

Advanced Materials for Aerospace and Space Applications

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ABSTRACT

Constant swirls of innovative ideas are starting to push composites and hybrid metal-composite components for use in an ever expanding circle of products. Recent discoveries of Graphene/Au composites have invigorated innovations for its application to aerospace and space products.

Attributes such as a low CTE, stiffness, and light weight attract other manufacturers of smaller products to use composites for enhanced performance and durability.

The uses and economics of composites is an enormously broad subject. Examples of composite materials will be described in this paper to provide samples of applications selected for their far reaching potential to enhance product performance. Examples will also be presented to explain the application of carbon based composites where the product performance or application would not be possible without special materials.

This paper will also describe emerging materials such as graphene and some of its applications to enhance the performance of current technologies

It is easy become enamored with the composite big parts built for trains, planes, automobiles, ships, and wind turbine blades. We sometimes forget that there is a world of composites that exists outside these highly visible products where composites materials are contributing in substantial ways to other product's improvement. Many times the use of composites is integrated into the larger products in the form of components where tribology is critical to performance or coatings are needed to provide thermal protection.

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INTRODUCTION

"Change the way you look at things and the things you look at change."

- Wayne W. Dyer

On July 8, 2009, the earth shook as four Thiokol solid rocket motors ignited, propelling a 48,000 pound (20,000 kg) bullet shaped vehicle up and away from its launch pad.

Approximately seven seconds later, the engines stopped and the vehicle silently coasted upward as the boost skirt drawn by gravity fell away toward earth ≈6000 feet below. As the vehicle

coasted skyward in a sequence of events separated by seconds, the coast skirt separated and deployed parachutes; the forward fairings fell away; the crew capsule deployed its parachutes and began its decent towards earth. The flight test performed at the North American Space Administration's (NASA) Wallops Island Flight Facility in Virginia was a flawless performance. Figure 1 Shows (Courtesy of NASA) the MLAS vehicle accelerating up and away from its launch stand. The test vehicle weighed over 45,000 pounds (20,000 kg) and was over 33 feet (10 m) tall. MLAS is a proposed alternative to the Max Faget invented Launch Escape System (LES) that would be activated if a malfunction of the launch vehicle took place requiring immediate abort.



Figure 1. MLAS Launch from Wallops Island, Virginia

If you were to drive 850 miles down the coast about 3 1/2 months later to the Kennedy Space Center in Florida, the ground would shake again. This time a solid rocket motor of the type formerly used on the space shuttle would ignite sending an ARES I-X rocket skyward. [Figure 2](#) (Courtesy of NASA) shows the ARES I-X lifting off from its pad on October 28, 2009.

As the rocket lifted and gained speed the thrust of the motor pushed against the upper section it was carrying accelerating the vehicle past Mach 2. Tremendous load transferred into the frustum and inter-stage connecting the solid rocket motor to the upper section that holds fuel and payload. The successful launch was the first test for the ARES I design that was to become the vehicle to carry a human payload into space as part of the Constellation Program. The human payload would be housed in the Orion spacecraft.

Successful launches are not unusual for NASA. What was unusual was the use of composites and other advanced materials to replace structural components on the two vehicles. The ARES I-X used composites for the critical frustum and inter-stage that connected the solid rocket motor to the upper section of the vehicle.

The uses and economics of composites and other advanced materials in aerospace and space applications is an enormously broad subject. When presenting the depth and breadth of advanced materials in individual applications they would exceed the framework of this medium. Therefore, a few examples will be described in this paper to provide samples of applications selected for their far reaching potential to enhance product performance. Examples will also be presented to explain the application of carbon based composites where the product performance or application would not be possible without special materials.



Figure 2. ARES I-X Launch from Kennedy Space Center

METAL GRAPHITE COMPOSITES

The embedding of metals in the porous system of engineering graphite materials primarily enables their electrical characteristics. A broad range of metals is available for this purpose, and are introduced in a powdered form during the ceramic process or subsequent impregnation of a porous body that has graphite embedded. The metals include copper, silver, lead, antimony¹, and numerous light metals such as aluminum.

This means an optimum material is available for many applications where high current density or excellent spark suppression are required. Light metal and graphite composites can be utilized if stiffness requirements and a low specific weight are required simultaneously. Due to high thermal conductivities and a low coefficient of thermal expansion, special Aluminum Graphite Composites can be used in several electronic applications. [1]

COPPER GRAPHITE COMPOSITES

An excellent electrical conductor, copper reduces the electrical resistance of conventional graphite materials by up to 85%. The percentage of copper is precisely set to suit the application and usually varies between 25 and 80%.

1. The largest applications for metallic antimony are as alloying material for lead and tin and for lead antimony plates in lead-acid batteries. Alloying lead and tin with antimony improves the properties of the alloys which are used in solders, bullets, and plain bearings. Antimony compounds are prominent additives for chlorine- and bromine-containing fire retardants found in many commercial and domestic products. An emerging application is the use of antimony in microelectronics.

Typical areas of use for graphite materials impregnated with copper are systems for transmitting electrical current. In particular these include carbon brushes used in electric motors. [2]

A change to more expensive silver graphite composites should be considered if greater conductivity or current densities are required in an application.

SILVER GRAPHITE COMPOSITE COMPOUNDS

Silver impregnated in the pores of graphite materials enhances electrical conductivity by a factor of $2 < 3$ compared to copper graphite compounds. Silver graphite compounds can be produced by pressing of powder mixtures or (for a lower silver content) impregnation of a porous graphite with liquid silver salts.

Use of silver graphite compounds is confined to sophisticated applications involving high current densities and transmission of low currents and voltages where low transmission resistance is involved. Its limited use is primarily due to the high cost of the material. Applications include carbon brushes in wind turbine generators, silver graphite brushes for signal transmission in Tachogenerators², aerospace applications, and for measuring current transmission and collectors in wire winding machines. [3]

ALUMINUM GRAPHITE COMPOSITES

Aluminum graphite composites are metal matrix composites (MMC), that combine the characteristics of both graphite and aluminum. By varying the raw materials mix and processing conditions, it is possible to influence the performance of the composite materials properties such as thermal conductivity, thermal expansion, and stiffness.

Aluminum Graphite parts are used in applications where high temperatures and strong alternating thermal loads are present. These conditions cause high power losses, and can be found in several electronic applications. High temperatures and temperature cycles have a strong impact on the reliability of these assemblies. Improved durability of the electronic system can be achieved by using parts made of Aluminum Graphite. This is because Aluminum Graphite's coefficient of thermal expansion (CTE) is very similar to the CTE of several ceramics and semiconductors. And Aluminum Graphite has a lower density when compared to conventional materials such as copper. The lower density reduces the weight of the component. [4]

Possible applications of parts made of Aluminum Graphite are base plates, substrates, and heat spreaders used in power electronics, microelectronics, and optoelectronics.

LIGHT METAL GRAPHITE COMPOSITES

Embedding light metals in porous systems of graphite materials enables improvement of their electrical conductivity and reduces the specific weight to low levels. Some light metals also improve the tribological characteristics.

Aluminum and magnesium are metals used to light metal graphite composites. Typical applications include bearing and seal systems.

Aluminum infiltrated graphite combines high thermal conductivity with a low coefficient of thermal expansion. Together with low density these materials are ideally suited for heat-sinks or heat spreaders in many electronic applications. [4]

FIBER REINFORCED COMPOSITES

The number of known fiber reinforced composites is continually increasing. Their composition may vary across a broad range, but structurally they are all similar. They consist of a matrix material embedded as fiber components into another material. Carbon (CFC), plastics (CFRP), ceramics (CMC), metals and cement or concrete are utilized as a matrix. Typical fiber components consist of glass, carbon, polymers, or ceramics. Boron, steel, aramid or natural substances are also employed.

The properties of the fiber and matrix material can be combined in fiber reinforced composites to produce a product that is superior in many respects to the pure materials involved. They are light, durable, robust, and exhibit an enhanced resistance to cracking despite considerably lower weight, and have comparable or higher rigidity and strength. Embedding fibers into brittle matrices such as ceramics or carbon achieves plasticity and resistance to galling, a frequently desirable material attribute. The technology can be traced back to observations made in the 1920's when it was noted that fibers exhibit considerably greater strength in the direction of the fibers than the same material in another form. As a general rule thinner fibers produce stronger composite material. [5]

Fiber reinforced composites are increasingly used in aerospace and space applications. They are used wherever individual materials cannot meet specified requirements, and where a combination of positive characteristics and low weight is needed under demanding conditions. Specific modification of properties enables development engineers to produce perfectly tailored materials for sophisticated applications.

CFRP - PLASTIC WITH SPECIAL PROPERTIES

The properties of carbon fiber reinforced plastics (CFRP) differ so much from matrix material that a relationship is barely discernible. CFRP materials are distinguished by their extremely high strength and rigidity. Low density is also a

2. Tachogenerators are electromechanical generators capable of producing electrical power from mechanical energy, usually the turning of a shaft.