Apr 27th, 2:00 PM - 4:00 PM

Paper Session III-B - Composite Materials for Use in Ground Support Equipment

Daniel G. Berrien

Lockheed Space Operations Company

Composite Materials for Use in Ground Support Equipment

by

Daniel G. Berrien
Lockheed Space Operations Company
Titusville, FL

January 1995

Composite Materials for Use in Ground Support Equipment

by
Daniel G. Berrien
Lockheed Space Operations Company
Titusville, FL
January 1995

Abstract:

A three year research plan has been executed under a Lockheed Independent Research and Development project which explored the use of composite materials for Ground Support Equipment. The research focused on the use off-the-shelf Fiberglass and Graphite reinforced composites. They were evaluated for use in access equipment and structures in the Orbiter Processing Facilities, Vehicle Assembly Building, and Launch Pads 39A and 39B.

The plan included the following elements:

- Gathering vendor information and product availability
- Compiling design standards and modeling methods
- Testing electrostatic properties of various composites in various configurations
- Fabricating and using prototype composite access equipment
- Exposing samples to the Launch Pad Environment in various locations to map applicability areas

The paper discusses the methodology, results, and conclusions of the research plan. An emphasis has been placed on the use of the lower cost off-the-shelf advanced composites and their potential role in GSE for access and corrosion control applications.

Introduction:

When designing Ground Support Equipment (GSE), many of the tasks involve situations where high strength, light weight, and corrosion resistance are either critical design criterion or hard requirements. Other factor such as availability, manufacturability, cost, and degree of safety and reliability play major roles in the design process. One way to help engineers satisfy these requirements is to implement the use of composite materials for Kennedy Space Center facilities and Ground Support Equipment.

In the past, design engineers have been limited in their design approach by the types of materials available. Steel, aluminum, and other metallic alloys are readily available, but they cannot always meet the weight to strength, deflection, and corrosion requirements. Without the information and data available to use composite materials, engineers are handicapped and are sometimes forced to produce a design which falls short of the desired performance. This situation can be alleviated by the implementation of composite materials.

An evaluation of the possibility of using composites at KSC was performed and it was found that there were problems with the implementation. There was no comprehensive, authoritative specification or standard for the application of composite materials at Kennedy Space Center (KSC). If composite materials were to be used to expand design capabilities and alleviate environmental problems, engineering and design data, criteria, and guidelines had to be established. A research plan was developed and executed by Lockheed Space Operations Company to address these deficiencies.

The research plan was designed to provide the necessary materials data and design criteria as well as provide opportunities for applications testing. The project was broken down into research and application phases. In the initial research phase, companies that supply composite materials were identified and contacted. A survey of the structural shapes, mechanical components, costs, and time requirements for procurement was conducted. The mechanical properties, chemical reactivity properties, costs, types of composite materials, and fabrication and assembly processes were identified and categorized. Because of KSC's limited composite production capability, this investigation placed a heavy emphasis on off-the-shelf structural shapes.

To effectively work with composite materials, more than just material data is required. Composites require a different design approach than metallics and KSC presents a number of special environments. To address these concerns, a design manual geared towards using off the shelf composites was created. The design guide covers materials, fabrication methods, design guidelines, environmental concerns, inspection and repair, off the shelf composite manufacturers, adhesive bonding, and composite fastener suppliers. Emphasis was also placed on the analysis of composites.

The analysis and design of composite structures pose a change from the current analysis methods being utilized for metallic structures. Different factors of safety and failure modes for composite materials exist and must be treated with special attention. Interlaminar shear, individual ply stresses, surface cracking and edge delamination all play a critical role in the failure of composite materials. Engineers have been trained in the use of MacNeal-Schwendler Corporation's NASTRAN finite element analysis program utilizing composite materials. For a specially designed lay-up, the program simplifies the analysis of interlaminar shear and individual ply stresses. It can also be used in a more traditional manner when only the gross material properties are known such as when using off the shelf composite materials. Post processing is accomplished using SDRC I-deas software.

Applications:

The applications phase of the project required that test applications be selected. It was decided that much information could be gained by going through the composites design process on an existing project in work. The payload bay access ladder for use in the Orbiter Processing Facilities was chosen due to its associated constraints. The access ladder needed to be light weight, have minimal deflection, operate in a clean room environment, meet all Class I electrostatic requirements, and have a resistance to all the chemicals used in the Orbiter Processing Facilities as well as Hypergolic fuels and oxidizers.

The design was approached with composite materials as the primary material of choice. Many aspects of the design process that were not adequately understood were revealed. Separation of materials, surface wear, electrostatic requirements, and hypergolic compatibility were among those topics identified for further investigation. Most unknown aspects such as separation of materials could be addressed through existing literature review, but topics such as hypergolic compatibility as well as electrostatic testing (beyond the effects of lightning protection in aircraft) had yet to be well explored. Test programs were developed to address these concerns.

Electrostatic Testing:

The electrostatic requirements identified in the Payload Bay Access Ladder study spawned a test program to investigate ways to alleviate electrostatic build-up in composite structures. Kennedy Space Center has specific and stringent electrostatic requirements for use around the Orbiter. The program was designed to explore material selection and combinations of fabrication techniques.

Lockheed Missiles and Space Company was selected to perform the testing due to their past experience in the field. Five composite panels were fabricated using various reinforcing materials. Fiberglass/Epoxy and Graphite/Epoxy materials were used in the construction of the five panels. The materials are detailed below: All panels were 4 feet square.

Panel	Description
1	Plain Fiberglass/Epoxy
2	Fiberglass/Epoxy with Astrostrike perforated copper mesh 30 mils below the surface.
3	Plain Graphite/Epoxy
4	Graphite/Epoxy with Astrostrike perforated copper mesh 30 mils below the surface.
5	Graphite/Epoxy - Nickel coated Graphite outer plies

The panels were then prepared for measurement. All resistance measurements were performed per UL 799 and ASTM F150. The five panels were cut into twenty different samples. Some were coated with a silver filled conductive coating and tested. All samples were then subjected to bolting and bonding configurations to compare conductivities across the various joints. A conductive adhesive was used for all bonding operations. A conductive coating was also applied to selected joints. After each configuration change, the samples were tested.

In general, graphite reinforced materials in any configuration will provide enough conductivity to avoid the build-up of electrostatic charge. This makes it the material of choice for electrostatically sensitive applications. The addition of the Astrostrike copper mesh gave minor improvement to the Graphite/Epoxy samples and no improvement to the Fiberglass/Epoxy samples except for the bolted panels. No direct attempt was made to have the bolts contact the Astrostrike, but it may have occurred. The resistivity measurement results for coated and bonded overlap specimens were variable. In general, the purely bolted specimens out-performed the purely bonded specimens. Resistivities of resins loaded with conductive fillers are proportional to the average spacing between the conductive particles. This can vary with the method of application. The use and application of the silver-filled conductive adhesive and coating in this study were on a best effort basis based on the manufacturer's instructions. The application of conductive coatings to the overlap joints resulted, in most cases, in higher resistances when compared to bolted only joints. This indicates that the Graphite/Epoxy substrates are more conductive than the coating material. This may have been improved by spraying with less solvent.

Hypergolic Compatibility:

The issue of material compatibility with KSC specific environments also arose. One of KSC's specific environments is the use of fuels, oxidizers, and cryogenic fluids. Monomethyl hydrazine, nitrogen tetroxide, hydrazine, and liquid hydrogen, nitrogen, and oxygen are all in use in areas where composites would be implemented and may be exposed. The compatibility of composite materials with these fluids is critical to the safety of structures and personnel. A test program was developed to test a cross section of composite material resins and fibers to try to gain an understanding of the chemical properties that affect the materials compatibility with the fluids.

Due to budget constraints, the test program was not implemented. In the future, the materials that have been tested for compatibility by other programs will be used as a basis for material selection. Because a small change in formulation can result in different reactivity properties, each material will have to be tested by the NASA Material Science Laboratory (DM-MSL-2T) to determine chemical compatibility for the desired application. In past tests, vinylesters have shown to be incompatible with nitrogen tetroxide. This is surprising due to vinylester's reputation for resistance to chemicals. The lack of testing will pose a limitation on the design process, but over time, an adequate materials data base will be collected with resin and fiber material combinations standardized and approved for use at KSC.

Prototype Access Platforms:

In order to gain direct experience with the materials, two access platforms were designed and built from off the shelf advanced composite materials. A 10 foot by 2 foot pick board and a 4 foot by 4 foot float platform were fabricated by Lockheed Fort Worth Company. The platforms followed a simple box frame structure with decking on top. The graphite reinforced square tube box frame structural members were procured from Johel Plastics Inc., and the decking was made from IM7/977-3 aerospace grade Graphite/Epoxy. The object of the test program was to gain direct experience fabricating structures from off the shelf materials and to evaluate the performance of the materials under field conditions.

Both platforms were fabricated without using any fasteners. The existing 10' x 2' pick boards are made from aluminum while the existing 4' x 4' float platforms are made from plywood. The composite platforms were designed to be compatible with the existing platforms if they needed to be installed together where a mechanical interface was required. Some minor problems were experienced during fabrication because of the relatively large tolerances on the off the shelf material components. Even with these design and fabrication limitations, the 10' x 2' pick board showed a 25% weight savings over aluminum and the 4' x 4' float platform showed a 15% weight savings over wood. The 10' x 2' pick board was much easier to handle while the 4' x 4' float's advantage was that it was made from self extinguishing resin which allowed for permanent indoor facility installation. The platforms were proof loaded and given to the Lockheed High Crew for use in all environments.

After a year of field use, the platforms were removed from service and inspected. No major problems were found with either the bond lines or structural members. Sharp corners showed some signs of delamination from impact damage. In the future, all exposed corners will be rounded and reinforced with a layer of resin. The platforms were then loaded to destruction.

The 10' x 2' pick board was designed for a load of 500 pounds in the center of the board. The board failed at a load of 2,600 pounds when the decking separated from the frame due to shear forces. This exceeded the OSHA required factor of safety of 4. The testing continued until the box frame failed at a load of 5,100 pounds. The center deflection was in excess of 6.5 inches. The 4' x 4' float platform was designed for a load of 750 pounds. The platform failed catastrophically at 7200 pounds. Deflection measurements could not be taken.

The testing results showed that both platforms were over designed. This is a common tendency for engineers working with unfamiliar materials. This is especially true for a man rated application. Even without optimizing the platforms, the demonstration impressed both the engineers and technicians involved with the project. This positive impression greatly helps the effort to implement composites.

<u>Launch Pad Exposure:</u>

In order to properly apply composite materials to solving corrosion problems at the Launch Pads, the areas in which composites can be applied had to be defined. The Launch Pads pose a special environmental problem. Although much research and testing have been invested in the effects of salt spray, sun light, chemicals, and temperature exposure, never have they all been evaluated together in the levels present at the launch site.

The combination of heat, pressure, ultraviolet light, SRB exhaust chemicals, and salt exposure all help to degrade materials on the Pads. All these factors are present in different intensities in different areas of the Pad and have complex interactions. In order to determine where composite materials will survive, material samples were exposed to the Launch Pad environment in different locations. The samples consisted of fiberglass reinforced vinylesters and polyesters procured from 3 different manufacturers in the shape of structural channels.

The composite material samples were exposed to the Launch Pad environment for a total of seven (7) launches. The materials were mounted on the Launch Pad Fixed Service Structure (FSS) Orbiter side handrails on the 115, 135, 175, 215, and 255 foot levels. These launches occurred over a 16 month period. The samples were then removed, cut into tensile specimens. The batches were sorted by manufacturer and location. Additional test specimens were cut from materials that had been randomly selected from the procured samples and stored indoors for the exposure period. These were used as baseline samples.

The Material Science Laboratory performed the tensile testing on the samples. The data was then returned for evaluation. A *Two-Sample t-Test Assuming Equal Variances* was performed on the data comparing the baseline samples to the exposed samples at each level.

A difference in the tensile test means could not be established for any of the comparisons using a significance level of 0.001 ($\alpha = 0.001$). This indicates that beyond surface effects at the 135 foot level, the exposed material samples showed no signs of environmental degradation. The samples on the 135 foot level displayed surface degradation on the vehicle side of the samples. This was caused by the radiant heating exceeding the capabilities of the materials. No protective coatings were intentionally applied to the materials, but the 115 foot samples were painted during normal Pad refurbishment. Future composite uses at the Pads would recommend but not require that a protective coating be used.

Summary:

Overall, the project has successfully established the foundation for the application of composite materials at Kennedy Space Center. The technology was imported and transformed into a usable format. The application testing provided invaluable experience and results to effectively guide future endeavors. The next phase is to move the project into the field on a larger scale and replace existing equipment and structures with composites. This will include gratings, stairways, dollies, and other access equipment. The main thrust will be directed at corrosion prevention.