Space Applications of Composite Materials

Zaigham Saeed Toor

Abstract—**This paper efforts to review the potential uses of Composite materials in Space industry. Composite materials have revolutionized the space industry by virtue of their multi-functional, multi-directional and tailorable properties that can sustain the extreme environment of outer space. Fiber Metal Laminates (FMLs), Metal Matrix, Polymer Matrix and Ceramic Matrix composites have proven effective in Satellites, Launch Vehicles and Space Centers application due to their Light weight, dimensional stability, high specific strength, thermal stability, tribological properties and diverse material combinations. This review emphasized the importance of FMLs, Carbon and epoxy composites along with other material systems in the major elements of a space program.**

Index Terms— **Composite Materials, Material Selection, Fiber Metal Laminates, Space Technology**

I. Introduction

THE space program and development in space research has been the prime focus of many developed and developing countries. It provides the country with a broad scope of beneficial applications which includes citizen development, mass communication, agriculture, economy, defense, scientific and medical research [1, 2].Satellite, Launch Vehicle and Space Centre are the three key components under the umbrella of any space program. Satellite can be described as any entity dedicatedly launched into space that orbits a star, planet or earth with a mission to gather and collect information as shown in Figure 1[3]. Launch Vehicles can be described as heavy rockets that are used to transport Satellites, astronauts or other payloads to Space from earth and vice versa as shown in Figure 2[4]. Space Centre or space port can be described as a port or pad from where the satellite or payload is launched into space using a launch vehicle. It is also used to receive Launch vehicles bringing astronauts back to earth after a mission as shown in Figure 3[5].

Aluminum and its alloys have proved promising candidates in the aircraft and space industry for quite a long time now. This is attributed to their exceptional strength to weight ratio, workability, cost-effectiveness, corrosion resistance and ease of accessibility.[6, 7]. Composite materials are potential candidates in space applications and have dominated the space industry due to their cost-effectiveness, ease of process ability, high strength to weight ratio, multi-functionality and diverse properties in terms of thermal insulation and ablation[8-11].

A special breed of composites called Fiber Metal Laminates (FML) have gained a lot of popularity regarding aerospace applications. FML can be defined as the reinforcement of aluminum sheets using alternate layers of fiber-reinforced adhesives. This combinations gives a synergistic effect on the composite product that incubates attractive properties of the metal and the reinforcement such as corrosion resistance, thermal insulation, damage tolerance, weight reduction, fatigue endurance, specific strength and cost-effectiveness. In simple words, a lot of metallic disadvantages are automatically tailored by incorporation of FMLs in aircraft structures [12-15].This paper presents the development in FMLs by reinforcing aluminum alloys using Carbon fiber and epoxy reinforcements along with applications of other composite systems in Satellites, Launch Vehicles and Space Centers or Spaceports.

Fig. 1. Jupiter-3 Ultra High Density Satellite after Caleb [16] with permission from Space News and SSL.

Manuscript received March 24, 2018.

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Fig. 2. Launch Vehicle Launching to Moon after Rebecca[17] with permission from NASA Earth Observatory.

Fig. 3. China's Tiangong 1 Space Launch Centre mounted with Launch Vehicle after Tariq[18] with permission from Space.com.

II. Composites in Satellite

Schelder[19] has discussed different types of fiber composites used in satellite. The author reported that High Modulus and Unidirectional Carbon fiber composites are used in strap elements, boom, housing and solar panels of the satellite. These applications are attributed to the anisotropic tailorable properties of the composites using different orientations, high stiffness, specific strength, low thermal expansion/conductivity and dimensional stability. It was also reported that Glass fiber and Kevlar fiber composites are applied in the fabrication of satellite antennas due to their low transmission loss and electrical conductivity. Similar results have been reported by other authors on the subject [20-24]. Boudjemai et al.[20] has discussed the modelling analysis of Aluminum matrix hexagonal honeycomb plate. The authors reported that Aluminum honey comb composites are frequently used in satellite structures due to their enhanced energy absorption and high bending stiffness. Similar results have been reported by other authors on the subject [2, 19, 21-26].Toor[2] has discussed applications of Aluminum matrix composites in satellite. The author reported that Aluminum Matrix Composites have vast applications in Satellite Structure, Payload, Attitude Control System, Power System, Thermal Control System and Propulsion Control System. This can be attributed to the multifunctional properties of these composites such as low outgassing, high specific strength, low Co-efficient of Thermal Expansion (CTE) and weight reduction. Similar results were reported by other authors on the subject[19-26].Imperial Metal Industries (IMI)[27] have discussed the chronologically the most initial stage of Aluminum-Carbon reinforced plastic laminates satellite application. The authors reported that these honey combs formed by laying up Carbon reinforced plastic on Aluminum sheets helped in 33% weight reduction in the satellite structure assembly as compared to their metallic counterparts and a synergistic effect of the Carbon Fiber Reinforced Plastic (CFRP) with aluminum was observed as shown in Figure 4.Similar conclusions have been reported by other authors on the subject[28-36].

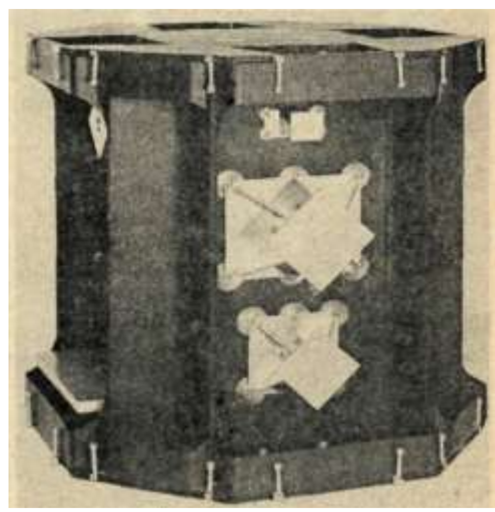

Fig. 4. Al-CFRP Laminate Satellite Structure Assembly after IMI[27] with permission from Flight International

Patil et al.[35] has reviewed Aluminum-Glass Epoxy reinforced laminates. The authors reported that Aluminum-Carbon Epoxy reinforced laminates have higher mechanical properties as compared to their Glass fiber counterparts but they have an issue of galvanic corrosion and unstable Carbon interface which can be addressed by pre-treatment of aluminum and proper processing. Mallick[32] has discussed the space applications of FMLs. The author reported that Honeycomb Aluminum core –Carbon reinforced epoxy laminates we applied in Satellite or payload bay door due to their high specific strength and weight reduction. Similar conclusions have been reported by other authors on the subject [27-31, 33-36].Jaroslaw et al.[28, 31] has discussed the Impact resistance and damage growth of Aluminum-Carbon epoxy reinforced laminates. The authors reported that these laminates have excellent interfacial strength and damage tolerance attributed to synergistic effect of stiffness and good mechanical properties of Carbon-epoxy reinforcement along with the ductile behavior of the aluminum. It was also reported that the best configuration of the plies used in the laminates was at 0°/90° and ±45° orientation. Similar conclusions have been reported by other authors on the subject [27, 29, 30, 32-36].Dinca et al.[29] has discussed mechanical properties of FMLs. The authors reported that Aluminum-Carbon Epoxy reinforced laminates have exceptional damage tolerance, fatigue, crack resistance, tensile and bending strength as compared to glass fiber and metallic counterparts. Similar conclusions have been reported by other authors on the subject [27, 28, 30-36]. It can be inferred that tailorable properties through ply orientation, good damage tolerance, fatigue resistance, corrosion resistance, weight reduction and high specific strength make these laminates an attractive candidate for satellite structure applications after further research in degassing, vibrational and thermal properties is carried out for necessary qualification of the material system.

III. Composites in Launch Vehicle

Steven et al.[37] has discussed the development of Next Generation Launch Vehicles by application of Advanced Grid Stiffened Structures (AGS).The authors reported that using automated process of five-axis filament winding machine to helically wound fiber impregnated in uncured resin on a mandrel gave a rib-skin AGS structured composite which was cost-effective, more reliable, high strength, better damage tolerant and highly moisture resistant. This technique was used to manufacture a payload shroud, a conical component that encapsulates the payload on a Launch Vehicle[38] which resulted in 61% weight reduction and 88% fabrication time reduction as compared to its aluminum counterparts as shown in Figure 5. Similar results have been reported by other authors on the subject [39-44].

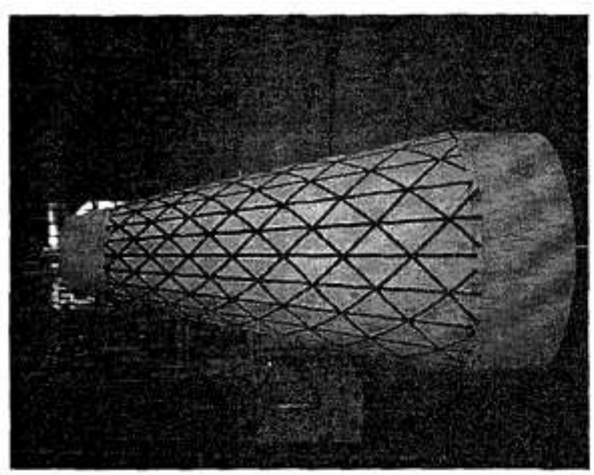

Fig. 5. AGS Payload Shroud after Steven[37] with permission from IEEE Aerospace Conference

Christin[39] has discussed the development, manufacturing and applications of Thermostructural composites. The author reported that Carbon and Silicon Carbide preform fibers oriented in both 2D and 4D directions, when reinforced with Carbon or Silicon Carbide matrix using Chemical Vapor Infiltration (CVI), Pyrolysis (PIP) or Resin Pitch Polymer Impregnations, resulted in high temperature composites which were applied in Launch Vehicles exit cones, Throat nozzles, brake discs and thermal insulation of the boosters. This is attributed to their light weight, corrosion resistance, High temperature abrasion resistance, dimensional stability and good thermal capacity as shown in Figure 6.Similar results have been reported by other authors on the subject[37, 40-44].

Fig. 6. Carbon-Silicon Carbide Composite Throat Nozzle after Chrisitn[39] with permission from Advance Engineering Materials

Krenkel et al.[42] has discussed advanced friction systems and space applications of Carbon-Silicon Carbide composites. The authors reported that Carbon-Carbon porous composites when reinforced by melting Silicon and Silicon Carbide as matrix using Liquid Silicon Infiltration process, resulted in a composite material that can be applied in disc brakes, jet vanes of nozzles, engine flaps and nose caps of Launch Vehicles. This can be attributed to the high resistance to wear, good thermal shock, low density, good resistance to abrasion and exceptional tribological performance as compared to their Ferrous and Carbon-Carbon composite counter parts. Similar results have been reported by other authors on the subject [37, 39-41, 43, 44]. Voevodin et al.[43] has discussed tribological composite materials for space applications. The authors reported that nanocomposite coatings produced from hybrid physical vapor deposition using Gold matrix reinforced with Yttria Stabilized Zirconia, which was further encapsulated with amorphous Molybdenum Disulphide and Diamond Like Carbon, resulted in an exceptional multifunctional coating which could be applied on Launch Vehicles to sustain, dry, vacuum, very high and cryogenic temperatures. This can be attributed to their complex chemistry and material composition which can change itself with respect to the environment applied to protect and sustain the structure resulting in good wear resistance, high thermal shock and good tribological performance defines as Chameleon behavior as shown in Figure 7. Similar results have been reported by other authors on the subject [37, 39-42, 44].

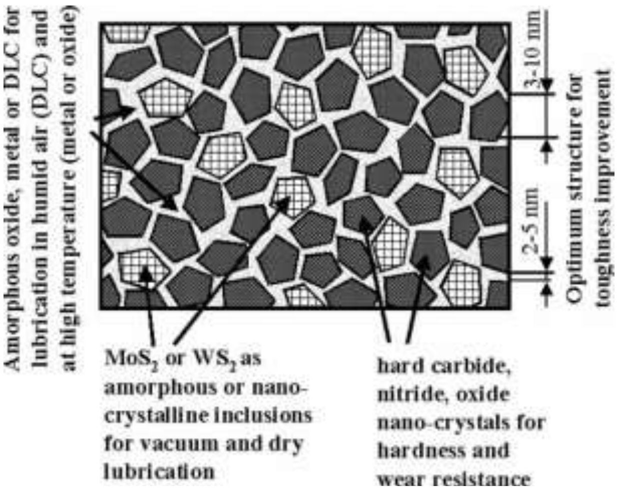

Fig. 7. Nanocomposite multi-functional Tribological Coating after Voevodin et al.[43] with permission from Elsevier

Kang et al.[41] has evaluated aluminum-composite joints for cryogenic tanks. The authors reported that Aluminum-6061-T6 lined Tanks when laminated with Graphite-epoxy composites using Bondex606, EA9696 and FM73 as adhesives, resulted in a reliable composite product which sustained joint strength at -150˚C.This characteristic make these composites a potential material system in Launch Vehicles Tank joints. Similar results were reported by other authors on the subject [37, 39, 40, 42-44].Glass[40] has discussed the applications of Ceramic matrix composites in thermal protection systems of Launch Vehicles. The author reported that Carbon-Silicon Carbide, Carbon-Carbon and Silicon Carbide-Silicon Carbide composites can be used in Thermal insulation of the Launch vehicles, space shuttle orbiter wings, cover plates, load bearing aero shells, fuel tubes, body flaps, assembly joints and thermal barrier coatings. This can be attributed to their exceptional High Temperature endurance, thermal shock, light weight and good dimensional stability as shown in Figure 8. Similar results were reported by other authors on the subject [37, 39, 41-44].

Fig. 8. Carbon-Carbon Aeroshell after Glass[40] with permission from AIAA International Space Planes and Hypersonic Systems and Technologies Conference

Zheng et al.[44] has reviewed thermal protection materials for Launch Vehicles. The authors reported that hot components of aero engines, payload components and thermal protection components can be fabricated from Carbon-Carbon composites. Although Carbon-Carbon composites have good thermal shock resistance, high specific strength, good corrosion resistance and very low co-efficient of thermal expansion (CTE), but for temperatures above 500˚C, oxidation resistance of these composites can be increased by matrix dripping and addition of Boron Trioxide, Boron Carbide and Zirconium Dicarbide as inhibitors. Chemical Vapor Deposition (CVD), Liquid Phase method and sol-gel techniques can be applied to develop these composite coatings. Similar results have been reported by other authors on the subject [37, 39-43, 45-48].

IV. Composites in Space Centre

The Launchpad facility at a space center is itself a huge complex structure as shown in Figure 3.A thrust of 31000KN[49] launches a space vehicle upwards from the Launch pad. The vibrations generated by such massive force are tremendous and very high strength materials are required for such structures. Published literature concerning Launchpad facility materials was not available, but it can be inferred from the above discussions that for portable launch pads, composite materials can indeed be developed which can be both light weight and have damping strength. However, composite materials have many applications in space center related systems as discussed below.

Theriot et al.[50] has discussed shielding of space radiations using composite materials from outer space. The authors reported that by reinforcing polyethylene with Regolith, a material extracted from the moon, an interesting composite was developed which could protect and shield the human body from space neutron emissions without the requirement of transportation of such materials from earth. Similar results were reported by other authors on the subject [51, 52].Zhong et al.[52] has discussed shielding tests of composites against cosmic radiations. The authors reported that hand layup method can be used to reinforce Ultra High Molecular Weight Polyethylene (UHMWPE) with glass fiber-epoxy and nano-epoxy. The composite produced gives good shielding and protection against chlorine based radiations along with enhanced mechanical properties of structural shielding applications. Similar results were reported by other authors on the subject [50, 51].Kumar[53] has discussed prospects of composites for space grade sensors, artificial muscles and actuators. The author reported that by reinforcing carbon or graphite with a charged polyelectrolyte membrane along with a noble metal, Ionic polymer-metal composites (IPMCs) are formed which have shown a great potential for accurate sensing and actuation movements. These composites can be applied in space suits of astronauts for better and precise movements, automated assembly of small structures, minor tuning of mechanical assemblies and rovers and robotic controls for space station and exploration. Similar results were reported by other authors on the subject[54, 55].

V. Conclusion

- Composites along with nanotechnology is an emerging research area to develop multifunctional materials for space applications
- For prolonged space missions we need to maximize weight reduction to increase the payload accessories, which can only be achieved by replacing currently used metallic structures with composites
- Composites developed using new materials available on planets and moon surrounding the earth will indeed revolutionize the field of Materials Science in Space research
- Replacing launch vehicles and satellite materials with high performance and cost-effective composites is an important research area for developing space programs
- In order to colonize space with humans, it is mandatory to develop such composites that have exceptionally long service life, have both structural and functional applications and at the same time be free from biological and medical side effects

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