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PROSPECTS FOR THE USE OF COMPOSITE MATERIALS IN SPACE TECHNOLOGIES

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ABSTRACT

This article examines the prospects for the use of composite materials in space technologies, focusing on their unique properties and opportunities to improve the design and functionality of spacecraft. Composite materials, due to their light weight, high strength and resistance to extreme conditions, are an ideal choice for the space industry. The article discusses various types of composites, including ceramic matrix composites, carbon nanotubes and metal matrix composites, each of which has certain advantages for specific applications. Special attention is being paid to the potential of these materials to enhance the safety of space missions, including protection from space debris and micrometeorites, as well as improving fire resistance and heat resistance. The study highlights the need for further developments in the field of composite technologies to achieve more efficient and safe space travel.

Keywords: Composite Materials, Composites, Space Technologies, Space, Modern Technologies.

I. INTRODUCTION

Outer space represents one of the most uninviting, life-threatening, and expensive environments in which to conduct research. Without the significant engineering advances made possible by the space race that began in the 1950s, space exploration would have been an impossible task due to the many unique technical and physical challenges faced in space travel. Despite ongoing efforts, space travel still poses many risks to astronaut safety and mission success. The development of new functional materials such as Teflon has greatly advanced the capabilities of the space industry, although initially many materials were adapted from existing commercial products. Research is now focused on creating specialized materials that can address specific problems in spacecraft design and operation [1]. One can also see an increase in the global market for advanced space composites (Fig.1.).

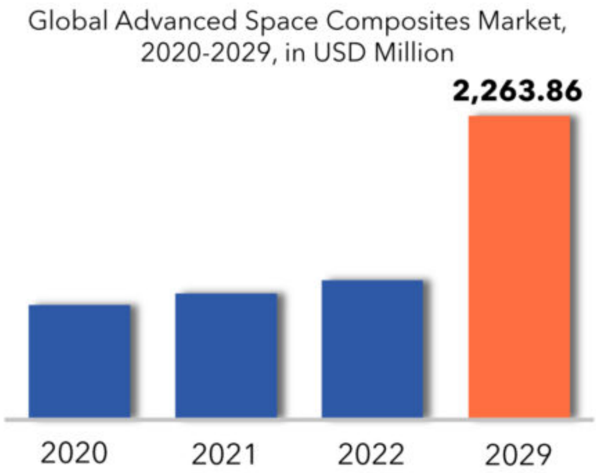

Figure 1. Global advanced space composites market

One significant threat in outer space is the risk of high-speed collisions with space debris and micrometeorites traveling at speeds up to 42 km/s, which can cause severe damage to the spacecraft, including air leaks. According to the Union of Concerned Scientists, there are more than 3,000 active satellites in orbit and the amount of space debris continues to grow. In this context, new materials with high mechanical strength are being researched to protect spacecraft from collisions, as well as materials capable of self-healing after impact to increase the durability and safety of space missions (Fig.2.).

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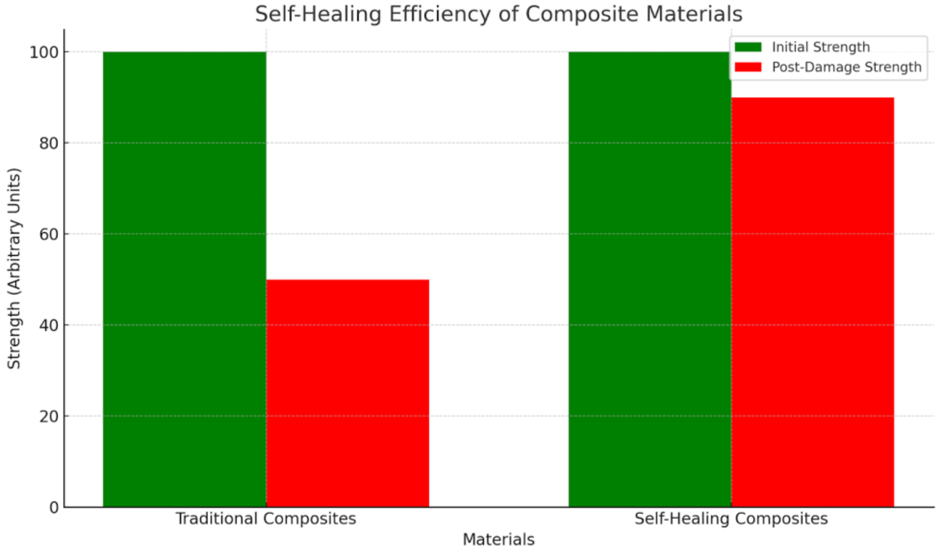

Figure 2. Efficiency of self-healing composite materials [8]

In the event of a fire in a spacecraft where there is a high oxygen content, the risk of fire spread increases. It is important that the materials used in the structure of the spacecraft have high fire and heat resistance to reduce the risks associated with the potential ignition of critical systems.

Space dust also poses a serious threat to space missions, especially during lunar and Martian surface exploration. Studies show that inhalation of space dust can lead to chronic respiratory diseases. Thus, the development of self-cleaning or anti-adhesive materials that can effectively repel space dust becomes a priority to increase the safety and efficiency of long duration space missions [2,3].

II. PROSPECTS FOR THE DEVELOPMENT OF COMPOSITE MATERIALS IN THE AEROSPACE INDUSTRY

The prospects for the use of composites in the aerospace industry are promising. With the ever-increasing demand for lightweight materials that can withstand the extreme conditions of flying at high altitudes and high speeds, composites will inevitably evolve. Modern designs already utilize a combination of composite materials and traditional metals, but their use is expected to expand further in the future. Let's take a look at three promising areas for the development of composite technologies in aerospace:

1. Ceramic matrix composites (CMCs): Although ceramic materials are brittle, their thermal qualities make CMCs ideal for building powerful and heat-resistant engines.
2. Carbon nanotubes: This innovative material retains the strength of carbon fiber and adds flexibility, expanding its applications in areas such as wing manufacturing and electromagnetic shielding.
3. Metal matrix composites (MMC): Combining carbon or ceramics with a metal matrix, MMCs are being explored for use in helicopter blade and gas turbine engine structures.

Thus, the future of composite materials in aerospace heralds new technological breakthroughs that could radically change the design of aircraft and even lead to the creation of spacecraft resembling those we see in science fiction [4,5].

III. THE NEED FOR COMPOSITE MATERIALS IN THE SPACE INDUSTRY

In aerospace engineering, the use of composite materials is becoming increasingly preferred over traditional metals due to a number of their outstanding characteristics. Composites outperform metals in strength, stiffness, durability and corrosion resistance, while significantly reducing structural weight. These materials exhibit improved endurance limits, reducing the number of parts in structures and extending their service life.

A special feature of composites is their high adaptability: the physical and mechanical properties of these materials can be fine-tuned or optimized for specific applications by modifying the composition and structure. This property makes composites particularly valuable for innovative projects in the aircraft industry, including the design of complex curved shapes such as engine cowls, wheel fairings and wing tips.

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The advantages offered by composite materials contribute to significant improvements in aircraft performance. Aircraft built using composite technology can reach higher altitudes, reach higher speeds and travel longer distances, while being able to carry larger payloads. This is made possible by reduced weight and increased fuel efficiency. The use of composites has spurred many key innovations in aerospace over the past decades, significantly pushing the boundaries of what is possible in this area.

In turn, reinforcing fibers are a key element in the composition of composite materials, playing a crucial role in providing the required strength and stiffness. These fibers are oriented in such a way as to maximize their mechanical performance in the direction of their alignment. Three types of fibers are particularly valued in the aerospace industry: carbon, glass and aramid fibers (Fig.3.).

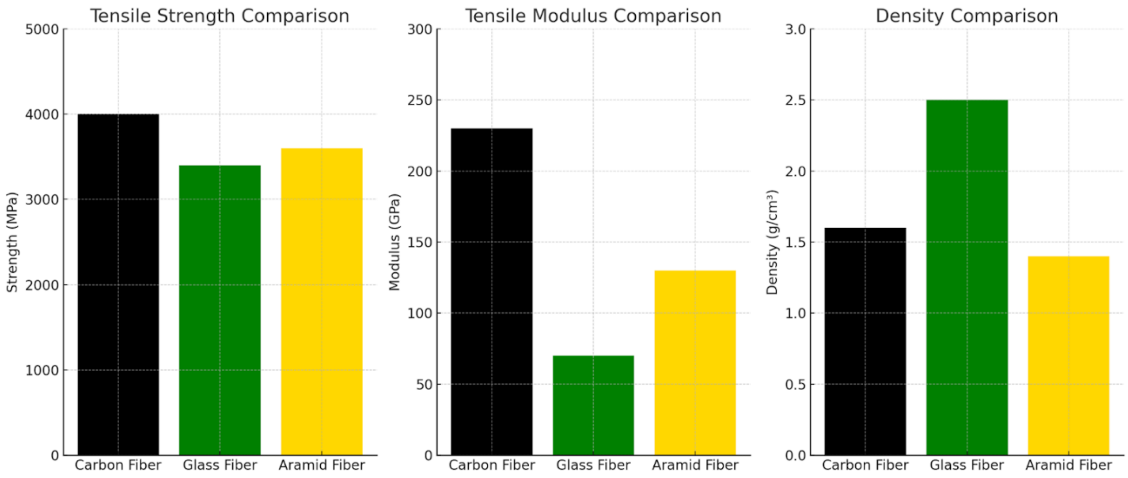

Figure 3. Comparison of mechanical properties of carbon, glass and aramid fibers

This graph shows three sub-graphs comparing the strength, stiffness and density of carbon, glass and aramid fibers:

Tensile strength (in MPa):

Carbon fiber: 4000 MPa

Glass fiber: 3400 MPa

Aramid fiber: 3600 MPa

Modulus of elasticity (in GPa):

Carbon fiber: 230 GPa

Glass fiber: 70 GPa

Aramid fiber: 130 GPa

Density (in g/cm^3):

Carbon fiber: 1.6 g/cm^3

Glass fiber: 2.5 g/cm^3

Aramid fiber: 1.4 g/cm^3 [8,9].

Each type of fiber has a unique chemical composition at the molecular level, which determines its physical and mechanical properties on a macroscopic scale. Carbon fibers are known for their exceptional stiffness and strength, making them ideal for structural applications where minimum weight at maximum load is required. Glass fibers, on the other hand, offer an excellent price/performance ratio, as well as good impact resistance and chemical resistance. Aramid fibers such as Kevlar stand out for their outstanding impact strength and thermal stability, making them the preferred choice for protective applications [6].

The most important characteristics of these fibers include not only strength and stiffness, but also parameters such as impact toughness, temperature stability, density, electrical and thermal conductivity, chemical compatibility, fatigue resistance, and cost effectiveness. These properties make reinforcing fibers indispensable in the creation of advanced aerospace materials that require high performance under extreme conditions.

Speaking of carbon fibers, individual strands of carbon fiber are 93-95% composed of carbon atoms, which gives the fiber its characteristic black color. (Figure 4.)

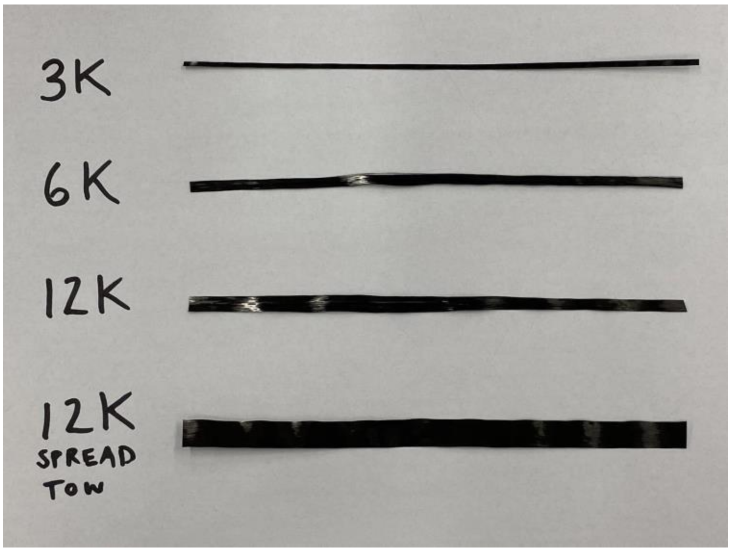

Figure 4. Carbon fibers of different densities [6].

Carbon fiber can be produced from three polymer precursors, including polyacrylonitrile (PAN), viscose and pectic. The most common polymer precursor is PAN. There are several chemical and mechanical processes required to convert the polymer precursor into carbon fiber strands. The fibers are then chemically altered to stabilize the compound. These fibers are then heated to high temperatures, causing almost all non-carbon atoms to be displaced, leaving behind dense carbon crystalline structures. At this stage, the fibers are treated with binders to improve their ability to bind to the resins. The individual fiber strands are only 5 to 10 microns (0.0002 to 0.0004 inches) in diameter. They are combined into bundles consisting of fiber bundles ranging in length from 1,000 (1k) to 320,000 (320k) individual fibers (Figure 5.)

Figure 5. The structure of carbon fibers [6]

The development of this material began in the early 1960s and quickly led to the creation of high-performance fibers applicable in aviation and astronautics. Over time, through multiple experiments with manufacturing processes and a variety of starting materials, not only the strength of carbon fiber but also its adaptability in various applications has improved significantly. It should be noted that there are different types of carbon fiber, each with unique values of strength, stiffness, and cost.

Carbon fiber has an outstanding combination of high strength and stiffness at low density, which makes it preferable to glass and aramid fibers. It is also characterized by weak electrical conductivity, but transfers heat well along the fibers. Due to these properties, carbon fiber is stable over a wide range of temperatures and has a low coefficient of thermal expansion.

IV. APPLICATIONS AND LIMITATIONS

Due to its high strength-to-weight ratio, carbon fiber is ideal for use in aerospace applications, from airframe structures to spacecraft heat shields. However, its use is not limited to the space industry: carbon fiber is also used in the manufacture of boats, race cars, and sports equipment. The main disadvantage of carbon fiber is its conductivity, which can cause galvanic corrosion when in contact with some metals and create problems in applications requiring signal transmission, such as antenna fairings.

When machining carbon fibers, it is important to use diamond-coated tools, especially when machining composites, because they minimize chip creation and prevent thermal damage to the bonding resin. Carbon fiber dust, being conductive, can harm electronics by causing short circuits and must be carefully controlled in production environments as it also poses a health hazard to humans by causing skin and respiratory irritation [7].

V. CONCLUSION

The use of composite materials in space technology represents a promising trend in aerospace engineering that promises to revolutionize the design and operation of spacecraft. These materials, combining lightness, strength and resistance to extreme conditions, allow for significant improvements in fuel efficiency and flight safety. Developments in ceramic matrix composites, carbon nanotubes, and metal matrix composites are opening up new opportunities for lighter and more reliable spacecraft. However, in order to realize the full potential of composite materials, additional research and innovations are needed to improve their characteristics and performance. In conclusion, composites are well positioned to be the key to the future of space exploration, enabling safer and more efficient space exploration.

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