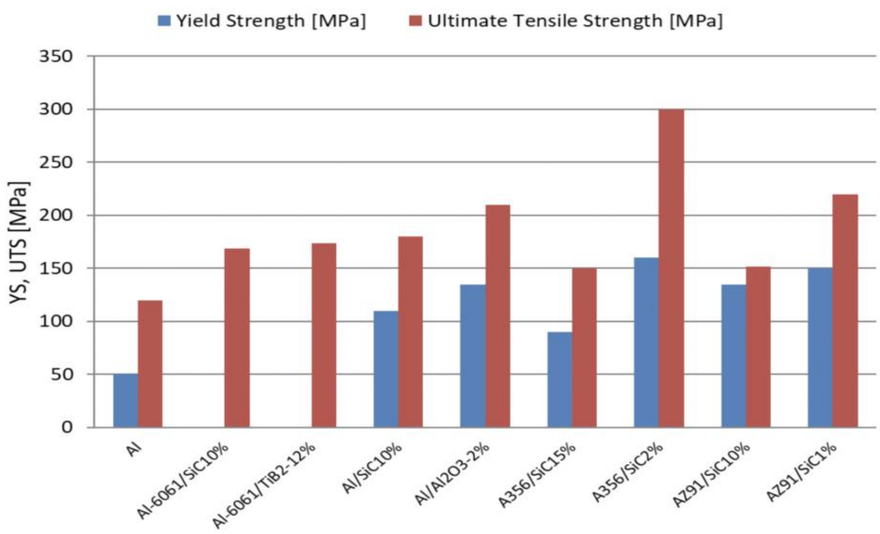


Fig. 5. Impact of the reinforcement type on the strength properties of composites; Al-6061/SiC12% reinforcement particle size 40-45µm; Al-6061 / TiB_2-10% - 1-2 µm; Al/SiC10% - 10µm; Al/Al_2O_3 2% - 25 nm; A356 / SiC15% - 40 µm; A356/SiC2% - 20-30 nm; AZ91/SiC10% - 7µm; AZ91/SiC1% - 30 nm [12]

The leading position in military manufacturing is also held by composites based on aluminium alloys. Composites of this type have a unique combination of properties that can be easily modified by fiber content. Compared with high-strength steel, this material offers the following advantages:

- similar durability,
- half the density (and hence – half the mass of the produced element),

[1] p index from “particulates” means that the SiC reinforcing particles in the composite are large – typical size > 1 µm and length ratio to the smallest dimension of the particle is < 5

- retaining strength properties even above 300°C,
- electrical conductivity four times higher than that of steel (and about half as much as pure aluminium), and
- heat-induced elongation reduced by approx. 50%, (about 75% lower than aluminium).

Creep depends on the time and temperature in which it occurs; no magnetic properties and good hardness make this material a very promising material. Aluminium composites reinforced with boron fibers were used as material for cylindrical barriers of the cargo space of a space shuttle's hull, or as the arm of the space shuttle manipulator. Aluminium booms reinforced with graphite fibers were also used for the Hubble's telescope antenna arms [13].

3. FIBER COMPOSITES

Polymer composites (Fig. 6.) find wide application in the military industry. For example, concave surfaces requiring a specific reinforcement orientation (e.g. wings and tail) are produced with the method of laying fibers or straps, as is the case, e.g., with the upper wing surface of the Bell Boeing V-22 Osprey rotorcraft [15]. Composites of carbon fiber in epoxy resin are widely used to build the central part of the wing in the strategic “stealth” bomber B-2 “Spirit” (Fig. 7). Lightweight aircraft constructions from composite materials are often manufactured with the 3D spinning method, which produces preformed multilayer reinforcements, for instance ones of the double-tee bar shape, primarily for the construction of aircraft wings and stiffened panels, frame of the keel, and frames for the construction of the fuselage.

Composites of the future include composites known as advanced plastic composites (AC) or high-performance plastic composites (HPC), where fibers of higher strength and thermal properties are used as reinforcement: boron, titanium, carbon (Fig. 8), graphite, silicon carbide, and aramid fibers Kevlar-49 and 149; new high strength and high modulus polyethylene fibers (Spectra - Alied Corp. and Dyneema - DSM, the Netherlands) for ballistic purposes; and monocrystalline fibers known as whiskers (discontinuous fibers of very high strength, diameter about 0.001 mm; ratio of length to diameter L/D=100). Hybrid reinforcement, combining two or even three types of fibres, is also widely used. Carbon composite has well and truly joined the mainstream of aerospace construction, not least in the commercial aviation sector. Here, aircraft that are up to 50% by weight carbon are proving their worth as fuel-efficient carriers, polluting less and saving their operator’s money compared with previous-generation metal types.

For example, DSCS-III, a military communications satellite, is built, among other materials, from over 23 kg of Kovar, in which the main alloying additions are nickel (29%) and cobalt (17%). The replacement of this metal by an aluminium (Al) composite reinforced with SiCp/SiCp particles, which is used for elements operating at high temperatures in ground systems, would help save over 13 kg of mass and part of the price of the expensive components made from Kovar. In addition, in solar cells produced from new materials, which are a combination of gallium and germanium arsenide, an efficiency of 23% was achieved, which is twice as much as amorphous silicon produced so far [17].

An example of using all the materials discussed before is the American APH AH-64A assault helicopter. Its half-shell load-bearing structure is made in 90% of aluminium alloys and special steels developed for the aviation industry, the so-called ESR (Electroslag Remelted) steel [18].

In the fuselage cover, modern composites prevail. The cabin and crew seats, fuel tanks, avionics compartment covers, engine nacelles and transmission system covers are made of bulletproof Kevlar. Kevlar plates reinforced with boron laminate, covering the bottom part of the fuselage and the crew's cabin, protect even against 23 mm-calibre anti-tank and bullet-thawing bullets. Boron "armour" was also placed in the shield separating the front and the rear of the cabin. The rotor head was made of aluminium and steel alloys, whereas the steel girders of the rotor blades (5 layers of stainless steel) were connected with pipes made of fiberglass. Each of its four blades was reinforced with laminated plates (22 layers, damage to even 10 of them has no slightest effect on the rotor's work and load-bearing capacity); they are also coated with Kevlar and steel sheet. The leading edge is made of a titanium-aluminium alloy. The leading edge and the front part of each blade were additionally covered with stainless steel and the flow part was made of composites. As a result, the service life and fatigue resistance of the rotor blades thus protected have been extended to 4 500 flight hours [19].

The CFRP (Carbon Fibre Reinforced Polymer) composites in the polymer matrix were used in the construction of the vertical and horizontal ballasts for the Boeing 777. Moreover, in the Airbus A300 / 310 series, a CFRP composite was used for the tail stabilizer structure [20].

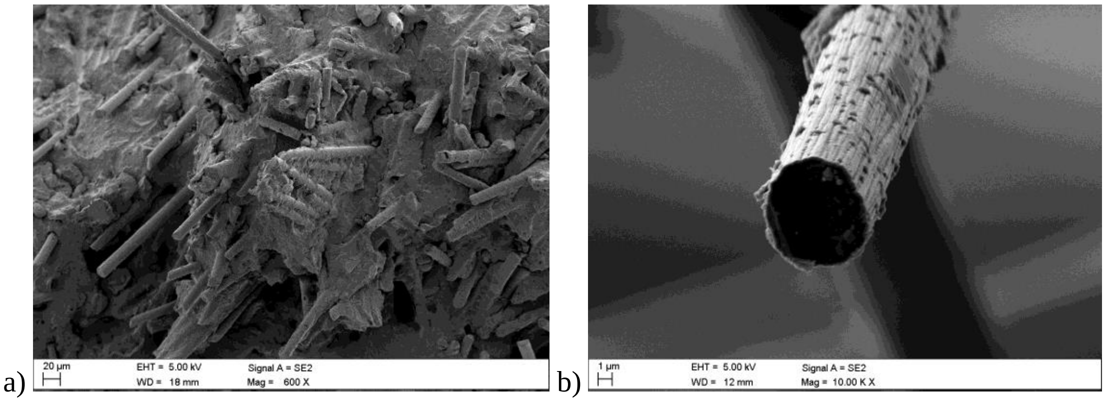


Fig. 6. Polymer composite on a polyamide matrix: a) single carbon fibre with TiN layer deposited on the outside, b) [the authors own work]

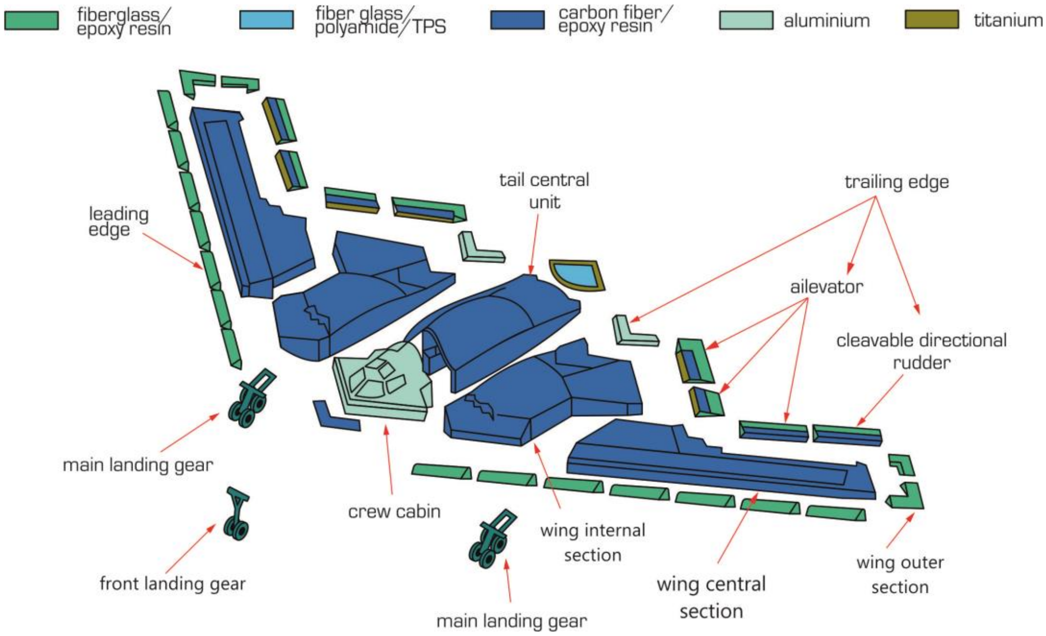


Fig. 7. Bomber B-2 Spirit of the stealth class [16]

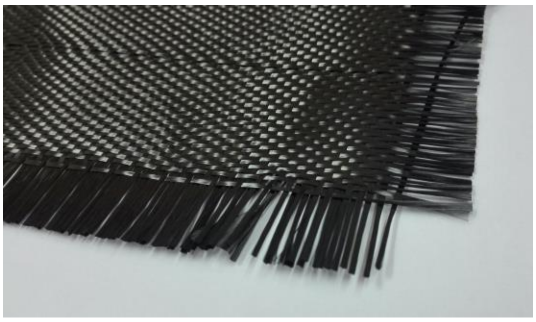


Fig. 8. Graphite fibre mat [the authors own work]

4. MULTILAYER STRUCTURAL MATERIALS AND ARMOURED GLASS

The constructors of the latest European combat aircraft Eurofighter have based the construction, in addition to classic aluminium alloys, on composite materials, Al-Li and titanium alloys. The wing was made of carbon composites, steering surfaces - slats made of Al-Li alloy, flaps - internal segments made of carbon composite, external made of titanium alloys, and wing ends made of Al-Li alloy. In addition, the majority of the aircraft's fuselage was made of carbon composite, and only the front part, which at the same time constitutes the radar cover, was made of a glass-epoxy composite. The vertical structure is very similar. The front steering surfaces were made of titanium alloys [21].

Aircraft cabin covers (windshields) are made as multilayer constructions (it is a sandwich construction - a shell construction type, which consists of two thin plastic or sheet covers with a foam or honeycomb filler placed between them. They are joined in an autoclave under high pressure and high temperature) from high-strength glass bonded with organic materials or liquid polymers. As a result, they provide effective protection for the crew in the event of a collision with a bird weighing up to 1.8 kg at a collision speed of 650 ÷ 750 km/h. Often such covers are covered with a layer of electrically conductive material, which provides additional protection against icing, lightning, electrostatic field, and UHF radiation, i.e., Ultra High Frequency, radio wave range (radio band) of the frequency of 300-3000 MHz and wavelength of 10-100 cm, or so called decimetre waves. Diathermy glass (which transmits thermal radiation) for various infrared radiation ranges is also often used.

The Moscow Institute for Science and Technology of Technical Glass is the author of the patent for armored shafts, which consist of blocks of high-strength glass and polymers able to withstand hits from three 7.62-mm pistol or rifle bullets shot at the same place. Moreover, the institute was the first in the world to obtain glass with a tensile strength of 1500 ÷ 2000. For comparison, the tensile strength (R_m) of most commonly used steel in aeronautical constructions for heat-improving HGSA equals "only" R_m=1200 MPa. Additionally, the Moscow Institute has developed hardened glass, applied in large-size glass components, e.g., for the covers of aircraft cabins.

The Moscow Institute's patent also includes covers for aircraft cabinets of a sandwich structure (high-strength glass glued with liquid polymers or organic materials) providing effective protection during collisions with birds weighing 1.8 kg at a collision speed of 650 ÷ 750 km/h.

The subject of intense research is the phenomenon of electrochromism (change of the transparency of glass under the influence of electricity, an effect achieved in a special glass pane, consisting in placing a transparent layer of transparent glass or plastic with a liquid crystal coating under the influence of electrical current. Due to the electrical current influence, the crystal particles arrange its distribution in lines, which causes the glass to become transparent). The degree of glass transparency achieved by the Russians varies from 2-5% to 70-80%.

The front part of the aircraft fuselage, including the shell and the fairing of the cabin, and the shell of the middle part of the fuselage are most often constructed of the 2090 aluminium alloys, EN-AW 2091 and EN-AW 8090, whereas the internal parts are made from the aforementioned alloys deformed super-plastically. The wing cover and the tail are also made of the aforementioned alloys, and the wing girders are made of composite materials [22].

Currently, in modern combat aircraft, the vertical stabilizer has a lightweight honeycomb core made of thin sheets of aromatic polyamide. All other elements are made of impregnated epoxy tapes: the upper belt of the rotor blade girder contains glass and carbon fibers in equal proportions and is stiffer than the nose girder (Fig. 9). The inner and outer layer covering the rotor blade of the helicopter is made of carbon fiber fabric (Westland Helicopters Ltd.). The production cost of such blades is twice as high as of those made of metal, but their fatigue life is four times higher and reaches about 20,000 flight hours.

5. AIRCRAFT ENGINE MATERIALS

The basic material used in the construction of a military aircraft engine are heat-resistant alloys that provide the ability to carry mechanical loads at high temperatures (above 550°C). They are characterized by high strength, and resistance to heat and corrosion, the latter being much more intense than at ambient temperature. They can be divided into three sub-groups: alloys based on nickel, cobalt, or iron.

Heat-resistant nickel alloys mainly contain chromium additions (up to 20%) or molybdenum (up to 20%) and iron (up to 10%), as well as small additions of sulfur, manganese, titanium, niobium tungsten, or vanadium. For example, in the PW2037 engine used in the Boeing 757 passenger aircraft and in the heavy military transport aircraft Boeing C-17 Globemaster III, the high-pressure and low-pressure compressor and the turbine blades are made of a Ni alloy.

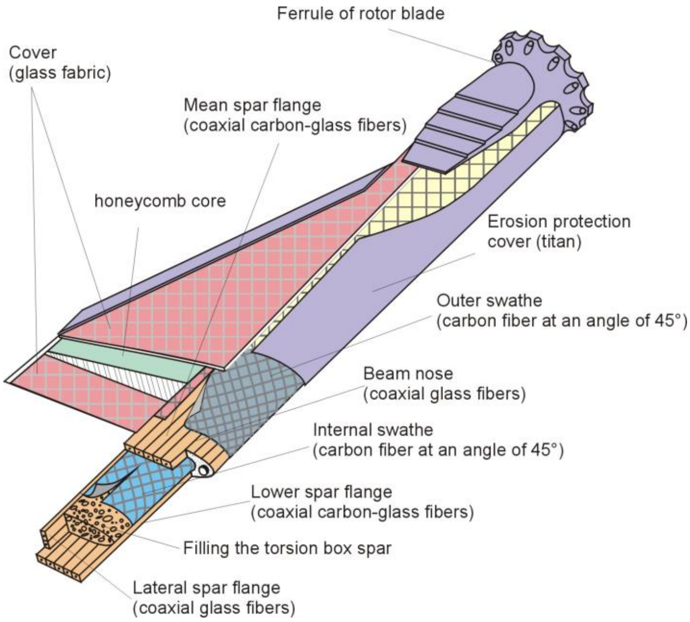


Fig. 9. Rotor blade of a modern helicopter [16]

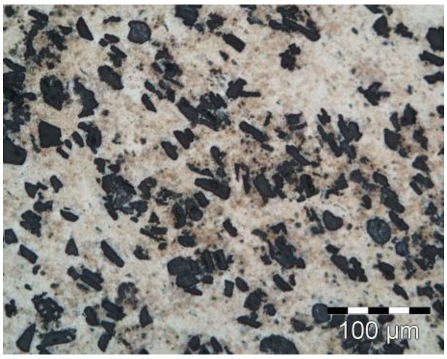
Nickel alloys are most often used for building the internal parts of the aircraft engine, because they retain their strength and resistance to creep (slow deformation of the material owing to the action of permanent, long-term loads) even at 1093°C. The alloys based on cobalt and nickel are used for the construction of rotor blades and external engine components. Iron-based alloys are used only when the operating temperature is not higher than 482°C, actually acting as a substitute when manufacturers want to minimize the cost of the product – they are cheaper and easier to process. Regardless of such benefits, the temperature-related limitation proves decisive, and this type of alloys is relatively rarely used in military technology. For example, a single turbine blade made of an alloy based on nickel and cobalt - known as Inconel - costs as much as 10,000 dollars.

Titanium alloys are used for the production of the so-called “Cold parts of a jet engine,” e.g., compressor blades. Although titanium is a relatively expensive metal (about 5 times more expensive than iron alloys), it is characterized by an extremely favorable weight-to-strength ratio (low weight/high strength), material quality factor (strength-to-density ratio), and resistance to oxidation. The titanium alloy, characterized by high strength, was used, among others, for the construction of so-called “tub in the cockpit” of the American close air support A-10 Thunderbolt II aircraft, the task of which is to protect the pilot from projectiles fired from the ground [23]. A material often used is the TiAl6V4 alloy, often applied after hardening with 880÷950°C and tempering (another step in heat treatment after hardening) within the range of 400÷600°C, which enhances its strength up to 1200 MPa. It is used for the construction of various construction elements, pressure vessels, heavily loaded machine elements and various other elements in the aerospace industry. Ti alloys are also used for the construction of high- and low-pressure compressors in the PW2037 turboprop engine. An example of combat aircraft in which titanium and its alloys were used is the Lockheed F-22 Raptor. They constitute approximately 40% of the aircraft's weight. The use of the unique technology of joining titanium elements (Ti-64 and Ti-62222 grades), called vacuum electron welding, ensures obtaining high-strength edges and simultaneously minimizing the number of joints used.

Ceramic composites are equally often used to produce parts of mechanical components working both at low and high temperatures. This is also important when it is necessary to preserve the form and cohesion of the material. Materials of this type are used in the following advanced military constructions [24]:

- turbocharger rotors, valves and their seats, piston heads, rotors, blades, stator of combustion engines and turbines,
- rocket nozzles and rocket protection plates (thermal protection), e.g. STS “Atlantis” - silica fibres and RCC (Reinforced Carbon Carbon);
- hybrid ball bearings; and
- ceramic armour, bulletproof vests.

Another variant of composites with ceramic fibers and matrix is used, among others, for the construction of aircraft brake discs (carbon-carbon, or better still, silicon carbide-silicon carbide). The C-C composite is predicted to be one of the main materials to be used in modern material solutions of jet engines in the near future. Their disadvantage is their brittleness, but they have the advantage of being able to be used in temperature up to 2500°C [25].

a) 

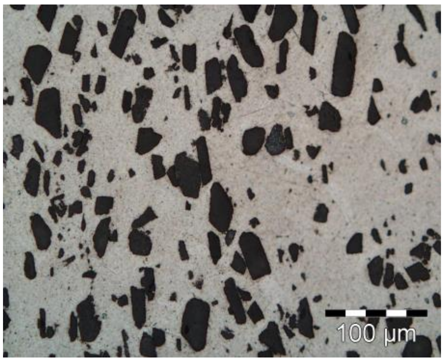
b) 

Fig. 10. Composite materials a) Duralcan W6A-15A, b) Duralcan W6A-20A [the authors own work]

In metal matrix composites, the most commonly used metal is aluminium, titanium, or magnesium. The leading manufacturers of these composites in the world are Alcan Aluminium Corp. (DURLACAN composite – Fig. 10), as well as ALCAN, ALCOA, hydro-Aluminium. These composites have found application in brake system components operating under conditions of high friction wear and thermal shocks (brake discs and drums) [26].

However, despite the many undeniable advantages of aluminium alloys, they also have some disadvantages, which include low hardness and abrasion resistance, which, especially for applications requiring high mechanical and functional properties of the surface of the manufactured element, can quite effectively limit the possible application of this material. This state of affairs was the reason for seeking possible solutions aimed at increasing the properties on the surface of the tested materials through the use of laser technology for surface treatment on a substrate of foundry Al-Si alloys [29].

While melting ceramic powders into the matrix of tested aluminium alloys with laser power in the range up to 2.0 kW, at a speed of up to 0.5 m/min (Figs. 11, 12), where the amount of ceramic powders administered was up to 10 g/min (Figs. 15, 16), the existence of zonal remelting structure was confirmed. The confirmation consisted of isolating, in the received top layer, an SP melting zone a heat-affected zone (Figs. 11, 13) and transition zones (Figs. 12, 14), i.e. an overall structure markedly different from that of the material after standard heat treatment. The structural tests and the aforementioned foreign works equally confirm that the remelting zone, with the exception of fine-grained grain, is also characterized by the presence of a dendritic structure in which the directions of crystallization of dendrites are consistent with the direction of heat removal from the laser beam impact zone.

Increased hardness, which is one of the main aims in shaping the surface layer of Al-Si-Cu alloys, and better mechanical properties of the obtained composite layers are possible in particular when melting tungsten or silicon carbide particles into the treated alloy surfaces. The final functional properties of the finished product are determined not only by the proper selection of the ceramic powder used for fusing but also by its distribution and volume share in the matrix, modelled by various technological operations. Based on the performed investigations, the hardness of the surface layer could be enhanced by ca 15 % compared with the material after standard heat treatment (Fig. 17).

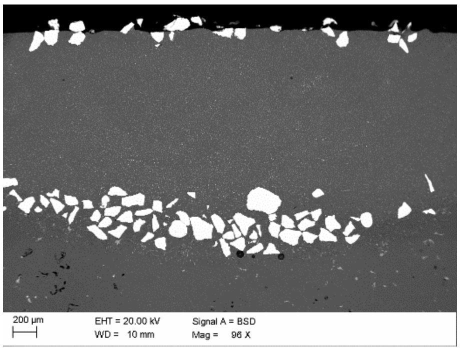


Fig. 11. The surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 2.0 kW, 1.5 g/min, remelting rate 0.25 m/min

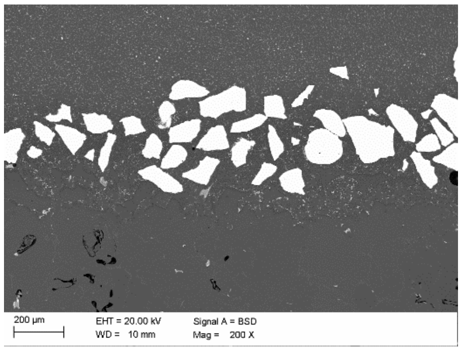


Fig. 12. The surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 2.0 kW, 1.5 g/min, remelting rate 0.25 m/min

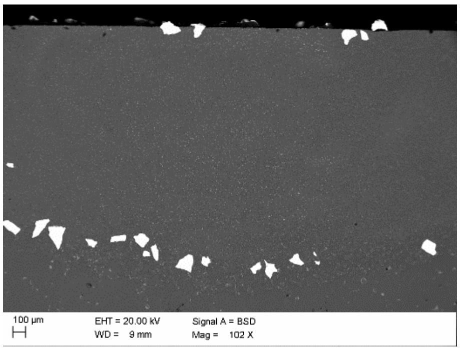


Fig. 13. The surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 1.5 kW, 1.5 g/min, remelting rate 0.25 m/min

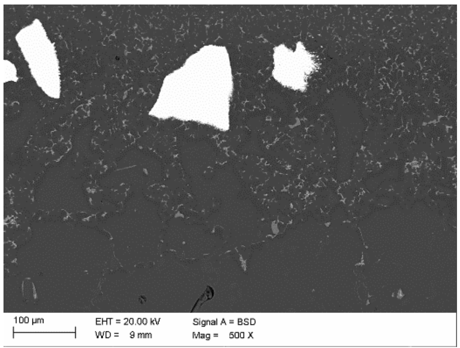


Fig. 14. The surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 1.5 kW, 1.5 g/min, remelting rate 0.25 m/min

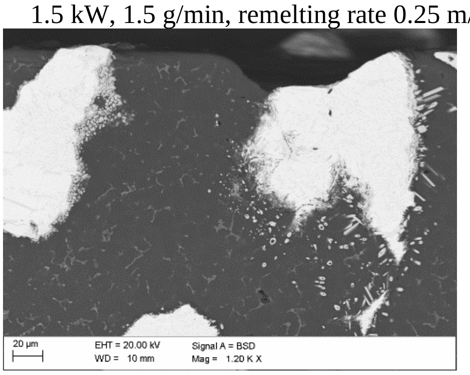


Fig. 15. The surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 2.0 kW, 8.0 g/min, remelting rate 0.25 m/min

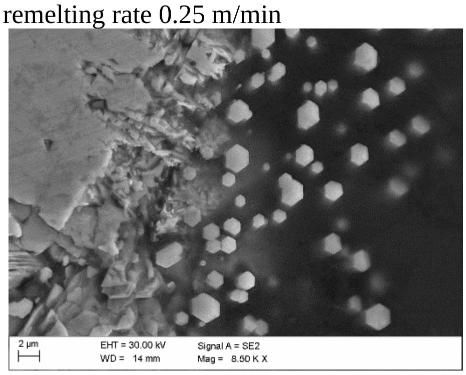


Fig. 16. Boundary of the powder-Al matrix of surface layer of AlSi9Cu alloy after melting the ceramic powder, laser power 2.0 kW, 8.0 g/min, remelting rate 0.25 m/min

Based on the results of the measurement of hardness of cast aluminium alloys subjected to laser alloying, it can be stated that for all the examined cases, except for SiC powder alloying, the hardness of the surface layer increased or remained unchanged compared with the hardness of the surface layer subjected to standard heat treatment (Fig. 17), where, before feathering, the hardness measured was 78 HRF and 82 HRF for AlSi9Cu and AlSi9Cu4 alloys, respectively. The greatest increase in hardness, compared with the initial state, was found in the AlSi9Cu4 foundry alloy with tungsten powder WC - 85 HRF embedded in the surface layer.

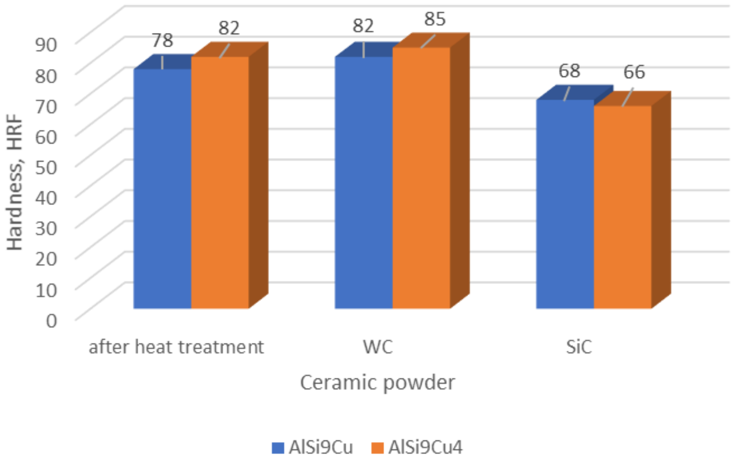


Fig. 17. Results of hardness measurements of samples from Al-Si-Cu casting aluminium after laser fusing

CONCLUSIONS

The use of modern materials, such as titanium alloys, composite materials with a polymer matrix, ones reinforced with polymer fibres, or ceramic composite materials, has allowed to reduce the mass of aircraft (Fig. 18), which in turn improved their performance. Moreover, the use of modern composite materials has also lengthened the service life of parts and equipment, thus extending the lifetime of the entire aircraft. For example, elements made of composites (usually polymer or ceramic) are characterized by a much higher resistance to corrosive atmospheric factors. In addition, modern materials allow to improve the camouflage of units – e.g., the use of ferrite paint in aircraft.

In general, the following can be stated:

- The application of WC or SiC remarkably improves the properties of the Al alloys surface, where the increase in hardness reaches even up to 15 %. However, the laser treatment parameters should be determined very accurately to avoid the occurrence of damage, uneven surface or pores in the manufactured surface; so for each material, specially dedicated conditions should be applied, especially concerning proper line energy supply during laser surface treatment.
- Analyzing the use of materials from the birth of military aviation, one can notice a trend of using ever newer construction materials, the main goal of which is to reduce the weight and thermal expansion (Fig. 18) and increase the strength properties (Fig. 19) of the aircraft and extend its life. This process does not cease, and the near future will probably see the industrial application of other materials, which are currently at the stage of laboratory tests.
- The hardness value increases together with the laser power used in the case of tungsten carbide powder so that the highest power applied results in the highest hardness value in the remelted layer, the relationship being conversely proportional with the use of silicone carbide powder.
- The investigations carried out in this paper make it possible to conclude that as a result of laser surface alloying, as well as remelting of the Al-Si alloy with the ceramic powder, especially carbides, a desirable surface layer of high quality is possible to achieve. The surface layer in

case of alloying with carbides contains no cracks or defects and shows much higher strength value compared with the material that was not alloyed and only laser-remelted. In the case of WC ceramic carbide powder, increasing laser power increases the depth of the remelting material; the resulting depth is higher than in the case of using SiC, rendering also the surface more regular.

- This technique is appropriate, first of all, for small elements (e.g., engine pistons repairs), revealing the same cross-section structure – containing the remelting zone (RZ), the heat affected zone (HAZ), and the substrate material. In some cases, there is also a small intermediated zone between RZ and HAZ, which needs further investigations to recognize its nature.

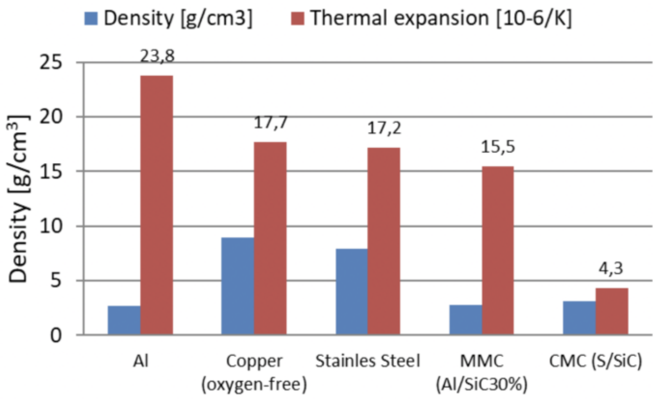


Fig. 18. Comparison of density and thermal expansion of construction materials used for aircraft construction; based on [27-29]

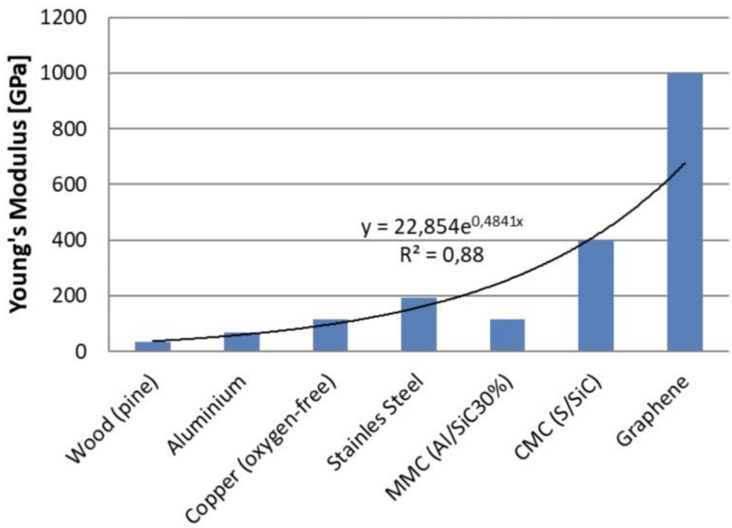


Fig. 19. Comparison of Young's modulus of basic construction materials used for aircraft construction based on [27-29]

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Received 02.11.2019; accepted in revised form 06.05.2021