



PREFERRED  
RELIABILITY  
PRACTICES

# APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

---

## **Practice:**

Fabrication of ablative composite materials for solid rocket motor nozzles requires a precision, integrated, multi-disciplinary, multivendor approach to design and manufacture. Creation of the material requires stringent process controls during manufacture of the rayon fiber, weaving the rayon fiber into cloth, carbonizing the rayon cloth, impregnation of carbon cloth with resin and filler, wrapping the carbon-phenolic onto a mandrel to the proper thickness, curing, nondestructive inspection and final machining to the designed configuration. Environmental conditions and cleanliness levels must be closely monitored when bonding the ablative material to the metal housing. The critical material properties for acceptance of carbon cloth-phenolic prepreg material are cloth content, dry resin solids content, volatile content, carbon filler content, and resin flow. Use of certified and highly skilled tape wrapping operators, bonding technicians, machinists, and destructive and nondestructive testing personnel, is a must.

## **Benefits:**

Adhering to proven design practices and process controls during manufacture of ablative composite nozzle components will result in a high quality product with few rejects. Successful design and manufacturing of ablative composite materials for solid motor nozzles provides for proper transfer of the combustion gases from the burning propellant surface through the nozzle without damage to the metal structure. Use of a properly controlled manufacturing process will result in the proper density, percent resin content, compressive strength, interlaminar shear strength, thermal conductivity, coefficient of thermal expansion, and tensile strength.

## **Programs That Certified Usage:**

Shuttle Solid Rocket Motor; Shuttle Redesigned Solid Rocket Motor.

## **Center to Contact for More Information:**

Marshall Space Flight Center.

MARSHALL  
SPACE FLIGHT  
CENTER

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

### Implementation:

The increased interest in carbon-phenolic composite materials at NASA is due to the use of these materials as the ablative materials in the Solid Rocket Motor (SRM) nozzle of the Space Shuttle and potential follow-on solid rocket motor upgrades. The practices discussed here are the current industry standards, and, however successful, much work is yet to be done. Most of the manufacturing practices have evolved by the trial and error method and could benefit greatly from further scientific investigation. Almost all of the nozzle materials and processes need continued research and development efforts as NASA strives for optimal performance from advanced materials. In the design of ablative nozzle components, considerable attention should be given to thermo-structural, thermochemical, process modeling and other computer predictive and analysis codes. Various computer based analytical and simulation programs are available and have been used successfully in characterizing ablative materials and their erosion, char, and thermal protection characteristics. Typical programs that have been used for this purpose are: Charring Material Ablator (CMA), Aerothermal Chemical Equilibrium (ACE), Momentum and Energy Integral Techniques (MEIT) (ACE and MEIT are used in conjunction with the CMA program), and PATRAN (geometry of nozzle, a general model for structural and thermal analysis). Computational Fluid Dynamics (CFD) is a discipline that is finding increasing usage in evaluating the exhaust flow in SRM nozzles and in determining potential heat transfer to nozzle components. These techniques are important tools for the designer who is applying ablative composites to solid rocket motor nozzles.

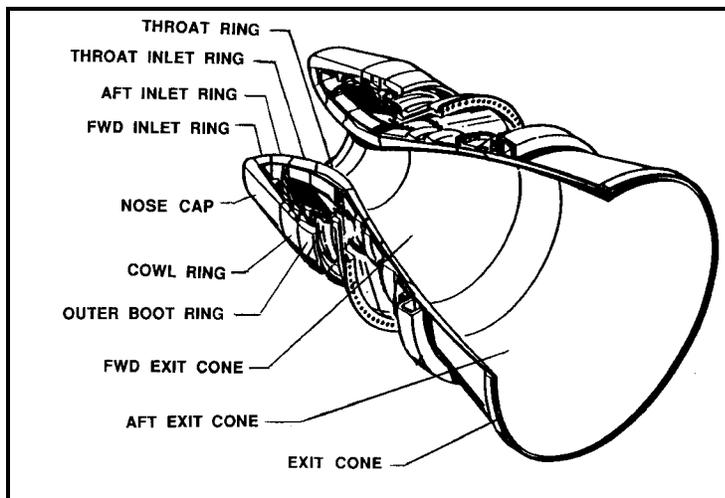


Figure 1. SRM Nozzle

As shown on Figures 1 and 2, the aluminum structure of the SRM nozzle is protected from the heat of the expanding gasses by a series of carbon cloth phenolic rings backed up by glass or silica cloth phenolic rings. The glass and silica cloth phenolic backup rings are provided for structural, insulation, and galvanic corrosion protection. In lieu of one single ring, a series of rings is used for ease of manufacture and handling. Factors of safety for ablative carbon cloth phenolic vary between approximately 1.5 and 2.0 for erosion and are usually about 1.25 for char, depending upon the

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

location of the ablative carbon cloth phenolic in the nozzle. Generally, the factors of safety in the entrance section of the nozzle are higher than in the exit section.

The optimum angle between the plies and the flame surface in SRM nozzles using ablative carbon cloth phenolic has been proven to be between 30 degrees and 60 degrees, depending upon the location, contour and heating conditions at various sections of the nozzle.

### Manufacture of Carbon Cloth:

The carbon cloth used to fabricate composite solid rocket motor nozzles is impregnated with the binder or matrix prior to wrap and cure. This preimpregnated material is commonly called "prepreg" in the composite industry. The diversity of the manufacturing process requires six different vendors before final material is produced. These vendors: 1) produce rayon thread; 2) weave cloth; 3) carbonize cloth; 4) produce resin; 5) produce carbon fillers; and 6) impregnate carbon cloth with resin and filler (production of prepreg). Constant monitoring of all phases of the manufacturing process is required to ensure satisfactory quality. The rayon thread is manufactured, then woven into cloth 60 in. wide. The rayon cloth is carbonized by slowly heating to 1000 deg. to 1500 deg. C in an inert atmosphere. Critical factors to be controlled in this process are the rate of temperature increase, time, and maintenance of an inert atmosphere in the oven.

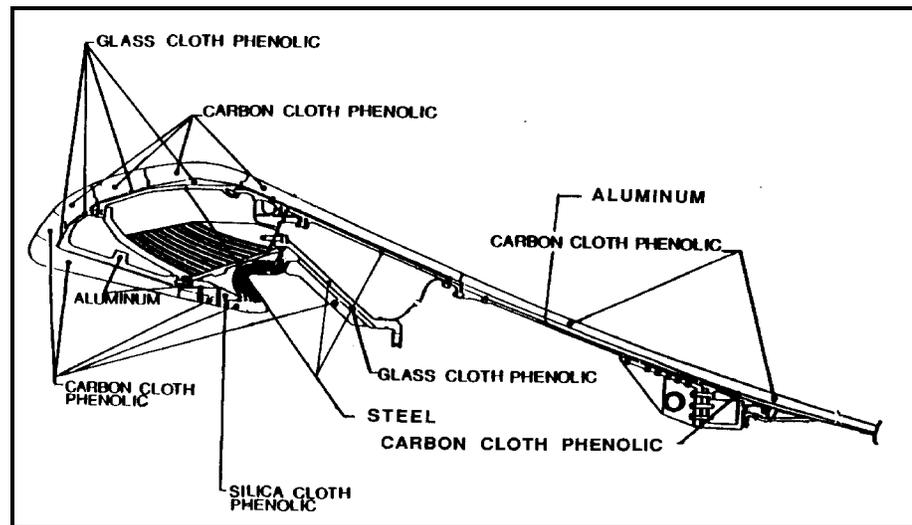


Figure 2. Ablative Materials in Nozzle

After carbonization, the carbon-cloth is impregnated by drawing it through a heated container of phenolic resin and carbon filler to form prepreg. Critical factors that must be carefully controlled in the preimpregnation process are temperature of the resin/ filler mixture, tension and speed of the cloth through the resin/filler mixture, pressure on the roller to ensure penetration of resin into the cloth, oven temperature after impregnation to remove volatiles, and control staging of the resin. The prepreg should meet the uncured material acceptance test data properties shown in Table 1 and the cured material acceptance test data properties shown in Table 2. However, it should be pointed out that since the structural minimum - maximum properties

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

---

shown on Table 2 vary by factors greater than 2 indicate that additional material, process and cure controls improvements are required to narrow the variation in material capabilities.

**Table 1. Uncured Material Properties of Carbon Phenolic**

Property	Percent by Weight		Retest Properties Percent by Weight <u>1/</u>	
	Minimum	Maximum	Minimum	Maximum
Cloth content	47.0	60.0	---	---
Dry resin solids	32.0	37.0	---	---
Volatile content	3.5	6.0	3.5	6.5
Carbon filler content	8.0	16.0	---	---
Resin flow	10.0	20.0	8.0	23.0

1/ Procuring activity verification of potential extension of material shelf life after six months from date of supplier manufacture.

The prepreg material has a six-month shelf life from date of manufacture. Potential shelf life may be extended if the material meets the retest properties of Table 1. The prepreg tape rolls should be cut on a 45 deg. bias in widths of 3 in. and 12 in. The bias cut allows the cloth to stretch and conform to the different mandrels, and the narrow widths help avoid wrinkling and folding of the material during the wrapping process. The rolled prepreg is bagged with desiccant and stored in an environmentally controlled cold storage until it is required for processing.

### Glass Cloth Phenolic:

The glass cloth phenolic shown in Figure 2 is used to provide structural integrity, a corrosion barrier, and insulation. It is fabricated in a manner similar to that of carbon cloth phenolic. The product should conform to the uncured material acceptance test data properties and the cured material acceptance test data properties shown in reference 5.

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

**Table 2. Cured Material Physical and Mechanical Properties of Carbon Phenolic (At Room Temperature Unless Otherwise Specified)**

Property	Limits		
	Minimum	Maximum	
Density, grams per cubic centimeter (g/cc)	1.4	1.52	
Resin content, percent	30.0	38.5	
Compressive strength, psi (edgewise)	warp direction	25,000	65,000
	fill direction	20,000	55,000
Interlaminar double shear strength, psi	3,500	8,000	
Thermal conductivity, Btu/ft-hr-degrees F at 250 deg. F	across ply	0.10	1.1
	with ply	0.10	1.1
Coefficient of thermal expansion in/in-degrees F x 10 exp -6 at 400 deg. F	across ply	5.0	20.0
	with ply	2.0	9.0
Flexural strength, psi	warp direction	25,000	55,000
	fill direction	20,000	55,000
Tensile strength, psi (edgewise)	warp direction	15,000	40,000
	fill direction	10,000	35,000

### Silica Cloth Phenolic:

The silica cloth phenolic shown in Figure 2 is also used to provide structural integrity, a corrosion barrier, and insulation. It is fabricated in a manner similar to that of carbon cloth phenolic. The product should conform to the uncured material acceptance test data properties and the cured material acceptance test data properties shown in reference 6. The silica cloth phenolic is a higher purity material than the glass cloth phenolic, and is only used in the cowl ring.

### Nozzle Ablative Composites Fabrication:

The fabrication process for the components of the nozzle includes two tape wrappings and two machining operations. Because of the sensitive variables occurring during tape wrapping of the prepreg tape, a highly skilled operator is required who understands what is required when one of

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

---

the variables changes. The critical manufacturing variables are heat input, cooling input, roller pressure, machine speed, and tape tension. There are many other random variables that play a less significant role. The material is wrapped onto a mandrel which has been machined to the desired contour of the component as specified in the manufacturing plan. Depending upon the component location, the first wrap could be either bias-cut carbon cloth phenolic, glass cloth phenolic, or silica cloth phenolic tape wrapped on the mandrel at a specified angle (which depends upon the nozzle component) to the centerline of the nozzle. Enough tape should be wrapped to provide machining stock and tag ends after cure.

The tape wrapping process places the tape at the proper angle and debulks the tape material to minimize movement of the tape during cure. Debulking of the tape should be achieved by applying heat and pressure at the point of contact with the mandrel or the previous ply. Heat should be applied prior to wrapping to make the tape tacky. The pressure roller forces the fibers to nest and compact (debulk) within the resin/ fabric matrix. CO<sub>2</sub> is used to cool the resin to stop further cure, and dimensionally and thermally stabilizes the billet for further processing. All ablative components are cured in a hydroclave except the aft exit cone, outer boot ring, and the cowl, which are cured in an autoclave.

After wrapping, the billet and mandrel are vacuum bagged for waterproofing, then installed in a hydroclave for final cure. Curing of the carbon-cloth liner requires a pressure of 1000 psi at 310 deg. F for a minimum of five hours. After the cure cycle, a test ring should be removed and tested to verify the properties of the cured carbon cloth phenolic. The carbon cloth is then machined to configuration.

In preparation for the second wrap, a coat of phenolic resin is applied to the machined surface of the first layer of phenolic. The second layer of phenolic tape is wrapped at the desired angle to the nozzle centerline using the same process as described for the carbon-cloth phenolic. The component is vacuum bagged and cured in an autoclave at 250 psi at a temperature of 310 deg. F for approximately four hours. Carbon and glass rings should be removed and tested to verify properties of the cure. The billet is final machined, removed from the mandrel and x-rayed to verify absence of voids, delaminations and low density indications. Following x-ray, the machined component is ready for bonding to the metal housings. Bonding of the machined ablative component to the metal housing is accomplished in a clean environment and requires strict process control.

### Inspection, Destructive, And Non-Destructive Evaluation:

A very important development in nondestructive testing that promises to help maintain the meticulous cleanliness required to ensure bonding of composites to adjacent metallic structures is computer controlled scanning of the metal surface with devices based on Optically Stimulated

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

---

Electron Emission (OSEE) principle. Computer controlled contamination scanning (CONSCAN) is a system developed by MSFC using the OSEE technique for automated scanning of metal surfaces prior to critical bonding operations. The CONSCAN system provides the sensitivity and spacial resolution necessary when scanning large areas to ensure that surfaces are sufficiently free of contaminants that reduce bond strength. Scanning the surface with CONSCAN provides a map of surface contamination levels, which clearly identifies those areas that require further cleaning. Rescanning after the additional cleaning operation provides results of that recleaning. These data provide a permanent record of surface cleanliness levels. The data records may be used at a later date to help identify the specific process during which contamination occurred and to correlate surface cleanliness levels with subsequent debond locations.

The carbon cloth prepreg, glass cloth prepreg, and silica cloth prepreg should be visually inspected to ensure that there are no broken fibers, voids, or lack of resin or filler. Coupons of these materials should also be tested to verify uncured and cured properties. After final machining of both glass cloth and carbon cloth wraps, the materials should be x-rayed to verify absence of voids, delaminations, and low density areas. Defects of this type may be cause for rejection and scrappage. An alcohol wipe may be performed on the finished surface. Collection of alcohol in a spot or line before drying, will indicate a crevice or void in the surface. The x-ray technician should be highly skilled in taking and reading the x-rays to avoid scrapping an expensive component due to erroneous low density indications. Low density indications could be caused by fiber ends not being flush with next butt end and the gap being filled with resin and filler, density variations, and interlaminar resin-rich areas.

The tag ends and rings removed after curing should be used to verify mechanical properties. Tag ends and rings could also be used for plasma torch testing to verify the erosion rate and the factor of safety.

### **Technical Rationale:**

Precision design and manufacturing procedures for ablative material for solid rocket motor nozzles have been developed over a period of 30 years. The design of the ablative material depends upon factors such as the solid propellant composition; combustion gas temperature, velocity and composition; and relative position of the material in the nozzle. Problems that have surfaced over the years were analyzed, improvements proposed; and, when approved through the NASA change board process, were designed, prototyped, ground tested and flown. Information for this practice was derived from a number of sources, including procurement specifications and manufacturing plans for the SRM and RSRM experimental studies, problem reporting and corrective action (PRACA) reports at MSFC, AIAA reports, and from personal interviews and telephone interviews with individuals from MSFC organizations and contractor organizations.

## APPLICATION OF ABLATIVE COMPOSITES TO NOZZLES FOR REUSABLE SOLID ROCKET MOTORS

---

### Impact of Non-Practice:

Not adhering to the proven practices for the design, manufacture, and testing of ablative composite materials could result in low material density, separation of fibers, and contamination. These defects could cause expensive scrappage and possible schedule delays. The ultimate impact of not adhering to precise in-process controls could be burn-through of the nozzle causing loss of mission, vehicle, and life.

### References:

1. Hall, William B.: "Standardization of the Carbon-Phenolic Materials and Processes, Volume I, Experimental Studies," Professor of Chemical Engineering, Mississippi State University, August 31, 1988.
2. Kelly, P. and Thompson, A.: "AIAA 89-2661 Low Density Indications in Radiographs of Solid Rocket Motor Ablatives," 25th Joint Propulsion Conference, Morton Thiokol Inc., July 10-12, 1989.
3. TWR-10341 (CD) Rev. D: "Manufacturing Plan for Space Shuttle Redesigned Solid Rocket Motor Project," Prepared by Morton Thiokol Inc., Manufacturing Engineering, NASA Contract NAS8- 30490.
4. TWR-10341 (CD) Rev C: "Manufacturing Plan for Space Shuttle Redesigned Solid Rocket Motor Project," Prepared by Morton Thiokol Inc., Manufacturing Engineering, NASA Contract NAS8- 30490.
5. STW5-2651F: "Glass Cloth Phenolic, Preimpregnated Specifications," Morton Thiokol Inc., May 5, 1987.
6. STW5-2652E: "Silica Cloth Phenolic, Preimpregnated Specification," Morton Thiokol, Inc., August 13, 1987.
7. STW5-3279A: "Carbon Cloth Phenolic, Preimpregnated Specification," Morton Thiokol, Inc., May 8, 1987.
8. MSFC: "Problem Reporting and Corrective Action (PRACA) Systems," Run Dated Nov. 1, 1991, PRACA Record Numbers A07293, A08066, A09099, A11024, A11356, A11466, A12155, A12234, A12235, A12242, A12430, A12438, A13394, A09676, A09677, A10979, A11854, A11855, A11054, A11076, A11108, A11133, A11182, A11659, A11686, A12979, A13812.
9. Nichols, R. L.: Solid Propulsion Integrity Program (improvements made through this program), ER41 Solid Propulsion Research and Technology Office, Marshall Space Flight Center, AL.
10. Sutton and Ross: "Rocket Propulsion Elements," Fourth Edition, Wiley and Sons.
11. Proceedings of Rocket Technology Subcommittees of The Chemical Propulsion Information Agency, 1989, 1990, 1991.