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Composite Recycling and Disposal

An Environmental R&D Issue

Aeronautic/aerospace applications, both military and commercial, are accounting for a large share of the growing composite market in value. However, their share of the market in volume is much smaller. Costs are high when large amounts of carbon fiber reinforcements are used. These high performance composite materials have six properties that give them an edge over traditional materials: longer life cycles due to high fatigue strength, increased corrosion resistance, improved fire resistance, easier design because of functional integration, possibility of complex shapes & lower weight. Increased usage of composites in military and space systems, as well as in commercial aircraft development, is expected to continue far into the foreseeable future.

*Figure 1—ATI reclaimed carbon fibers**

The DoD is increasingly emphasizing environmental issues and liabilities relevant to weapon systems that have reached end of their design life cycle. These weapon systems need to be disposed of in a cost effective, safe, and environmentally responsible way. Due to the materials used in these systems, disposal can be very costly.

Disposal costs are to be developed as part of the life cycle cost analysis per the document DoDI 5000.2. Minimizing disposal costs is in Boeing's best interest. DoD customers are well aware of life cycle costing requirements. If they perceive disposal costs as excessive, they may consider reducing the number of weapon systems purchased under a multi-year contract.

Recycling and disposal of composites create issues that must be addressed. One such issue concerns end-of-life aircraft structures that contain carbon fiber composites coated with hexavalent chromium primer. These composites that are coated with hexavalent chromium can be classified as hazardous waste and thus may not be disposed on land due to possible leaching of the chrome into the ground.

The EPA uses the term "hazardous waste" to identify wastes that could be harmful to human health and the environment. RCRA regulation 40 CFR 261 Subpart A defines the terms "solid waste" and "hazardous waste." A waste is defined as hazardous if it meets the RCRA definition of solid waste **and** is specifically listed as hazardous **or** exhibits a characteristic of hazardous waste. To be classified as a hazardous waste, under 40 CFR 261 Subpart C, a solid waste must exhibit one or more of the following characteristics: ignitability, corrosivity, reactivity, or toxicity.

This characterization of waste is a very important concern to companies and manufacturing facilities. The cost to dispose of a hazardous waste can be more than 20 times the disposal cost of a non-hazardous solid waste. When a waste is classified as hazardous, appropriate actions need to be taken to ensure that it does not pose a threat to human health and the environment if land-disposed.

EPA's Land Disposal Restrictions (LDR) require that protective treatment standards be met before hazardous waste is land disposed. One method to determine if treatment standards are necessary is the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP analyzes the waste and determines what quantity of a regulated substance (such as chromium) is present. If the substance quantity is below the regulatory level, no further action is necessary. However, if the regulatory level is exceeded, then treatment standards are mandatory before the hazardous waste can be land disposed.

Incineration is another option for composite disposal, but if the composite is carbon fiber, then it cannot be incinerated without taking the proper precautions, due to the potential release of small electrically conductive fibers into the environment that, if not captured, can cause electrical interference issues.

With regards to recycling, salvage/scrap dealers throughout the country specialize mainly in metal recovery. However, the metal scrap they purchase can often contain carbon fiber-reinforced composites. A significant concern of these salvage/scrap dealers is the proper identification of various materials in scrap aircraft assemblies and how to shred, sort, and recycle this mix. They will need to decide whether spending capital on R&D to develop the capability for processing such a material mix makes good business sense.

These scrap dealers have an opportunity to salvage large amounts of recyclable scrap aircraft, which are located at the Aerospace Maintenance and Regeneration Center (AMARC), in Tucson, Arizona. AMARC is a joint service facility managed by the US Air Force Material Command, and an aerospace storage and maintenance facility adjoining Davis-Monthan Air Force Base, which provides a service to all branches of the US military (Air Force, Navy, Marines and Army), as well as the Coast Guard and other national agencies.

Many of these stored aircraft, which number more than 4200, can be returned to an operational status in a short period of time. However, AMARC has also been referred to as "The Bone Yard," because of other work that AMARC carries out, which involves reclamation of spare parts and the eventual disposal of spent airframes. Once the spare parts are reclaimed, the aircraft leftover "carcasses" are then sold to salvage/scrap dealers who specialize in metal recovery.

Two major concerns of AMARC while processing these carcasses involve composite materials and hexavalent chromium coatings. AMARC does not remove the coatings or composite parts from these carcasses, and thus these concerns are passed on to the salvage/scrap dealers, who must then contend with these issues. Due to these two issues alone, many salvage/scrap dealers tend to avoid these carcasses, with some even refusing to bid on them. The design and material choices in the long run affect the value of the aircraft to be recycled.

Before 1970, manufacturers were not bound by strict environmental legislation, as many if not all, of the current environmental laws and regulations had not yet been fully developed. This lack of legislation permitted the manufacturer to freely choose various types of materials and manufacturing processes without being concerned about the environmental ramifications. The manufacturing decisions made years ago, without taking into account the environment due to lack of legislation, have had a major cost impact during disposal.

One company that has shown an interest in researching the feasibility of processing such a material mix is Huron Valley Steel (HVS). HVS was established as a metal recovery and processing company, mainly processing scrap automobiles. Even though HVS is a leader in processing metals, it has not had much experience with composites. HVS recognizes the need to research and develop technology that would be capable of sorting and recycling composites from metals.

HVS has a Research and Development (R&D) facility in Michigan, Fritz Enterprises, for sophisticated sorting devices. The Environmental Assurance (EA) group at Boeing St. Louis has asked HVS to study separation feasibility in scrap aircraft parts containing composites and metals. To obtain scrap aircraft parts, EA is working with the Navy to secure excess AV-8B fuselages for the R&D efforts in Michigan.

The Navy and EA are requesting that Fritz submit a final report to them once the project is completed. The report will contain information on the process and techniques used in the segregation effort as well as other pertinent information. The Navy has an interest in such a research program because the Navy and all other defense agencies, as well as companies that own and operate commercial aircraft, are concerned about the liability when the aircraft reach the end of their design life cycle. DoD would like to have the option to recycle these composite aircraft.

The capability to sort dissimilar materials, composites from metals, is the first step in recycling composites. However, the ability to extract the carbon fibers from the composites is probably even more important.

Composite recycling efforts in the past mainly concerned grinding, shearing, chipping, or flaking the composite into suitable size to be used as filler material in new molded composite parts. Pyrolysis, thermal decomposition of the polymer at high temperature, has also been studied as a preparation method before grinding. Using this approach, the composite is ground into a fine powder. This method may be suitable for certain types of composite recycling, such as in the automotive industry, whose composite parts typically contain large quantities of filler. However, composite aircraft parts usually contain valuable carbon fiber and resins, and in order to efficiently extract and recycle these components, other recycling processes must be used.

Other processes such as acid digestion could be used to reclaim the fibers. However, this process appears to be impractical from an environmental point of view. Acid digestion uses hazardous chemicals and creates a mixture that will require further processing. The selection of the recycling process is very important. It is neither practical nor wise to use recycling processes that produce hazardous by-products that greatly reduce the economical and/or environmental advantages and benefits of the recycle effort.

Technology companies, such as Adherent Technologies Inc. (ATI), have been successful in separating carbon fibers (Figure 1) from carbon fiber-reinforced epoxy composites and reclaiming the valuable carbon fibers. ATI's engineering/environmental division develops processes that specialize in composite recycling and technology.

Figure 2—ATI pilot-scale reactor (Image courtesy of ATI)

In 1992, ATI began investigating catalytic conversion of plastics and composites. Catalytic conversion is a tertiary recycling method that produces chemicals or fuels from scrap or waste products. It's the necessary first step in recycling the complex mixtures in scrap aircraft composite materials that results in the extraction of carbon fibers.

ATI's batch reactor process (Figure 2) mixes the scrap composite, after mechanical size reduction, with a heat transfer fluid and catalyst. The mix is then processed under increased temperature and pressure. By-products generated include phenolic compounds that are being investigated for use in phenolic-based adhesives for the wood industry.

Boeing Commercial Airplanes (BCA), Product Development-Phantom Works, has worked with ATI and has become actively involved with the assessment and evaluation of its carbon fiber recovery technology. A life cycle objective of the 7E7 is to identify environmentally friendly processes for composite wastes from manufacturing, through the airplane's operations, to the end of its useful life.

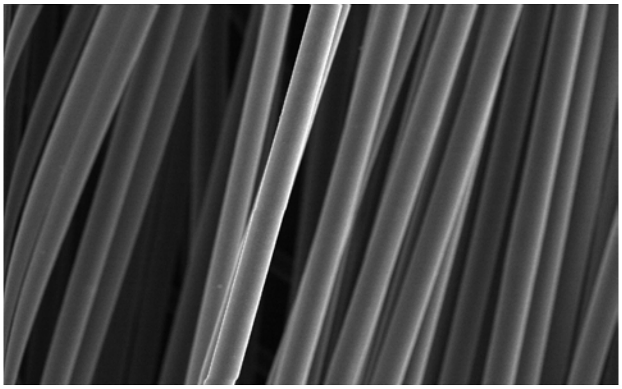

*Figure 3-- Scanning electron microscope micrograph (500x) of reclaimed carbon fiber 99.78% pure**

Left-over composite scrap, termed off-fall, from the fabrication of composite parts, is potentially a large source for ATI's carbon fiber recovery process. BCA has provided samples of uncured prepreg, epoxy graphite composite that BCA has processed through its batch reactor. The results show that the ATI process could dissolve uncured epoxy resin **and** reclaim carbon fibers. Analysis of reclaimed carbon fibers (Figure 3), performed by ATI, indicates very similar properties to virgin fibers. The primary difference is in the length of the reclaimed fiber. Reclaimed carbon fiber, known as short fiber, cannot be reused in applications where longer, continuous carbon fiber, is needed. However, the demand for chopped and milled carbon fiber is projected to steadily grow (Figure 4).

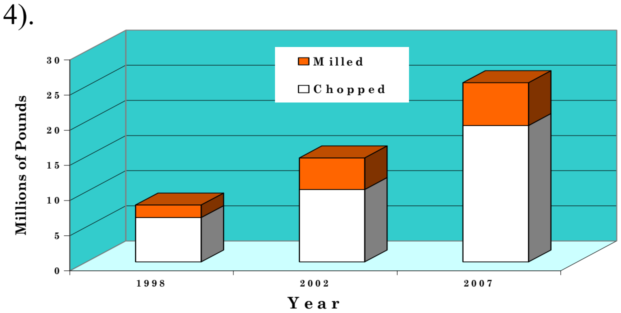

*Figure 4 -- Projected growing global demand for chopped & milled carbon fiber**

Markets have been identified for recycled carbon fiber. Cellular phones and lap top computers with housings made lighter in weight by use of thinner walls are two examples. Other potential markets for the reclaimed fibers include injection molding resin compounds, thermoset molding compounds, and non-woven sheet reinforcements.

The cost for aerospace grade virgin carbon fiber is ~$22.00/lb. ATI estimates a cost of ~$2.50/lb. to reclaim these carbon fibers. With ~market value for the reclaimed fibers of $5.00/lb., the ~net market value for the reclaimed carbon fiber would be $2.50/lb. The weight % of carbon fiber in composite aircraft parts is ~65 %. Respective ~composite usage for AV-8B, F/A-18E/F, F/A-22, and C-17 aircraft is 1,370, 2,930, 5,340 and 15,500 lbs.

Figuring 65 weight % carbon fiber, respective composite aerospace parts for these aircraft contain 890, 1,910, 3,470, and 11,700 lbs. of carbon fiber. Using a net market value of $2.50/lb. for the reclaimed carbon fiber, its ~value from the respective aircraft would be $2,200, $4,800, $8,700, and $25,200.

Increasing use of composites in both military and commercial aircraft poses the approaching need to enhance the recycling option over landfill and incineration disposal of aerospace composites. Boeing is promoting a cooperative effort involving the Navy, HVS, and ATI to help each understand the other's goals, concerns, and issues. Once these elements are understood, significant progress may be made in reducing the amount of composites currently land filled. Land filling generates no return, places a burden on the environment, and presents the potential for future liability.

* Source: Final Report—Tertiary Recycling Process to Reclaim Composite Aircraft Components—Contract No. N00421-98-C-1032—Prepared for NAWC, Pax River, MD by ATI.

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