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Recent advances in application of composite materials in the aerospace industry

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ABSTRACT

Composites have been developed as light-weight materials which can successfully replace traditional metals in the aerospace industry due to their outstanding mechanical properties and lower weight in comparison to conventional metal alloys. This study introduced composite materials, capable of withstanding extreme working conditions. However, some of the advantages and possible failures may rely on manufacturing inaccuracies, selected technique of fabrication method or final forming, so developing of materials engineering and mechanical engineering plays an important role to provide the composite with the best possible performance. Nevertheless, a right selection of matrices and reinforcements assisted with contemporary nanotechnology helps to obtain satisfying results in composite design. The paper described polymer matrix composites, metal matrix composites as well as ceramic matrix composites with special emphasis on examples of their application in the aerospace industry and recent advances based on current scientific knowledge. The presented manuscript shows that due to the development of aerospace engineering and constant need of modern light-weight materials for extreme applications, the topic is still relevant nowadays. The paper was influenced by authors' scientific research conducted so far in the field of composite materials and a growing popularity of authors' review article from 2019, which needs an update after several years. A concise form of this kind of review may meet the expectations of young researchers and scientists.

Keywords: composite materials, aerospace industry, fiber, matrix.

INTRODUCTION

Motivation to consider this topic was a growing popularity of authors' previous paper [1] in the same field. Therefore, as a few years have passed since it was published, the authors would like to meet the expectations of many young scientists or researchers and provide an extended as well as enhanced version of the up-to-date and more complex review. Hence, a special emphasis was placed on recent advances in the subject of composite applications. In addition, the presented paper was influenced by authors' research in the field, continuously conducted over the years [2,3].

As it is known, extreme working conditions must be taken into consideration while designing parts in the aerospace industry. These conditions include but are not limited to high temperatures, high pressure and high-speed gas flow erosion [4–7]. Thus – regardless of a specific type – each material needs to meet these high requirements and has the appropriate properties, such as high fracture toughness and strength, high fatigue and temperature resistance, ability to vibration damping, corrosion resistance etc. In addition, it is crucial to provide the materials with possible lower density, because low weight is a key aspect of aerospace engineering. Using lightweight materials is connected with about 30% lower overall expenditures only because of fuel saving [8–10]. Moreover, minimization of cost production must be also considered; in addition, the highest possible level of user safety needs to be ensured. For that reason, there is a constant need to look for brand new, better materials designed for application in the aerospace industry. They should have better properties and possess a higher durability while providing the same or lower weight and the same or higher security level. It is worth noticing that ongoing development in the aerospace engineering is related to the increasingly stringent material; requirements. Therefore, it is difficult to invent the materials which have enhanced characteristics and that is why this field of study stays relevant nowadays. However, development in engineering scientific studies helps to provide reliability-based design optimization (RBDO) methods such as Kriging model, which can be useful for reliability design and optimization of offshore wind turbine support structure, but may probably also be successfully applied in the aerospace industry [11,12].

Composites are one of the largest and most important group of materials used in the aerospace industry. In recent years, they have still been in common use. According to definition, composite means a material that is made of two or more components having different properties. This causes that the composite possesses the properties that are a result of combination of single component properties. In general, composite materials, in comparison to metals, have higher mechanical strength, higher specific strength (ratio of tensile strength and density), better fatigue resistance, greater corrosion resistance, higher stiffness and better designability [13–19]. Therefore, this makes composites the good candidates to constantly replace metals in different applications. However, each composite material needs to be designed properly to serve its purpose [20]. Furthermore, properties of composites are constantly improved based on continually conducted scientific research [21–26].

Considering the composition of a composite material, it consists of at least two components: one is a matrix and the other is a reinforcement. Matrix, as a component of composite, joins and protects reinforcement by filling the space between it and is responsible for the material shape of a final element and for transferring external stresses. Reinforcement (e.g. carbon, glass or aramid fibers) takes approximately 10–20% of a composite content and is responsible for all other specific properties of a given material. Fibrous composite materials are the most common. Different properties of a composite can be obtained by changing reinforcement structure and using fibers of a different type [27]. However, Macek et al. investigated the influence of short carbon fibers orientation on fatigue life of a polymer matrix composite [28]. Development of material engineering and especially nanotechnology helps to provide nanocomposites (nanoparticle based composites – NBCs) with better mechanical, chemical and physical properties than conventional composites, by adding nanoparticles of i.a. graphite flakes or carbon nanotubes [21,29]. Matrices are made of polymers (PMCs – polymer matrix composites), metals (MMCs – metal matrix composites) and ceramics (CMCs – ceramic matrix composites).

One of the crucial aspects of composite application is user safety and material failure prevention. The latter may be influenced by changing environmental conditions, which are typical for many branches of engineering, especially aerospace and automotive. Failures in composite materials are caused by mechanical forces as well as physical phenomena initiated by outer factors or substances [30,31]. Moreover, composites must face impact loading [32,33]. The damage phenomena of composite materials depend on their disadvantages such as brittleness and weak interlaminar properties [34–36]. The above mentioned composite disadvantages can cause a catastrophic failure and a space accident [37–40]. In general, the damage in composites includes matrix and fiber failures. The following failure examples can be distinguished: delamination (related to separation of laminate layers), debonding (related to separation of matrix and fibers), matrix cracking, fiber bridging, fiber pull-out and fiber breakage [41–46]. Additionally, matrix failure mechanisms may be referred to the failure mechanisms of bonded joints (after taking into account surface properties), because materials used as matrices are also widely applied as adhesives e.g. epoxy resins. Adhesive bonding of composite materials has become important and interesting subject of scientific research. Yuan et al. proposed a novel solution that helped to improve the bonding between PEEK and titanium in hybrid composite laminates [47]. In contrast to both screwing or riveting this method of joining means lower weight, which is a key aspect in aerospace engineering. However, knowing high requirements in this field only specific adhesives may be used and this requires deep investigation first. It was revealed that adhesive joints based on selected epoxy resin are influenced by thermal shocks which causes dramatic loss of bonded joints performance [48,49].

In the aerospace industry, composites – as lightweight materials – are mainly used for fabrication of engine components (e.g. rocket engine parts) and also as structural materials of airplanes, e.g. interior (e.g. passenger seat, interior panels), spacecraft body, fuselage skin, external panels, mounting components, doors, wings, fairings, stabilizers or flaps [13,50–54]. Some details for the Airbus A380 aircraft – which was produced from 2007 to 2021 – are given in Figure 1. As it can be seen, composite materials were employed for e.g. vertical and horizontal tails, unpressurized fuselage and floor beams for upper deck [13]. Consequently, the use of composites has been increasing over the past years. As it was shown in Figure 2,

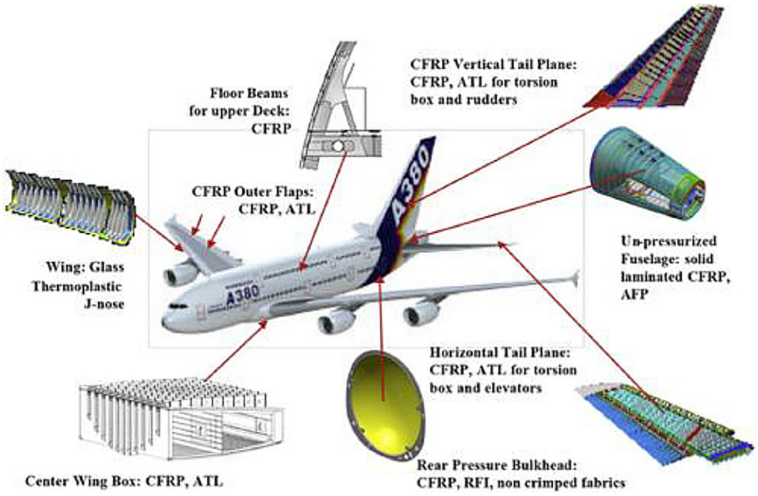

Figure 1. The use of composite materials in the Airbus A380 aircraft [13]

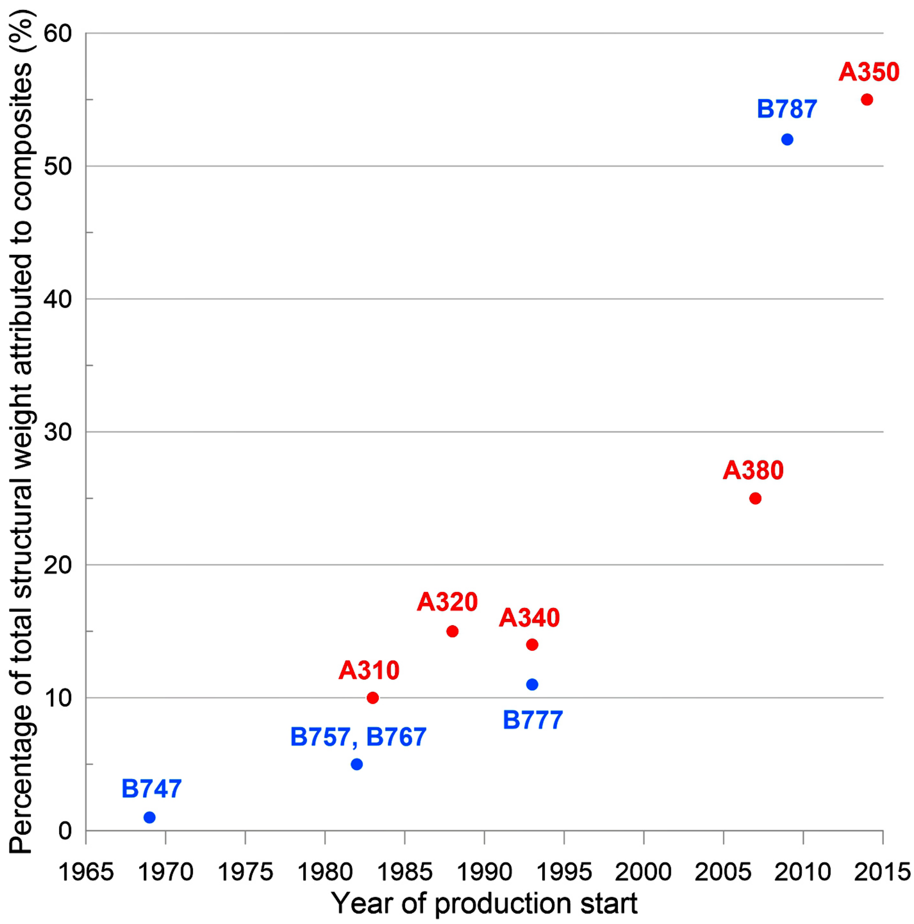

Figure 2. The percentage of total structural weight attributed to composites in the case of selected models of Boeing and Airbus aircrafts [13]

the percentage of total structural weight attributed to composite materials is higher for newer aircrafts in the case of selected models of both Boeing and Airbus. Taking Boeing as an example, it can be concluded that production of each newer aircraft involves more composites than the older one. However, the increase for the Boeing 747, 757, 767 and 777 aircrafts which all entered the market from 1969 to 1993 is not so significant as in the case of the Boeing 787 aircraft, comparing to the Boeing 777 aircraft. Composites constitute approximately 11% of the Boeing 777 aircraft which appeared in 1993, while for the Boeing 787 aircraft that is in production since 2009 the percentage is over 50% [13]. Therefore, the Boeing 787 Dreamliner was announced as the first composite aircraft [27]. The structure of the Airbus A380 aircraft was made of approximately 25% of composites while the Airbus A350 aircraft which has been produced since 2014 is made of 55% of composites [13]. Nevertheless, the data based on Figure 2 are related to selected aircraft models from a year of production start so it compares only the first generations of each model. It is worth noticing that every aircraft model has several generations throughout the years and usage of composites may be different for a given generation of the same model. A specific example of composite application in the Airbus A350 XWB is a thermoplastic foam which is used for its interior and seats (Divinycell F, produced by Diabgroup). To minimize the noise of the Boeing 737 MAX engine during take-off and landing, another industrial material company – Hexcel – developed another solution. It is a permeable cap material embedded into honeycomb core (HexWeb® Acousti-Cap®) which reduces the aircraft engine noise [55].

Furthermore, a separate group of composites that can be applied in the aerospace industry are smart composites. This group includes self-healing composites and shape memory polymer composites (SMPC) [13,56–58]. Self-healing composites can be PMCs, MMCs and CMCs. They have the ability to react on damage occurred inside. Therefore, this may cause the growth of damage tolerance that is a desired property in aircraft [56]. For example, using boron trioxide healing agents embedded in a composite matrix may help to recover a matrix after it cracks to prevent a catastrophic failure. Material of that kind is used e.g. for engine parts working at extremely high temperatures. Moreover, self-healing epoxy composites are used as aircraft structure coatings to prevent corrosion as a consequence of damage [59]. SMPCs are applied as morphing wings of aircraft or solar arrays and reflector antennas of satellites [60,61]. They have a special feature and change their form in the effect of changing conditions such as electric or magnetic field, temperature. This happens by realizing the internal stresses inside the material. However, SMPC is not the only shape memory material but generally it has many advantages over e.g. alloy based shape memory materials: higher deformability and recoverability, a lower density, a lower cost [58].

In recent years, traditional analytical methods were almost completely replaced by numerical ones. However, in the case of composites and their complexity in micro-, meso- and macroscale, numerical simulations must take into consideration a large number of design variables and would be really challenging. Therefore, machine learning has become more important and is now often used to structural analysis and design of aerospace composites [62,63].

Furthermore, production of composites may cause some limitations in their application, e.g. difficulties in producing fillers of expected geometry. Nowadays, additive manufacturing technique is developed as an alternative to conventional production. Guo et al. checked that 3D printing works fine in the case of glass fiber reinforced epoxy and provided a solution that helps to fully manage the structure and guarantee the best possible material performance [64]. This way of production may cause that new areas of composite applications will be achievable in near future.

POLYMER MATRIX COMPOSITES

Polymer matrix composites (PMCs) are known for their high specific modulus and specific strength. As a result, they have some advantages over metal alloys [65]. From a matrix perspective two groups of PMCs can be distinguished and both of them are widely applied in the aerospace industry. There are thermoset and thermoplastic PMCs, having different matrix characteristics. Thermosets are the following resins: epoxy, polyamide, polyester or phenolic while thermoplastics include mainly polymethyl methacrylate (PMMA), polypropylene, polyetheretherketone (PEEK) and Nylon 6.6. From a general perspective PMCs are categorized based on reinforcement type, e.g. carbon fiber reinforced polymers (CFRPs), glass fiber reinforced polymers (GFRPs), or aramid fiber reinforced polymers. It is worth noting that reinforcement of fibrous composite can be made with more than one material type. Therefore, hybrid composites were introduced. In particular, hybrid polymer matrix composites (HPMC) can consist of, i.a. carbon/glass fiber [66], Kevlar, carbon and ceramic nanoparticles [67] or lignin and zeolite [68]. In aircraft structures, the most extensively used alternative material for aluminum alloys is CFRP applied widely for aircraft structural materials and surface components [69–72]. The Boeing 787 aircraft has up to 50% of its total weight in CFRP. CFRPs are used in the production of fuselage (body), wing box, empennage (including rudder and elevator), flaps, ailerons and landing-gear doors [13,56,73,74]. It was revealed that the tensile strength and elastic modulus of CFRP composite is three times and two times higher, respectively, than in the case of aluminum alloy material, whereas the density of CFRP is 50% lower than aluminum alloy [65]. While CFRPs are applied mainly in structural components and control surfaces, GFRPs are often used in semi-structural components such as aircraft fairings. In the areas where there is a need of high impact resistance aramid fiber polymers seems to be the best choice [56,75–77]. They are used in the following applications: wing to body fairings, landing gear doors, cowlings, engine nacelles, floors, partitions, bulk heads, access panels, galley, cargo liner panels [78]. However, carbon, glass and aramid are not the only materials used for fiber reinforcement in PMCs. The main disadvantage of carbon fibers apart from improving composite strength is that they can cause stress concentration in composite just due to their brittleness. As a result, some other materials were tested as an alternative candidates for fibers in PMCs: basalt, graphene, carbon nanotubes (CNTs) and even natural materials (e.g. hemp, bamboo, flax, recycled cellulose, banana) [13,79,80]. Moreover, an interesting aspect of increasing CFRP performance is creating a bio-inspired structure of a composite based on solutions present in nature [81–83]. As it is known, e.g. crabs, clams, turtles or conches, have surfaces with great impact properties [84–87]. Hou et al. demonstrated that structure of CFRP laminates inspired by a mantis shrimp is characterized by better fracture toughness as well as higher energy absorption ratio [88].

Basalt reinforcement in PMCs has been revealed as one of the most effective. It was proven experimentally that embedding basalt fibers into polybutylene succinate matrix was connected to the increase of material properties, such as tensile modulus, flexural modulus, tensile strength and tensile modulus [89]. Furthermore, graphene supposed to be another good candidate for fibers. Scientific research showed that adding graphene oxide with just 0.1% of entire composite weight to an epoxy caused that the material tensile strength raised from 53 MPa to over 70 MPa. In addition, PMCs reinforced with graphene have better mechanical properties comparing to PMCs reinforced with CNTs. [90,91]. Besides, improving the properties of PMCs is also possible by applying natural fibers as a reinforcement. They and CNT-reinforced PMCs are both widely used in military aircraft (e.g. conductive coating and structure of fighter jets) [13,79].

However, not only a reinforcement can affect composite performance but also a matrix. In general, polymer matrices have low flame resistance. Because many aircraft components require high flame resistance, some papers investigated modified matrices and showed that e.g. the ablation resistance of CFRP grew notably due to embedding rigid phenyl groups. Such material with good ablation resistance can be successfully applied in the aircraft areas where advanced thermal protection is required [92]. Additionally, Oliwa at al. revealed that an increase of GFRP flame resistance can be obtained by adding 1-3 wt% of bentonites modified with phosphonium salts or quaternary ammonium [93].

In 2025, working on developing a brand new composite materials which can be successfully used under extreme working conditions observed in the aerospace engineering is still relevant [26]. One of the solution is to use reinforced ethylene propylene diene monomer (EPDM). Composites of that kind can be applied for solid rocket motor combustion chambers. They are known as elastomeric heat-shielding materials (EHSMs) which can withstand extremely unfavorable conditions. The most common reinforcements for EPDM are Kevlar fiber and silicon dioxide [94–96]. However, recent research revealed superior improvement of EHSMs reinforced with zirconium diboride [26]. These was confirmed by an experiment on rocket motor subjected to high temperature and high-speed gas flow and make developed material a good candidate for potential aerospace applications under extreme environmental conditions [26]. It is worth noticing that the application of polymer matrix composites is not only limited to construction purposes. Such an interesting aspect with growing popularity is to use piezoelectric nanogenerators (PNGs) consist of piezoelectric nanowires (NWs) embedded in polymer matrix. Nowadays, PNGs are widely used as components for autonomous smart systems in many branches of engineering, including aerospace industry [97–99]. Although the main PNGs components are NWs, embedding them into polymer is crucial to provide suitable mechanical strength of the device, proper electrodes connection and to isolate NWs from their neighbors [100]. If the latter is not fulfilled to a sufficient degree, this may cause an undesirable loss in PNG efficiency [101,102]. One of the most important materials used for NWs is zinc oxide (ZnO) [103]. The NWs made of ZnO are mainly integrated with polymers, such as polymethyl methacrylate (PMMA), poly(dimethylsiloxane) (PDMS) and parylene-C [104–107]. Apart from the properties of a specific polymer, e.g. Young modulus, dielectric permittivity another aspect which can affect the efficiency of piezoelectric properties of PNGs is the thickness of polymer over NWs. It was proven by finite element method simulations and also experimentally that reducing the thickness of the polymer layer in PNGs is related to their better piezoelectric efficiency [100,107]. However, if the layer is too thin, it may cause loss of PNG performance [104,108]. Hence, it is important to specify the optimal thickness of a polymer layer in each given configuration.

METAL MATRIX COMPOSITES

Moreover, metal matrix composites (MMCs) are another meaningful group of composite materials. Their advantages include high wear resistance, fracture toughness and yield strength. Besides, they have a quite low coefficient of thermal expansion. These relevant physical and mechanical properties make them the good candidates for replacing alloys in aerospace industry [13,109]. MMCs are used for, i.a. fuselage and wing skins of aircrafts [110]. However, as in the case of other composites, their specific properties are related to a given material configuration. For instance, MMC using aluminum matrix reinforced by 30% of silicon carbide (SiC) has over 10% higher tensile strength, 60% higher elastic modulus and as much as 70% higher specific modulus than 2219 aluminum based alloy with the same density [111,112]. in modern aerospace applications, 2219 aluminum alloy has been replaced by specially developed 2195 aluminum alloy. AA2195 was used for the first time in aerospace engineering during NASA's STS-91 mission [113,114]. Nowadays, scientists show that the mechanical properties of AA2195 may be further improved by making MMCs based on 2195 aluminum alloy and graphene [115]. Improving of the properties of graphene based MMCs is also connected to graphene particles ability to arrest crack propagation [116,117]. It was proven experimentally that the ideal proportion of graphene is 0.5 wt% and exceeding the limit is referred to performance decrease [118,119]. Other reinforcement type of aluminum matrix composites' is magnetite which particles cause the increase of material magnetic properties [120]. Apart from aluminum, titanium, nickel, magnesium and copper are used as MMCs matrices [13,121]. The MMCs based on magnesium alloys are also in common use. Magnesium alloys with rare earth elements inside are well-known materials for aerospace applications [122]. Maqbool et al. showed that the wear performance of the magnesium alloy-based MMCs reinforced with aluminum, titanium and tin powder can be enhanced by a double-pass friction stir processing [123]. In recent years, MMCs have still stayed interesting for the researchers who examine their behavior and provide valuable results helping to develop appropriate solutions in a given engineering area [124–126].

Metal matrices reinforced with fibers represent fiber metal laminates (FMLs). FMLs, owing to their properties were applied in the Airbus A380 aircraft and in solid rocket construction [127]. They are used as fuselage skin mainly in military and civil aircrafts [110]. Particularly, FMLs were used i.e. in the following aircrafts: Lockheed C-130 Hercules (flaps), McDonnell Douglas C-17 (aft cargo doors), Airbus A400M (frames), Airbus A380 (fuselage and tails) [128–130]. Aramid reinforced aluminum laminates (ARALLs) have been applied for years in a structure of pressurized fuselage cabin and lower wing skin [131]. In the case of MMCs, using natural fiber is also common. For instance, palm kernel ash reinforced aluminum-magnesium-silicone composites were used in combustion chambers of fighter jets [132]. Subramanian et al. introduced a novel titanium-based FML reinforced with Kevlar and jute hybrid fibers which has potential for application in the aerospace industry [133].

However, in the case of FMLs, it is crucial to select the best possible forming method, because inaccuracies in forming may have a negative influence on material properties [134]. For instance, problems occur during autoclave forming process can lead to poor quality of FMLs [135,136]. Chen et al. investigated the influence of ultrasonic vibration-assisted hot press forming on the mechanical properties of FML and proved that in comparison to traditional forming, this process allows enhancing tensile strength, bending strength and shear strength of FMLs [137]. It was also revealed that surface treatment of metals can further improve the performance of FMLs [138–140]. Yang et al. proved that laser shock peening can enhance the fatigue resistance of FMLs [141].

The most commonly applied group of FMLs constitutes glass fiber reinforced aluminum (GLARE – glass laminate aluminum reinforced epoxy). GLARE is a hybrid material made of a few aluminum layers and glass fibers placed one after the other and bonded with an epoxy resin. Numbers of layers varied from 2 to 6 with the 0.2-0.5 mm thickness. GLARE is more expensive than aluminum and is also one of the most expensive composites overall. It has the following properties compared to metals: great stiffness and strength, high corrosion and fatigue resistance, low density. Examples of GLARE application are empennage and fuselage of the Airbus A380 aircraft or the Boeing 777 aircraft [56,142–148]. Annamalai et al. revealed that changing layup sequences may affect a growth in GLARE performance [143].

Besides, among MMCs there are IMCs – intermetallic matrix composites. Their application in the Boing 777 aircraft caused reduction of the engine weight by 150 kg. GE Aviation company developed General Electric GE90, a turbofan engine consisting of IMC made of titanium aluminides [149]. Improvement of MMC properties can be made by applying graphene or CNTs. That contributes to lower thermal expansion, better self-lubricant skills, higher strength and better damping ability. Cao et al. developed a novel solution to enhance the mechanical properties of FMLs through graphene nanoplatelets [150]. Carbon or ceramic fibers have no potential to enhance the properties of MMCs [151]. Moreover, the performance of MMCs may be enhanced by electrodeposition. Electrodeposited MMCs (e.g. by ceramic particles) are used as coatings and the interest in them has grown significantly in recent years [152]. The most frequently used ultra-high temperature ceramic is Zirconium Carbide (ZrC). Copper-based MMCs reinforced with ZrC is one of the most promising materials for laser coatings [153–155]. Furthermore, copper matrix composites reinforced with ceramics are widely used in many aerospace applications. Nowadays, these materials are still the object of scientific research providing brand new fabrication methods [156,157]. Similarly as in the case of CFRP, bioinspired MMCs have been also studied [158]. Mechanical, tribological and thermal properties of MMCs may be also enhanced by additive manufacturing [159]. This technique is helpful for low-volume manufacturing which is common in the aerospace industry [160].

CERAMIC MATRIX COMPOSITES

Matrices of ceramic matrix composites (CMCs) are mostly made of silicon carbide, carbon, alumina, aluminum titanate, silicon nitride, aluminum nitride, mullite or zirconia. Their reinforcement can be made of similar materials which allow obtaining different CMCs configurations such as: silicon carbide/silicon carbide, carbon/carbon, carbon/silicon carbide etc. [13,161]. As the CMCs designed for aerospace are able to withstand extreme environmental conditions, they are called ultra-high temperature CMCs (UHTCMCs). Materials of that kind have been thoroughly explored due to their promising properties, especially high temperature resistance, great hardness, good corrosion resistance and multifunctionality [13,162–166]. However, besides many advantages over traditional metals, reducing the cost has become a key challenge in the case of CMSs [167,168]. CMSs are able to resist extremely high operating temperatures, significantly over 1000 °C, so they can be used as materials for, e.g. engine components, such as exhaust nozzle or aircraft brake disks (carbon fiber reinforced silicon carbide) [169–171]. In particular, they are known from successful applications in turbine components, such as combustion liners, vanes, nozzles, blades, bearings, heat shields etc. or space propulsion [172–178]. They are also used in propulsion systems like scramjets, exhaust manifolds as well as turbocharger components, leading edges of wings or nose caps

[178–182]. Considering hardness property, it was examined that the CMC based on alumina has hardness of 23 GPa, which is about four times more than hardened steel [13]. Furthermore, the fracture toughness of CMCs can be strengthened by adding a small amount of nanomaterials, e.g. graphene or CNTs. Walker et al. revealed that adding 1.5 vol% of graphene caused a significant, over two-fold, increase in fracture toughness of a silicon nitride-based CMC [183]. Moreover, Liu et al. showed that adding graphene to alumina based CMC was also related to increase of material fracture toughness [184]. Additionally, the same manuscript proved that this only happen when graphene content was up to 0.38 vol%. Adding more graphene caused that fracture toughness started to decrease. Hence, there are some limitations in this case that need to be investigated first.

Fabrication method of CMCs can affect material properties and its final performance. It differs depending on the technique: hot pressing, slurry infiltration, melt infiltration, microwave sintering, spark plasma sintering etc. or whether it is a single or a hybrid technique [182,185,186]. Kessel et al. investigated wet-laid nonwovens as a reinforcement of CMCs and paid special attention to material fabrication and cracks occur during pyrolysis [187–189]. These days, additive manufacturing plays an important role in production of CMCs [190]. For instance, 3D-printed CMCs based on silica reinforced with zirconia and aluminum oxide are used in aeroengine turbine blades [191,192]. Han et al. proposed optimization solutions for additive manufacturing of fiber-reinforced CMCs [193]. Rishad et al. deeply analyzed the fabrication techniques of UHTCMCs, current changes and possible enhancements to increase their performance capability [182]. Moreover, CMCs machining can also affect material properties. For instance, Zhang et al. reviewed the current trends in laser processing of CMCs and showed how they can improve material performance [194].

CONCLUSIONS

On the basis of the presented review and authors' personal research conducted in the field of composites, the following conclusions can be drawn:

1. Composite materials have been introduced as the ones which can replace conventional metal alloys in aerospace applications due to their better mechanical properties and lower weight. CFRPs are the most commonly used in this field, but there are specific applications of other PMCs and also of MMCs or CMCs as well.
2. Current research shows that the topic remains relevant nowadays. The reason is that aerospace engineering is still developing and there is a demand for light-weight materials able to withstand more and more extreme environmental conditions. This is why the gaining popularity of composites in the aerospace industry is still observed.
3. Developing other branches of engineering such as materials engineering or mechanical engineering can be helpful to obtain composites with better performance. Hence, numerous valuable scientific papers concerning this issue are published every year.
4. Methods of fabrication as well as machining methods can affect the composite properties. Therefore, it is crucial to provide the best possible solutions based on current scientific knowledge.
5. Damage mechanism of composites that may lead to catastrophic failure must be considered.
6. For sure there are a lot of prospects in the field of study regarding composite materials and their application in the aerospace industry.

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