PREFERRED RELIABILITY PRACTICES

STRUCTURAL LAMINATE COMPOSITES FOR SPACE APPLICATIONS

Practice:

The creation of reliable structural laminate composites for space applications requires precision design and manufacturing using an integrated, concurrent engineering approach. Since the final material characteristics are established at the same time the part or subassembly is fabricated, part design, fabrication development, and material characterization must proceed concurrently. Because composite materials are custom-tailored to meet structural requirements of the assembly, stringent in-process controls are required to arrive at a configuration with optimum physical and material properties.

Benefits:

Conscientious adherence to proven procedures in the design, manufacture, and test of aerospace structural composites will result in low rejection rates and high product integrity. In specific applications, successful composite design provides design flexibility, increased strength to weight ratio, dimensional stability under thermal loading, light weight, ease of fabrication and installation, corrosion resistance, impact resistance, high fatigue strength (compared to metal structures with the same dimensions), and product simplicity when compared to conventional fabricated metal structures.

Program That Certified Usage:

Space Shuttle External Tank Composite Application Program, Space Shuttle Solid Rocket Motor filament wound case program, Advanced X-ray Astrophysics Facility (AXAF), Solar X-ray Telescope (SXT), Space Station Freedom, Solar X-ray Imager (SXI) and related composite applied research and product improvement projects.

Center to Contact for More Information:

Marshall Space Flight Center.

Implementation:

Design Practices. The most important concept in deriving acceptable structural laminate composite parts is the

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multidisciplinary approach to design wherein the material composition, filament orientation, and fabrication procedures are custom tailored to the specific part configuration. From the beginning of design analysis to the completion and flight of composite components, the integration of material structure and formulation with configuration and environmental considerations is essential. More than in any other product manufacturing discipline, composite development requires the designer to simultaneously consider the following: configuration, operational environment, tooling, quality, reliability, safety, nondestructive evaluation, and material characteristics. The physical properties of structural laminate composites tend to deteriorate due to environmental conditions after manufacturing. Therefore, design requirements must include, to a greater degree than in conventional structures, the operational environment (transportation, prelaunch, launch) and the storage environment. The matrix or binder composition, filament composition and form, and the specific manufacturing procedures used will heavily influence the acceptability of the final integrated unit.

Since the structural properties of the material are so strongly dependent upon the part fabrication process and tooling, design of the part and tooling configuration must be concurrent. This principle can be seen by comparing the

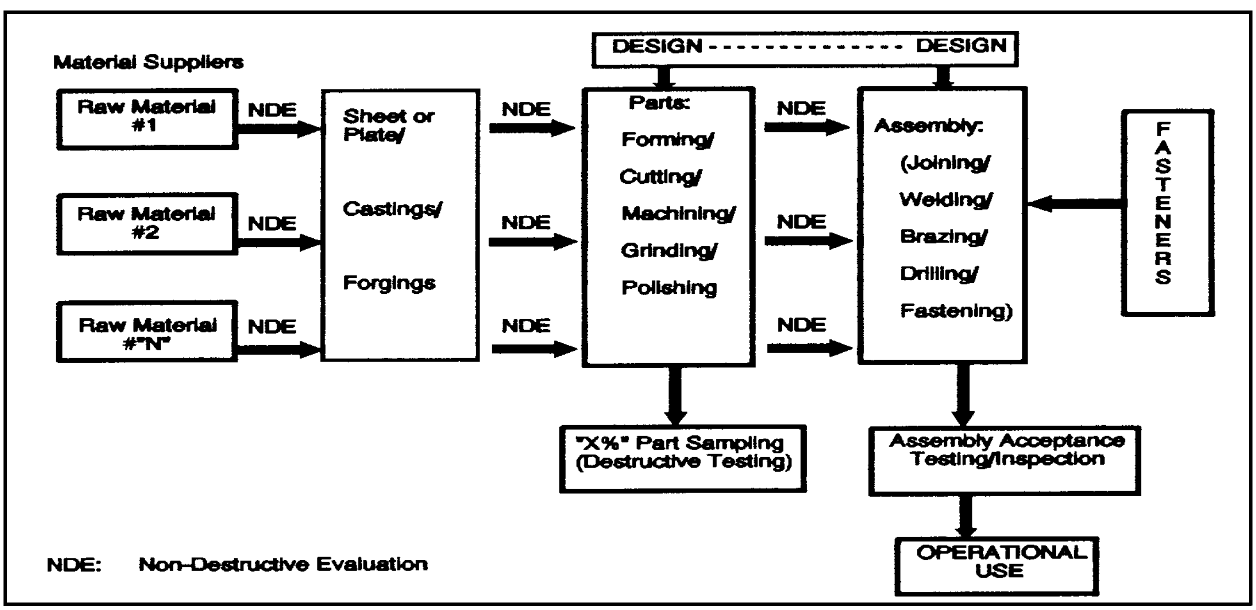

Figure 1. Conventional Metals Design, Manufacturing, and Testing

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conventional metals design, manufacturing, and testing procedure (Figure 1) with the corresponding cycle for structural laminate composites (Figure 2).

Figure 2 illustrates two important points: (1) part design and tool design go hand-in-hand; and (2) the manufacturing and fabrication process includes simultaneous production of the composite and fabrication of the structure. For structural space applications, composites must be designed properly and built properly. An important example of the need for laminate-unique considerations in the design process is that the design of the part and its manufacturing tooling

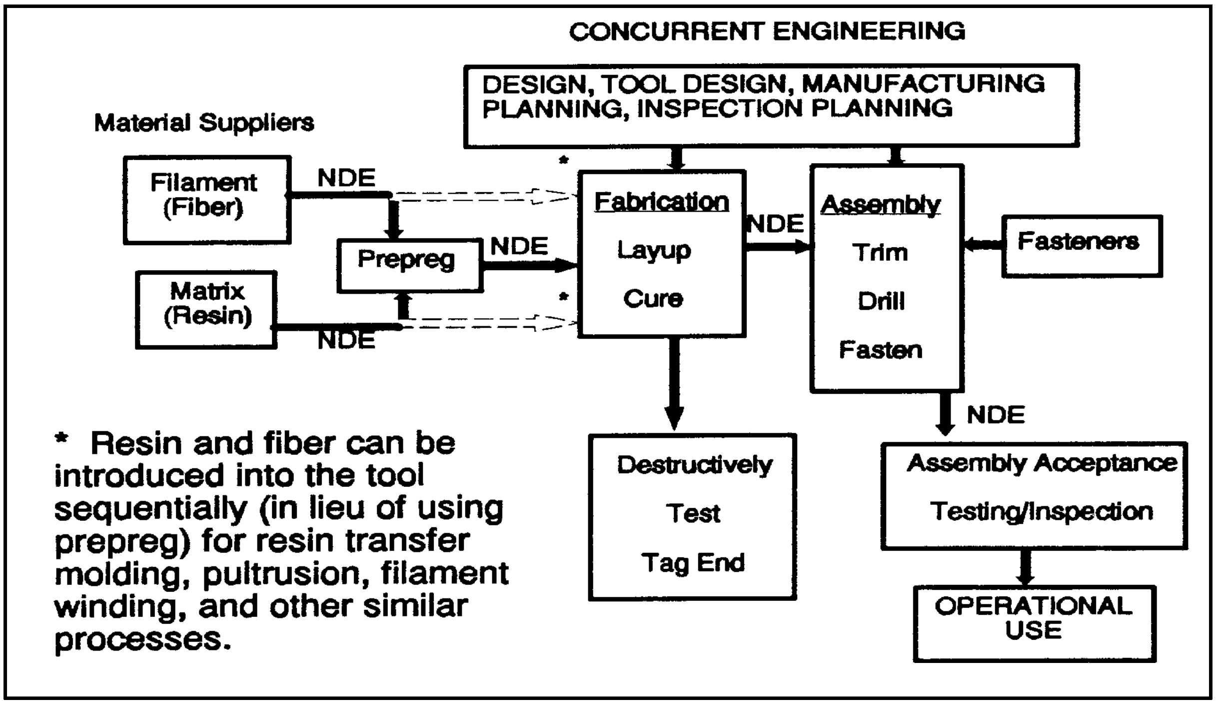

Figure 2. Structural Laminate Composites Design, Manufacturing, and Testing

include tag ends or trim area that must be removed and subjected to acceptance testing. It is common practice to use a safety factor of 1.5 for structural laminate composites. A safety factor of 2.0 is recommended for the materials located around fasteners.

The structural strength of the final design is dependent upon filament strength, matrix or resin strength, and fiber orientation (which should generally be in the direction of the applied force). The strength of the part is based on the

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interaction of fiber and matrix in a process that depends upon ply or layer thicknesses and percent of fiber volume. Typical fiber tensile strengths range from 200,000 to 800,000 psi while matrix tensile strengths range from 2000 to 5000 psi. When these two elements are combined into a graphite epoxy structural laminate, a composite tensile strength close to 98 percent of the uniaxial fiber strength is achievable. Part design must include the evaluation of coupon, section, and prototype tests in order to assure that part configuration/ material interactions are taken into account in the final configuration. Structural algorithms using finite element methods are used early in the design process, and these are supplemented by results from tests of prototype parts.

Graphite epoxy composite materials exhibit stress-strain relationships with less than 2 percent elongation and without the usual elastic-plastic behavior of metals. Where metals usually require only two design properties, modulus and Poisson's ratio, composite design will require five or more distinct directional variations of these properties. Thermal expansion properties can be designed so that zero expansion may be achieved, such as for optical benches. The resin used to bind the composite materials can typically absorb up to 5 percent by weight of water, which can affect dimensional stability of the composites. Ultraviolet radiation and atomic oxygen in space will increase aging and thereby decrease service life of the composite when left unprotected. *This iterative and integral design process will ensure a successful structural laminate composite part or assembly design.*

<u>Manufacturing Practices</u>. The matrices and fibers for structural laminate composites can be applied to a mold sequentially or the filament can be preimpregnated with the matrix material. The latter is the more common practice for aerospace structural laminates. Developing the correct process flow prior to production is crucial to modern composite manufacturing. Critical factors in the manual or automated lay-up of composites are the indexing or orientation of the filament and the sequencing of layer application. Curing temperature, pressure, and ramp rates are critical as they affect the degree of cross-linking of the polymers in the matrix material, adhesion to the filaments, porosity, filament spacing, and resulting overall strength and integrity of the final part. Lifetime of preimpregnated materials is an important consideration because acceptable properties can only be maintained for ten days to one month at room temperature or a material-dependent range of six months to two years in cold storage. Timing of the preimpregnation process, therefore, is a critical factor in the planning of the manufacturing process. The manufacturing environment

(humidity, temperature, and cleanliness) and the manufacturing process itself must be closely controlled to produce consistently acceptable products.

Automation using statistical process control of composite fabrication methods may be the single most important advancement needed to foster the use of composites for aerospace applications.

Testing and Nondestructive Evaluation Practices. Integral to the successful manufacturing process for aerospace structural laminates is the need for 100 percent in-process inspection, nondestructive testing, and coupon testing during the initial manufacturing phase. As inspection records are built up, the inspection requirements are reduced until only the problem areas are checked on each component. These problem areas should be defined by production results, design engineers, materials and process engineers, and shop fabricators. Early in the manufacturing process, filaments should be tested for tensile strength, strain rate, modulus of elasticity, density, diameter, stiffness, and surface morphology. Matrix rheology and mechanical performance must be characterized through chemical and physical testing. The preimpregnated material should be tested for resin content, flow rate, volatile content, tackiness, tack retention, and gel time. Filament count, filament spacing, drapability, and temperature exposure tests should also be conducted on the preimpregnated material. Coupons should be fabricated for each part to permit destructive tests (thermal, chemical, and structural) of the material which represents as closely as possible that which is included in the fabricated part. Wherever possible, part extensions should be trimmed off and tested to determine if the material meets strength, chemical, and thermal requirements. The final cured laminate composites should be tested for longitudinal compressive strength, longitudinal and transverse flex strength, longitudinal and transverse tensile strength, longitudinal and transverse shear strength, impact testing, and compression testing after impact testing. Nondestructive testing methods that may be used to verify absences of voids, delaminations, and low density areas are radiography, ultrasonics, thermography, eddy current, and acoustic emissions.

Nondestructive tests that may be used to verify cleanliness for bonding composites to adjacent metallic structures are Fourier Transform Infra Red (FTIR) spectroscopy, Non-Volatile Residue (NVR) analysis, X-ray Florescence (XRF), and Ellipsometry.

Nondestructive evaluation is an important inspection technique for determining defects without destroying the component. The typical nondestructive

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evaluation (NDE) technique for detecting defects in composites are shown in Table 1. Development of accept/reject criteria should be accomplished during the manufacturing and testing phase prior to production phase of the composite component.

Technical Rationale:

Experience with structural laminate composites on the Space Shuttle External Tank, Space Shuttle Solid Rocket Motor Filament wound case, Advanced X-ray Astrophysics Facility,

Table 1. NDE Techniques for Detecting Defects in Composite Materials

Defect Composite Method	X-Ray	Ultra-sonics	Computer Tomography	Alcohol Wipe	Thermo-graphy	Eddy Current	Dye Penetrant
Delaminations	X	X	X	X	X		
Density Variations	X		X				
Resin Rich/ Resin Poor	X		X				
Voids	X	X	X				
Crazing (Microcracks)		X		X			X
Wrinkles		X				X	
Conductive Materials						X	

Solar X-ray Telescope, International Space Station, and related composite applied research and product improvement projects has included experience with graphite/phenolics, glass/phenolics, graphite/epoxies, and graphite/bismalemides. Both woven fabric and tape forms have been used as reinforcing materials. Research and applications of composite materials at MSFC and by its prime contractors and subcontractors have included many other types and applications of composites. Several of these, such as filament winding, and pultrusion, fiber placement, and automated tape laying, are being considered for future design practices. Since knowledge of structural graphite epoxy composites is constantly expanding, this practice may also be updated in the future to reflect emerging advancements.

Impact of Nonpractice:

Failure to adhere to proven and acceptable practices in the design, manufacture, and testing of structural laminate composites will result in an unacceptably high rejection rate of fabricated composite parts. This rejection rate could be caused by unacceptable structural strength, delaminations, excessive (or inadequate) porosity, surface defects, inclusions, improper dimensions, or inadequate physical, thermal, or chemical properties as revealed in nondestructive testing or in destructive coupon testing. A high rejection rate could cause delays in the vehicle assembly, testing, and checkout process, and could possibly affect the launch schedule. Increased costs of manufacture would also result from a high rejection rate.

Related Practices:

Current Applications of Ablative Composites to Nozzles for Reusable Solid Rocket Motors; MSFC.

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