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Sustainable Materials In Aircraft Construction: A Viable Alternative To Aluminium?

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Abstract
This paper explores the viability of sustainable materials as alternatives to traditional metals like aluminium in aircraft manufacturing. Aluminium, widely used due to its lightweight and corrosion-resistant properties, poses significant environmental and structural challenges, including greenhouse gas emissions and susceptibility to thermal expansion. Composite materials, such as bio-based composites and natural-fiber reinforced composites, offer promising solutions by reducing weight, fuel consumption, and greenhouse gas emissions, while also being more cost-effective. The Boeing 787 Dreamliner serves as a case study, demonstrating how composite materials can enhance flight efficiency and sustainability. Although composites present challenges such as damage detection, thermal sensitivity, and manufacturing complexity, ongoing innovations are addressing these limitations. The paper concludes that sustainable composites have the potential to transform aviation, offering a greener, more efficient future.

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I. Introduction

Airplane construction primarily relies on materials such as aluminum, steel, and titanium alloys. However, these materials share negative environmental impacts, either in their manufacturing or extraction processes. For example, aluminum is extracted from bauxite through a complex chemical process, which generates significant waste. Approximately one ton of aluminum production results in roughly four tons of waste, known as "red mud" (Rainforest Rescue). Red mud can transform freshwater ecosystems into dead zones, making them uninhabitable and unable to support life. Additionally, this waste contaminates water sources and contributes to environmental degradation. Aluminum production also has a significant impact on the greenhouse effect, accounting for 2% of global greenhouse gas emissions, or approximately 1.1 billion tons of greenhouse gases annually (Bater et al.).

Aluminum's sustainability is not only challenged by its environmental impact but also by its structural limitations in aircraft. One issue is thermal expansion, which causes significant structural damage when aluminum is exposed to extreme temperature variations. This damage is costly to repair. Fortunately, various alternatives to aluminum are available for aircraft manufacturing. One such alternative is composite materials, which are made from two or more materials with different physical and chemical properties. Fiberglass is a well-known composite material, first used in the Boeing 707 in the 1950s. Other composite materials include Kevlar and carbon fiber. Kevlar, with its high modulus and resistance to deformation, is widely used in military vests and aircraft impact protection systems.

II. Objective

The objective of this paper is to determine whether sustainable materials offer a viable alternative to traditional materials in aircraft manufacturing, considering both environmental and structural requirements.

III. Common Elements Used In Aircraft Production

Aluminum

Aluminum is a lightweight material with high resistance to corrosion. It constitutes one-third of the Earth's crust. Aluminum alloys have a high strength-to-weight ratio, meaning they are extremely strong, capable of withstanding significant stress without deformation, while also being lightweight and easy to handle. These alloys are also corrosion-resistant, which prevents rusting when reacting with oxidizing agents such as moisture and oxygen in the air. The lightweight nature of aluminum allows aircraft to travel greater distances and may reduce operational costs.

Titanium

Titanium is favored for its high strength-to-weight ratio and biocompatibility. Recent advances in titanium alloys have made titanium more attractive than aluminum for aircraft manufacturing. Steel, although strong, is too heavy for efficient use in aircraft, as it negatively affects operational speed and overall performance. Titanium, on the other hand, is resistant to seawater corrosion, making it suitable for seaplanes (IITK).

IV. Sustainable Materials In Aircraft Manufacturing

Recycled Aluminum

Recycled aluminum is 100% recyclable and can be reused without any loss of value. It is also more cost-effective than conventional aluminum while maintaining a high strength-to-weight ratio and corrosion resistance.

Bio-Based Composites

Bio-based composites are fiber-reinforced plastics made from renewable materials. These composites are lightweight, cost less to maintain, and can cover long distances at high operational speeds. Bio-based composites, or other composite materials, are less expensive than metals such as aluminum, which can cost two to three times more than composite materials.

Natural-Fiber Reinforced Composites

Natural-fiber reinforced composites combine plant-derived fibers with a polymer matrix. These materials are renewable, lightweight, and possess a high strength-to-weight ratio, making them a suitable alternative to metals like aluminum and titanium. They can reduce engine weight, fuel consumption, and increase efficiency.

Environmental and Economic Benefits

Aircraft significantly contribute to environmental pollution due to high fuel consumption, which results in greenhouse gas emissions. Composite materials help reduce aircraft weight, fuel consumption, and greenhouse gas emissions. Although recycling composite materials is still expensive, ongoing research is improving their environmental performance. Composites' lightweight, corrosion-resistant, and flexible design enhances flight efficiency while reducing waste. Economically, composite materials are more cost-effective than traditional metals, and the global composites market is expected to grow from $9.69 billion in 2022 by 7.2% annually until 2030 (Grandview Research).

V. Case Study: Boeing 787 Dreamliner

Aircraft contribute to environmental pollution by burning large quantities of fuel, releasing greenhouse gases into the atmosphere. The use of composite materials in aircraft construction, such as the Boeing 787 Dreamliner, significantly reduces the aircraft's overall weight, leading to a reduction in fuel consumption and greenhouse gas emissions. This reduction maximizes the ratio between payload weight and fuel consumption, which helps mitigate climate change (Fera et al. 2020).

Boeing has incorporated carbon fiber into the aft body of the 787 Dreamliner. The aircraft begins with carbon-fiber tape infused with resin. Using composite materials in the Dreamliner reduces the need for fasteners, saving materials. The Dreamliner's airframe consists of 50% carbon fiber and other composites, offering high tensile strength while remaining lightweight. Rolls-Royce engines, which power the Dreamliner, also utilize carbon-fiber composites, saving up to 700 kg of fuel per aircraft (Sam Chui).

Boeing has also partnered with the University of Nottingham to develop processes for recycling carbon fiber-reinforced plastic (CFRP) composites. By using supercritical water to process these materials, the collaboration has produced higher-quality carbon fibers compared to previous recycling methods (Composites World).

Limitations of Composite Materials

Damage Detection: Composites are difficult to inspect for damage, making repairs tedious and expensive.

Thermal Sensitivity: Resin in composites can weaken at temperatures as low as 150°C, posing fire risks. Resin bonds break down at temperatures exceeding 300°C, causing structural failure (Verma).

Manufacturing and Maintenance: Engineers accustomed to working with aluminum face challenges when adapting to complex carbon-fiber composites, which take longer to manufacture (Aviation Austin).

UV Damage: Prolonged exposure to UV light can cause delamination and cracking in composites (Wills).

Brittleness: Non-metal components of composites are brittle and may fracture under pressure, potentially damaging the aircraft structure (Composite Envisions).

Transportation: Composite materials require refrigerated environments during transport to prevent reactions with atmospheric oxygen (3D Barriers Inc.).

VI. Conclusion

Sustainable composites present a promising alternative to aluminum in aircraft manufacturing. They reduce weight, fuel consumption, and emissions, improving efficiency, which is why they dominate the construction of aircraft like the Boeing 787 Dreamliner. Despite challenges such as damage detection and thermal sensitivity, ongoing innovations are addressing these issues. The adoption of composites could lead to a greener, more efficient aviation industry.

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