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Use of Graphene in Aircraft Structures for Enhanced Lightning Strike Protection - An Overview

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Abstract - *Lightning strikes can cause structural damage to an aircraft. Certain parts of the aircraft that are made of carbon fiber reinforced plastics (CFRPs) suffer mechanical damage. This can compromise the structural efficiency of aircraft. Hence there is a need to upgrade the existing lightning strike protection technology. Graphene, a carbon derivative, is a possible solution to enhance lightning protection, owing to its superior electrical, heat conductivities and mechanical strength. The study offers an overview on the damage mechanisms involved in a lightning strike to an aircraft, requisites for a lightning strike protection system and the viability of adding graphene to the carbon fiber composites.*

***Key Words*:** Lightning, CFRPs, Graphene, LSP, Electrical conductivity, Joule heating effect

1. INTRODUCTION

Aircrafts are generally made of alloys of aluminium yet certain parts of the aircraft are made of carbon fiber reinforced plastics (CFRPs), to make light weight and enhance few mechanical properties of the structure. A lightning strike is a rare event for an aircraft yet they do happen significantly often. It is generally assumed that every year a transport aircraft is struck by lightning once. Lightning strikes generally occur at an altitude of 5000 to 15000 feet mostly during the ascent and descent phases of flight. In this process, parts of the aircraft made of CFRPs suffer damage owing to the nonconducting nature of carbon fiber. In the quest to solve the problem, there is a need to explore graphene as a possible and viable replacement to CFRPs which may provide better lightning strike protection without the structural integrity of the aircraft compromise. At the time of the lightning strike, there is a direct contact between the lightning bow and the aircraft face. At present, CFRP structures are being employed considerably while designing aircraft in order to reduce the overall weight and to increase few specific mechanical parcels of airframe corridor. Therefore, the main emphasis is being given to the lightning protection aspects applicable to CFRP airframe corridor.

Lightning is an interesting phenomenon as in fig. 1. It captivates the interest of researchers who want to understand the complex nature and unpredictability of a lightning strike. The question about the intensity of the impact to an aircraft during a lightning strike brings up several doubts as to how are aircrafts protected against lightning and to what extent the protection systems are efficient. In today's modern world, air transport is significantly high and is spread all over the globe across different geographical locations and weather systems which make the possibility of a lightning strike even higher. Since there is scope for usage of advanced smart materials which are non-conventional, it is believed that lightning protection systems can be upgraded.

It is generally believed that the severe mechanical damage in and around the lightning strike zone of CFRP parts occurs during the transient current component, and the shock wave generated by the explosion of the vaporized material in the arc strike zone is the main cause. However, the effects of shock waves and current-induced apparent bulk magnetism caused by the supersonic expansion of the thermal plasma channel cannot be completely ignored [1]. The contribution of these magnetic forces must also be considered.

Figure 1 Lightning strike to the aircraft

2. DAMAGE MECHANISMS

There are different physical mechanisms through which damage to airframe structures occur while lightning strikes:

- Thermal effects of the resistive volume, joule heating due to the flow of current in the electrically conducting structures.
- Thermal effects due to thermal radiation from hot plasma channel.
- Thermal effects due to direct heat input from the hot plasma channels[2]

Recent investigations proved that contribution of thermal radiation is negligible [3], [4].

- Transient Mechanical Force effects the magnetic volume forces [5]
- Transient Mechanical Force effects the shock waves caused by the exploding materials and from the supersonic expansion of the hot plasma channel [6].

Some of the effects may be measured, quantified [7], [8] but, some cannot because they were a part of a complex transient interaction at the interface between composite structure involving the hot plasma and the plasma channel route, mechanical and the dynamic behavior of the composite structure.

3. LIGHTNING PROTECTION MEASURES

The aim of lightning the protection is to reduce the extent of mechanical and thermal damage to the composite structures to an acceptable minimal level, where the acceptable level may vary with the location use and the design of the airframe composite structure. Most critical airframe areas were considered to be the assembly and the lightning arc attachment areas.

The criteria for choosing the most appropriate lightning protection are a part of technical and commercial issues such as:

- The composite material should be compatible with the electro-chemical properties.
- The effectiveness of the lightning protection
- The dielectric coating and the adhesive ability with the composite structure.
- Resistant to threats from external environmental
- The additional load of the lightning protection system.
- System cost and the material costs of the lightning system.
- Complexity and the cost of manufacturing process of the lightning system
- And finally the cost of maintenance

The current lightning strike protection system (LSPs) involves the usage of a metal mesh integrated with CFRPs which provides adequate electrical conductivity but increases the weight of the aircraft. In order to strike a perfect balance between sufficient electrical conductivity and structural efficiency of the aircraft to protect CFRP structures, it is the need of the hour to explore non-conventional materials like graphene which offers both electrical conductivity and mechanical strength. The important challenge to protect non conducting structures from damage caused by lightning currents. For which diverters were provided, like punctures with external conductors. These divert the lightning flash to the surrounding metallic structure hence, intercepts the lightning flashes. There are two methods for protecting non-conductive composite materials, one is One approach is to use deflection strips on the outer surface to activate streamer spots and intercept the electric field generated by lightning strikes, and another approach is to apply conductive materials to the outer structure of the aircraft [9].

4. GRAPHENE AND ITS AEROSPACE APPLICATIONS

A promising new technology pushed forward graphene by the material scientists for aerospace applications. The new technology unitized graphene as it has many advantages its structure is like carbon tittles held together like a structure of a honey comb. This miracle graphene took a Centre stage and is in the minds of numerous scientists as it was experimentally been understood in many aspects since 2004. It is the smart work of the professors at the University of Manchester who derived a derivative of graphene from graphite[10]. Since then; this miracle graphene was explored and promised to be a part of multidimensional sectors including the aeronautical industry.

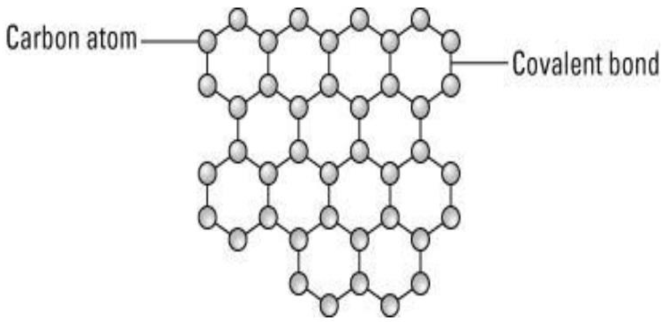

Figure 2 Layer of Carbon atoms in graphene

Graphene is one of the infinitesimal derivatives of graphite, conforming of carbon tittles as shown in fig.2. Graphene is considered to be a superior structure of the graphite because the it is made up of multiple layers of graphene, linked to each other through London Dissipation forces as the p-orbitals, the area around a snippet where electrons are most likely to be positioned in a derivative which are closed to those of another derivative, the electrons in these orbitals become delocalized and can flow freely between the layers. Because the layers themselve contain strong covalent bonds, the London force between the layers is weaker, thus giving the material a structural weakness. This bug does not exist in the graph structure[11].

Graphene not only is a very good electrical conductor but also having an ability to flow of electrons at a greater pace through graphene honeycomb structure. Generally metals have only one energy band pertaining to conduction whereas graphene is a relativistic system, has two bands, electrons and antiparticle holes.

Graphene stands apart from other ordinary semiconductors. Its properties are different can be categorized as hybrid between semiconductor and metal. Graphene electrons travel at a speed of about one hundred times less than light speed and seventy times faster than that of silicon electrons.

Hence it is considered as an unconventional material, where the holes and electrons move in a way that they have zero mass. Graphene has resistance lower than silver, high electrical and thermal conductivity.

The difference between aeronautical structures and other structures is that they need to meet two important challenges, light weight and high performance. In this context, graphene-based composites could have a game-changing impact on the performance and efficiency of future airframes [12]. This is mainly due to the unique physical and electrical properties of graphene, which can easily realize intelligent integration of lightning protection, impact resistance, and flame retardancy. The Improvements in the electrical percolation and the mechanical performance have been obtained by a combined action due to adequate balance between the chemistry of graphene edges and the exfoliation degree, which promotes the interfacial interaction between the carbon layers and the polymer.

Wang et al. Reduced graphene oxide (RGO) was successfully deposited on the composite surface using the infiltration-assisted resin film infusion method [13], reporting a considerably higher surface of about (440 S/cm) compared to other reported non-metallic LSPs Conductivity value. In the current study, the focus is on improving the surface conductivity of CFRP substrates for efficient lightning dissipation by providing a safe conductive path.

CONCLUSIONS

Carbon fiber composites are used to a large extent in aircraft applications. However, since carbon fiber reinforced composites are poor conductors of electricity, they are easily damaged by lightning strikes. Hence, this very reason has prompted aircraft companies to incorporate aluminium orcopper meshes into the composite materials, which add significant weight and cost. Graphene can be known for its high quality, superior, hardest, strongest and the toughest material.

The electrical conductivity with a feature of graphene enhanced composites has already been established. For withstanding the lightning strike a highly conductive carbon fibre reinforced epoxy composite material needs to be made which is possible with the addition of functional graphene with that of carbon fibre. This will also enhance the degree of safety. With the elimination of the metallic meshes from the aircraft structures the aircraft not only is lighter but also more fuel efficient. Due to enhanced strength of the graphene enhanced composites, structural integrity will not be compromised.

Multifunctional graphene materials specially designed to meet aerospace structural requirements, such as suitable thermal stability, fire resistance, mechanical properties, and electrical conductivity, have emerged as a promising candidate for aerospace composites [14]. Therefore, the development of graphene is such a marvellous material which results in a lighter, safer and cost-effective aircraft material with enhanced protection features against lightning strikes.

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