The Advanced Materials for Aerospace Industry

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Abstract. Airplane transportation makes a great contribution to the booming economics. However, it has a vital shortcoming: the cost of delivering goods by aeroplane is too high. Here is an effective way to reduce the cost of it, by improving the materials used in constructing the wings. Advanced materials and new techniques can make the wings of the aircraft better adapted to different flight conditions, thereby reducing the loss and costs of maintenance. The latest advanced materials are composites and smart materials, which have great potential for development, and good properties.

Keywords: Composite Materials, Smart Materials, Aerospace Industry.

1. Introduction

The aviation industry touches our lives in many ways. It makes people's travel more convenient and faster and also makes the transportation of goods more rapid and timely. It promoted the tourism and transportation industries to flourish, making the economy grow rapidly. But the airline industry has a fatal shortcoming -- it costs a lot. Usually, air transportation is 4 times more expensive than railroad transportation [1]. There are many reasons for the high cost of aircraft transportation: aircraft can carry only relatively small amounts of cargo at a time, and the price of fuel is super high. Therefore, if we can increase the load-bearing capacity of the aircraft and reduce its fuel consumption, we can greatly reduce the cost of air transport. At the same time, maintenance costs can be reduced by reducing aircraft wear and tear rates. Most of the existing research is to reduce costs by improving the fuel efficiency of aircraft, or by studying advanced technologies to improve the efficiency of shipping transportation. However advanced materials are widely used in many aspects and have a great impact. For example, fibreglass is used to support the exploration of solar panels in space, and graphene is used as a battery electrode material. It is found that the use of composite materials in wings has gradually entered people's field of vision, which is shown in the diagram below (Fig. 1)[2]. Among the composite materials, Al-based and Mg-based materials can reduce weight and maintenance costs, and Ti-based materials have corrosion resistance and high-temperature resistance. Each of these materials can greatly enhance the toughness and durability of the wing, thereby reducing costs.

2. Composite Materials

Composites, also called synthetic materials, are usually mixtures of two or more two types of constituent materials (constituent materials are various in physical or chemical properties). When they mix, the new material will have both the traits of each component. Each single element of the compound is unique and separated from one another, which tells the difference between heterogeneous mixture and compound materials. Composite materials with more than one different layer are called composite laminates. They have the advantages of lightweight and high harness simultaneously, thus having a wide application in structure and engineering fields. Composites based on different metals have different properties. For example, aluminium-based alloys have good hardness and corrosion resistance to make the wings more durable, while magnesium-based alloys are used to reduce the quality of the wings with low-density characteristics [3].

2.1. Al-Based Materials

Al is a kind of metal material which has good corrosion resistance. It can be mixed with a certain amount of other elements, such as Cu, Mg, Zn, and Mn, to change its physical and chemical properties, which has various applications. Composites that are based on Al to mix with other metals are called Al-based Materials. Because Mg itself is lightweight, the mixture of Al and Mg can gain a material that is both durable and lightweight. However, material Al has some disadvantages; for instance, it has low stiffness. Thus, it is worth doing experiments to try to figure out some potentially useful metals that can be mixed with Al to create a better, more effective composite that is resistant to corrosion, oxidation, and fatigue and has high hardness. Due to these mentioned advantages of Al-based materials, they have dominated the aerospace industry. Taking Al-Li alloy as an example, it has undergone three generations of upgrades. The first-generation Al-Li alloy increases its percentage of Li, decreasing the amount of Al, which makes the alloy total has a higher stiffness. The strength of the alloy increase is mainly due to the formation of the orderly delta 0 - Al3Li sediment. These precipitates have the same L12 structure as ordered gamma 0 precipitates in nickel-based superalloys. The partial covalent bond characteristic phase in intermetallic compounds increases the Young's modulus of the alloy but decreases the ductility and fracture toughness of the alloy at the same time. The ordered structure of the δ0-Al3Li precipitates further strengthens the hardness, but local shear on the ordered precipitates may produce excessive strain hardening concentrated near the grain boundaries, resulting in long-term diffusion cracking, which is one of the main reasons for the elimination of the first-generation alloy. Second-generation aluminium-lithium alloys have lithium concentrations between 1.0 and 1.3 wt%, less than 2wt% in any case. They are therefore characterized by extremely low density and are a promising metallurgical reaction. Early experiments yielded promising results with ultralight polymer-based structural composites, but they were quickly abandoned because of their high brittleness and low toughness. The third generation of aluminium lithium alloys, although heavier than the previous two generations of alloys, because the concentration of lithium is relatively small, these alloys show a good balance between processing properties and performance. It has the characteristics of high strength and high damage tolerance, and even shows good corrosion resistance, so it can be used in a wide range of wings [4].

2.2. Mg-Based Materials

As people’s awareness of green materials becomes stronger and deeper, recyclable resources have gained more and more attention. They could allow the use of limited resources to be more effective, maximizing the economic profits of these materials. Under this condition, Mg, as a metal with great recycling potential, plays a vital role in the aerospace industry. Besides, the amounts of Mg stored in the world are also plenty and ample [5]. Enough magnesium can be found in the earth's crust and in minerals in the oceans, which means even though the aerospace industry needs abundant Mg to support its development, the abundance and recyclable capacity can observe this need. Apart from the advantages mentioned, Mg is lightweight, so it makes huge contributions to the task of lowering the weight of airplanes at first, which shows great economic potential. Although it has so many advantages, it also has some vital shortcomings, disturbing the potential of Mg being fully used: its corrosion resistance is poor, resulting in the short life of things made from it. To compensate for this defect, researchers later created magnesium-based alloys and corresponding corrosion resistance technology to compensate for this. In the case of the above example in “Al-based Materials”, aluminium-magnesium alloy is an invention to improve this shortcoming. In addition, magnesium itself also lacks a certain degree of extensibility. In subsequent studies, magnesium base alloy Mg-6Al-1Ca (wt%) (AX61) perfectly compensated for this shortcoming. The scientists designed the extruded alloy so that it has a maximum tensile elongation of 27% and a hardness of 135MPa. Magnesium base alloys combined with a variety of metals show relatively comprehensive advantages of low density, high malleability, and high hardness. It can not only reduce the weight of the wing, thus reducing the consumption of oil and promoting more environmentally friendly and efficient

transportation but also enhance the corrosion resistance and toughness of the wing, thus making the wing more durable and reducing maintenance costs.

3. Smart Materials

Smart materials are the fourth generation of materials following natural materials, polymer synthetic materials and artificial design materials, and are divided into "advanced materials". It can respond to environmental stimuli, changing its structure or shape to suit its environment, so that the aircraft consumes less energy or flies faster. Therefore, smart materials have a wide range of applications in the aerospace field, such as deformed wings or brakes. Smart materials generally have the following characteristics [6]:

·Transiency: they can respond to different stimuli and can be situated in varies states.
·Immediacy: they respond to the external effects without wasting time.
·Self-actuation (intelligence): this ability is inside the material.
·Selectivity: the response is distinguished and predictable.
·Directness: both act and react are accrued in the same place.

3.1. Shape Memory Alloys

Shape memory alloys (SMA) are materials consisting of more than two metallic elements with shape memory effect (SME) through thermoelastic and martensitic phase transitions and their inversion [7]. They work by applying a strain pressure to the SMA first, and when the twinned martensite phase is converted to detwinned martensite, the cycle begins. When heated, the alloy's state changes to austenite, and when cooled, it returns to its original state, completing a cycle. In addition, the characteristics of high working density also allow shape memory alloys to reduce the weight and size of the structure. Because of its excellent properties, this Alloy has great applications in the aerospace industry [8]. For example, it was identified as a new lightweight material that could be used as an aircraft brake. Under the capability of memory alloys, one can preset a shape and then heat it when it needs to be started, making it change from martensite to preset austenite. The deformation caused by heating can produce the effect of force and achieve the characteristics of the "brake". After the whole process is over, the memory alloy can be cooled back from austenite to martensite, ready for the next use. Compared with other brakes, such as hydraulic actuators, it has the characteristics of more lightweight and low noise, which makes a great contribution to improving the performance of the aircraft [9].

4. Conclusion

This paper focuses on advanced materials that can be used to improve performance on wings, combining the recent five years of research on composite materials and smart materials. The results show that the composite material combines the advantages of different metals and has strong properties, such as high density, low weight and corrosion resistance [10]. Smart materials hold great promise, with the potential to act as brakes and allow wings to adapt to different flight conditions. This paper divides advanced materials into two categories for systematic analysis, which helps the aerospace industry to see the main advantages of different materials more clearly. This paper also has some shortcomings: only two large materials, composite materials and smart materials, are analysed, and the number of material analyses under these two categories of materials is not large. Future development can continue to extend in these two general directions, or more refined material classification, and add more specific material analysis.

References

[1] Fangni Zhang, Daniel J. Graham. Air transport and economic growth: a review of the impact mechanism and causal relationships,2020

[2] Lucjan Setlak, Rafal Kowalik, Tomasz Lusiak. Practical Use of Composite Materials Used in Military Aircraft, 2021.

[3] K.B.Nie, X.J.Wang, K.K.Deng, X.S.Hu, K.Wu. Magnesium matrix composite reinforced by nanoparticles – A review, 2021.

[4] Carols P. Bergmann, Stefano Gialanella, Alessio Malandruccolo. Topics in Mining, Metallurgy and Materials Engineering, 2020.

[5] Nathi Ram Chauhan et al 2022 IOP Conf. Ser.: Mater. Sci. Eng. 1228 012020.

[6] Antonio Concilio, Vinenza Antoucci, Ferdiando Aurichio Lenardo Lecce, Elio Sacco, Shape Memory Alloy Engineering FOR AEROSPACE, STRUCTURAL, AND BIOMEDICAL APLLICATIONS, 2021

[7] Ibrahim Nazem QADER, Mediha KÖK, Fethi DAGDELEN, Yildirim AYDOGDU, A Review of Smart Materials: Researches and Applications, 2019.

[8] Min-Soo Kim, Jae-Kyung Heo, Hugo Rodrigue, Hyun-Taek Lee, Salvador Pané, Min-Woo Han, Sung-Hoon Ahn, Shape Memory Alloy (SMA) Actuators: The Role of Material, Form, and Scaling Effects, 2023.

[9] Girolamo Costanza, and Maria Elisa Tata, Shape Memory Alloys for Aerospace, Recent Developments, and New Applications: A Short Review, 2020.

[10] Al Arsh Basheer, Advances in the smart materials applications in the aerospace industries, 2020.