Thermoplastic Composites in Space

Shigin G.V.
Scientific advisor: Ivanova V.S., Ph.D., Associate Professor
Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, 634050, Russia
E-mail: shigingerman@mail.ru

A composite is when two or more different materials are combined together to create a superior and unique material. The first uses of composites date back to the 1500s B.C. when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Later, in 1200 AD, the Mongols invented the first composite bow. These bows were extremely powerful and extremely accurate. The modern era of composites did not begin until scientists had developed plastics. In the early 1900s, plastics such as vinyl, polystyrene, phenolic and polyester were developed. These new synthetic materials outperformed resins that were derived from nature. However, plastics alone could not provide enough strength for structural applications. Reinforcement was needed to provide the strength, and rigidity. In 1935, Owens Corning introduced the first glass fiber, fiberglass. Fiberglass, when combined with a plastic polymer creates an incredibly strong structure that is also lightweight. This is the beginning of the Fiber Reinforced Polymers(FRP) industry as we know it today. Many of the greatest advancements in composites were incubated by war. World War II brought the FRP industry from the laboratory into actual production. Alternative materials were needed for lightweight applications in military aircraft. Engineers soon realized other benefits of composites beyond being lightweight and strong. It was discovered that fiberglass composites were transparent to radio frequencies, and the material was soon adapted for use in sheltering electronic radar equipment. By the end of the WWII, a small niche composites industry was in full swing. With lower demand for military products, the few composites innovators were now ambitiously trying to introduce composites into other markets. In the 1970s the composites industry began to mature. Better plastic resins and improved reinforcing fibers were developed. The composites industry is still evolving [1].

Imagine the space shuttle lifting off in an explosion of cryogenic fuel from its external tank and solid rocket boosters, climbing across the sky, entering space at hypersonic speed and then returning to earth through the scorching friction of earth's atmosphere. You would have to think long and hard to imagine a more severe testing ground for engineering materials. And if someday the space shuttle was strong enough and light enough to power itself into orbit under its own store of fuels, the miracle will be made possible through the innovative use of lightweight plastic materials known as composite thermoplastics. For many people, "plastic" means "cheap and breakable." But when engineers search for new ways to enhance weight savings, corrosion resistance, shock and vibration dampening and stealth they immediately turn to plastic - the only alternative material capable of meeting, and beating, the established performance of aluminum, brass, titanium and steel. The name "plastic" refers to the ability to form or shape a material, or to the mold ability a material adopts under forces such as pressure or heat. Engineers often use the term "polymer" when referring to plastic materials, because it more clearly describes how many chemical units form up in complex chains to create modern plastic resins. Polymers are created by subjecting various chemical and petroleum-based ingredients to heat and pressure in sealed vats or vessels. The process of mixing base materials with chemical additives to create specific types of plastic resins is called "polymerization." The resulting plastic materials can be classified in various ways - by chemical or physical structure, by strength or thermal performance and by optical or electrical properties. The most significant structural classification for polymers has to do with their shape at the molecular level. Polymers whose long, linear shaped molecules fold tightly together into packed and ordered areas are classified as semicrystalline. Polymers with bulkier molecular shapes not inclined to fold up into spaghetti-like crystals are classified as amorphous. Semicrystalline polymers are characterized by very good to excellent wear resistance and the ability to withstand high heat and exposure to caustic chemicals. Semicrystalline resins are however relatively more difficult to mold and also tend to exhibit uneven mold shrinkage with elevated stress levels. Amorphous materials are known for their excellent strength, stiffness and dimensional stability. Amorphous resins are generally easier to mold into tubular shapes and have a good "knit" or weld line strength coefficient. Amorphous resins have good dimensional stability and exhibit even mold shrinkage with lower stress levels. Engineering plastics such as Polyetherimide (PEI), polyphthalamide (PPA), and polyphenylene sulfide (PPS) are designed specifically for use in high operating temperature environments. Resins such as polyetheretherketone (PEEK) and various liquid crystal polymers (LCP) are also capable of withstanding extremely high temperatures. High-performance plastics also meet stringent outgassing and flammability requirements [2].

Picture1 - Engineering plastics and specialized high-temperature polymers are used in durable goods manufacturing

Space is very demanding, with zero pressure and huge thermal cycling in earth orbit requiring very low thermal expansion of materials. In earth orbit, temperatures may range through 250 degrees centigrade as a craft moves from the sun into the earth's shadow. To those needs, add in high exposure to radiation and re-entry temperatures of up to 1500 degrees centigrade. Of course, if a craft is going behind the earth to drop through the atmosphere of a very cold planet then even lower temperatures have to be expected. Ultraviolet radiation increases aging rates, as does atomic oxygen. Another requirement is stiffness – measured as the natural frequency of a structure. Typically, these natural frequencies have to be as low as 80 Hz to prevent breakup during liftoff [3].

Besides being able to satisfy the unique requirements of space, there are other major benefits. The combination of high strength and low weight makes composites attractive for use in space because of the high cost of hoisting payload into orbit. Every pound of mass costs anywhere from $8,000 for low earth orbit, to almost $100,000 when geostationary orbits are targeted (24,000 miles out). With organic-matrix composites such as carbon fiber, the ability to build up monococque structures using 3 dimensional weaving offers tremendously high strength. With carbon fiber and to eliminate the risk of voids in a structure, pressure impregnation is necessary. The benefits of modern plastic materials have not yet led to the wholesale elimination of metal from high-performance air, sea and space applications. Aluminum, for example, is still the material of choice for most high-density connectors and accessories. But several factors, including the drive to develop cadmium-free alternatives to plated aluminum parts, have contributed to the wider use of composites. Other important benefits of composites over metal materials include corrosion resistance, vibration dampening, weight reduction and stealth. Corrosion resistance is one of the most appealing attributes of composites is their unlimited corrosion resistance as compared to conventional materials. Aluminum interconnect components, for example, are subject to galvanic coupling which causes the metal material to be "sacrificed" to its cadmium/nickel plating. Since high-temperature plastic is not sacrificial to plating, finished products last longer, require less maintenance and directly reduce the overall cost of ownership of the interconnect system. Vibration dampening is another major benefit of composite thermoplastics is vibration dampening. Unlike metals, polymer plastics are less subject to harmonic resonance due to their lighter weight and inherent attenuating properties. Which means threaded components made from these materials are far less likely to vibrate loose when subjected to prolonged periods of vibration and shock. Again, reduced maintenance and reduced cost of ownership are the major benefits realized by systems built from vibration dampening thermoplastics. Weight Reduction is next to their anticorrosive capabilities, the characteristic of composites that makes them most attractive is their ability to provide increased strength and stiffness at lighter weights than conventional materials. The typical weight savings for composites over aluminum is approximately 40%. Weight savings versus other materials are even more pronounced: 60% for titanium, 80% for stainless steel, and 80% for brass. Composite materials directly reduce aircraft empty weights and increase fuel fractions. For the aerospace engineer, this leads directly to smaller, lower-cost aircraft that use less fuel to perform a given mission. Stealth is the reduction of magnetic signatures, corrosion related magnetic signatures and acoustic signatures is critical to the development of stealth applications. Signatures are those characteristics by which systems may be detected, recognized, and engaged. The reduction of these signatures can improve survivability of military systems, leading to improved effectiveness and fewer casualties. Composite thermoplastics are at the heart of a number of advanced stealth application development projects. Forty percent of the structural weight of the new F-22 will be polymer composites, and other systems such as the B-2 and F-117A are expanding their use of stealth technologies [2], [3].

There are currently upwards of a dozen different composites in use in space, each with specific properties for its purpose. A high percentage of all spacecraft, are built with composites – the return on reducing mass is exponential because of the fuel factor and supporting systems. For example, Glenair is the recognized leader in composite thermoplastic research and development for the interconnect accessory industry. In fact, no one else has tooled even a small fraction of the composite thermoplastic accessories available today from Glenair. The product line includes circular and rectangular connectors and accessories, cable junction boxes, conduit, conduit fittings, protective covers, shielding, shielding support rings, and more. Glenair composite components are produced in injection molded and machined versions and are ideally suited for use in harsh environments where resistance to high temperatures, outgassing, corrosive fluids, fire, shock and vibration is required. The range of composites for space applications continues to grow dramatically. There are exciting prospects of special composites being ‘grown’ by chemical deposition in a zero gravity environment, providing significantly improved strength: weight ratios and three-dimensional mechanical properties as yet unobtainable on earth. New production techniques are being researched for composite component production. ‘Pultrusion’ produces finished composite parts as a continuous stream. It is highly automated, much like metal extrusion and will reduce the cost of ‘volume’ components significantly. So, space continues to drive technology – especially in composites [3].

References:

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