Crew Exploration Vehicle Thermal Protection System Advanced Development Project

Compression Pad Material Processing and Acceptance Specification

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INTRODUCTION

The baseline technology for the Orion CEV TPS compression pads is the Enka rayon based, or NARC rayon based carbon phenolic used in the Space Shuttle Solid Rocket Motors since they are human-rated materials. While specifications exist for the space shuttle rocket nozzle carbon phenolic, the entry environment and mission requirements for heat shield applications are quite different. A specification specifically tailored to heat shield applications is warranted. Previous efforts in developing a heat shield specification for rayon based carbon phenolic were performed under the Mars Sample Return Earth Entry Vehicle project in 2001 and documented in reference (i). The major finding was that a combination of existing specifications for rocket nozzles and entry heat shields could meet the requirements of the MSR EEV project. The current specifications are the Marshall Space Flight Center Specification for carbon phenolic, designated MSFC-SPEC FM5055B, and the General Electric specification (document S0060-01-0076) for the Galileo Carbon Phenolic Heat Shield, designated GE R6537 Carbon Fabric Materials (prepreg). The specification documented herein is based largely on the MSFC-SPEC FM5055B but includes elements from the GE R6537 specification. Acceptance testing is also defined and the criteria listed within this document.

1. SCOPE: This specification will establish the requirements and mission assurance provisions for rayon based carbon fabric reinforced phenolic prepreg for the Orion CEV heat shield compression pads. Acceptance criteria will also be established as part of this specification. The compression pad functional requirements are included in the appendix to this specification. The contractor(s) selected for the compression pad fabrication will review and modify this specification as required to produce composites of the highest quality consistent with the contractor's selected process(es) and experience base.

2. APPLICABLE DOCUMENTS: The following documents of the issue in effect on the date of the procurement, form a part of this document, to the extent referenced herein:

<u>Government Specifications</u>

MIL-STD 961D
MIL-R-9299C
MSFC-SPEC FM5055B

a. Government Publications

Several specifications/methods (needing revision, tailoring, and updating to the needs of the Orion CEV TPS compression pads) are available from the following reports:

i. Delano, C., “MSR EEV Heat Shield Materials and Processes”, unpublished contractor report, ITT-Aerotherm, December 31, 2001

ii. Hall, William B. “Standardization of the Carbon-Phenolic Materials and Processes, NASA-CR-183226 and NASA-CR-182177 Vol. 1 and Vol. 2, August 31, 1988

iii. Beckley, D.A. and Stites, J Jr., “Statistical Characterization of Carbon Phenolic Prepreg Materials”, Volumes 1 and 2, Final Report (Hitco) NASA-CR-179416 April 1, 1988

b. Non Government Documents

i. TBD

3. REQUIREMENTS

Material Broad good prepreg consisting of 91LD phenolic resin, or SC1008 phenolic resin, or equivalent phenolic resin which meets the MIL-R-9299C specification, N908UP carbon powder or equivalent heat shield grade carbon powder and Enka-rayon based, or NARC rayon based carbon fabric are required for laminate carbon phenolic (LCP) compositions. The target weight percents of the three constituents in the cured LCP shall be 35, 15 and 50 respectively. The MSFC-SPEC (FM5505B) provided in the Beckley report is to be used as a guideline for preparing prepreg for laminate compositions (see page 74, vol 2, Beckley report, paragraph 3.3.1, Table I and paragraph 3.3.2, Table II of the MFSC SPEC FM5505B.)

Enka rayon based, or NARC rayon based based carbon cloth: Visual examination of the carbon fabric (MSFC-SPEC FM 5505B, paragraph 3.7 and Section 7) shall be100% as described in Volume 2 of the Hall report, pages133-137 and a report generated as described in Volume 1 in the Fabric Testing Section. The inspection was performed using a vertical method, a horizontal inspection method is acceptable substitute. Particular attention will be given to fabric alignment and strength of the stitched seams during the inspection for assurance that fabric tearing and/or seam failure will not occur during the prepreg operation. If seam reinforcement is deemed necessary such will be accomplished. The inspected roll shall be repackaged as specified unless it is to be coated right away.

Properties

Uncured Material: Characterization of the prepreg shall include volatiles, flow properties, and percent carbon powder and resin. Table I under paragraph 3.3.1 in the MSFC-SPEC (FM5505B) shows the maximum volatiles for LCP broad goods to prepare tape at 6.0%. This value for the maximum volatiles shall be reduced to 4.7%.

Cured Material: Mechanical property requirements for composites from the cured LMCP broad goods and billets molded are provided in paragraph 3.2.2.1 below. Demonstration of attainment of the composite properties listed in Table II the MSFC-SPEC (FM5505B) is not required.

Mechanical Properties The materials supplied shall exhibit the following properties when tested in accordance with the methods indicated.

Broad Goods and Bias Tape for Autoclaving

Laminated Properties: Cure as specified by the contractor or hydroclave cure with 1000 psi pressure @ 300-320°F for 45 minutes for 1/8" thick laminate. All properties listed are at room temperature unless otherwise specified.

Table 1. Acceptance tests and specifications

Property	Acceptance Criteria	Test Procedure
Density, or specific gravity	1.45 g/cc Minimum, ±1 g/cc variability throughout the part	MSFC-SPEC (FM5055B) paragraph 4.6.3.2, CT-Scan
Resin Content	35 ±5%	MSFC-SPEC (FM5055B) paragraph 4.6.3.2
Residual Volatiles	< 2.0%	MSFC-SPEC (FM5055B) paragraph 4.6.3.3
Tensile Strength Wrap and Fill	16,000 psi Minimum	ASTM-D-638 and MSFC-SPEC (FM5055B) paragraph 4.6.3.10
Tensile Modulus Wrap and Fill	2.0×10^{6} psi Minimum	
Compressive strength Across-ply Fill Warp	80,000 psi Minimum 40,000 psi Minimum 45,000 psi Minimum	MSFC-SPEC (FM5055B) paragraph 4.6.3.5
Compressive modulus Wrap, Fill, & across-ply	2.0×10^{6}	
Thermal Conductivity Wrap & Fill Across-ply	1.14 W/m-K Maximum 0.81 W/m-K Maximum	ASTM -C-177-04
Coefficient of thermal expansion at 450°F Across-ply Wrap/Fill	$< 9.0 \times 10^{-6}$ $< 15.0 \times 10^{-6}$	ASTM-E-831
Ply angle	20° ±0.50°	

Qualification: Qualification of this material, shall be the responsibility of the procuring activity of the heat shield fabricator(s). Specific requirements for qualification, where applicable shall be included in the design document which references this document.

4. QUALITY ASSURANCE PROVISIONS

Vendor Warranty – The vendor shall submit the following with each lot of material supplied:

Actual test data which shows conformance of the prepreg lot to the requirements of paragraph 3.2.1 and if specified, paragraph 3.2.2.1.

Certification that the material meets the requirements of this specification. Certificates shall include the designation, lot number(s) and date of manufacture so that the certificate can be identified with the shipment.

Acceptance Testing – Sampling, as required, shall be conducted by randomly selecting sufficient material from each lot received to carry out the tests required by the Orion CEV TPS ADP and Prime Contractor.

The compression pad fabricator shall review and evaluate supplier data and determine the extent of, and perform, any further testing required to adequately assure compliance and acceptability.

Failure of any portion of the material tested/inspected to conform to any of the requirements shall be cause for rejection of the entire lot.

Test Methods

Test methods described in Table 1, and the MSFC-SPEC (FM5055B) shall be used unless an equivalent test method which produces superior results exists. If alternate methods are used, copies of the method(s) shall accompany the delivered coupons, billets, or compression pads, or otherwise be transmitted

Tests for properties of cured compositions will be conducted on hardware tag ends e.g. residual volatiles or at a minimum using a process, which simulates processes used to produce the hardware to produce the test samples. If micro tensile or similar tests are to be performed on hardware tag ends, such may be used to replace of tests on cured compositions described in the MSCF-SPEC (FM5055B)

5. PREPARATION FOR DELIVERY - The items required in this paragraph (packaging, shipping and marking) shall be as described in the MSFC-SPEC (FM5505B)

6. NOTES

Source of Supply

Table 2. Source of supply and vendor designations

Material	Vendor	Vendor Designation
Carbon Fabric	Enka rayon, carbonized by NSP NARC rayon, carbonized by NSP	CCA-10 CCA-8
Carbon Powder	Cancarb LTD	N908UP
Resin	Ashland Specialty Chemicals, 91LD Cytech proprietarty, 91LD Hexion Specialty Chemicals (formerly Borden)	91LD SC1008
Prepreg	Cytec Engineered Materials	MX4926N MX4926 HRPF

Other suppliers may be considered provided satisfactory compliance to the requirements of this specification is demonstrated.

Revision to this specification shall be in accordance with the latest version of MIL STD 961D.

Appendix A

Compression Pad Draft Functional Requirements

A. <u>Mechanical Loads</u>

1. Ultimate mechanical load per compression pad, these loads are not requirements, but are provided for informational purposes.
    a. Preload + Launch Load - Bolt Relaxation = Total Compressive Load
        1. 108.6 kips + (1.4 * 88.7 kips) - (1.4 * 55.2 kips) = 155.5 kips
    b. Shear = 1.4 * 3.3 kips = 4.6 kips
    c. Moment = 1.4 * 65 in-kip = 91 in-kips
    d. Factors of safety
        1. 1.4 is the load factor of safety
        2. 2.0 knockdown factor on material properties
2. Positive margins against ascent loads and preload. In general terms, the current compression pad has a 20.32 cm base cylindrical diameter. The loading area is slightly lower than the area of the 20.32 cm circle due to the presence of the hole to accommodate the tension tie rod and the reduced diameter to accommodate the service module connection. The properties listed below are the minimum required for the above load case and for the compression pad design to achieve positive margin of safety. Any material system must satisfy the stated minimums. For 3-dimensional materials it is understood that the in-plane and across-ply definitions do not strictly apply.
    a. Compression
        1. minimum ultimate compressive strength (before knockdown)
            a. Across-ply direction 310 MPa (80,000 psi) @ 70°F
            b. In-plane (wrap/fill) direction 241 MPa (45,000/40,000 psi) @ 70°F
    b. Shear
        1. minimum ultimate shear strength (before knockdown)
            a. Across-ply direction 24.1 MPa (3500 psi) @ 70°F
    c. Tension
        1. minimum ultimate across-ply tensile strength as a function of temperature (before knockdown)

Across-Ply	
Temp (°F)	**Ultimate Stress, F (psi)**
20	3636
70	4345
250	3370
350	2762
500	970
750	493
900	284
1200	128
2000	437
3000	459
4500	489

3. Positive margin with respect to thermally induced loads
    a. Maximum thermal expansion coefficient at 450°F should be 9.0×10^{-6} in/in-°F in the across-ply direction.

B. Thermal Environment
1. Nominal reentry environment, not a requirement, but provided for informational purposes. A lunar skip return trajectory is shown in figure 1
    a. 610 W/cm2 peak heat flux (margined, no augmentation)
    b. Total heat load ~53 kJ/cm2 (margined, no augmentation)
2. Keep bondline temperature below specified limit
    a. 550°F for PICA
        1. maximum thermal conductivity of virgin material @ 70°F
            a. across ply – 0.81 W/m-K (1.30×10^{-4} Btu/ft-s-R)
            b. in-plane – 1.137 W/m-K (1.83×10^{-4} Btu/ft-s-R)
    b. 600°F for Avcoat
        1. maximum thermal conductivity of virgin material @ 70°F
            a. across ply – 0.81 W/m-K (1.30×10^{-4} Btu/ft-s-R)
            b. in-plane – 1.137 W/m-K (1.83×10^{-4} Btu/ft-s-R)

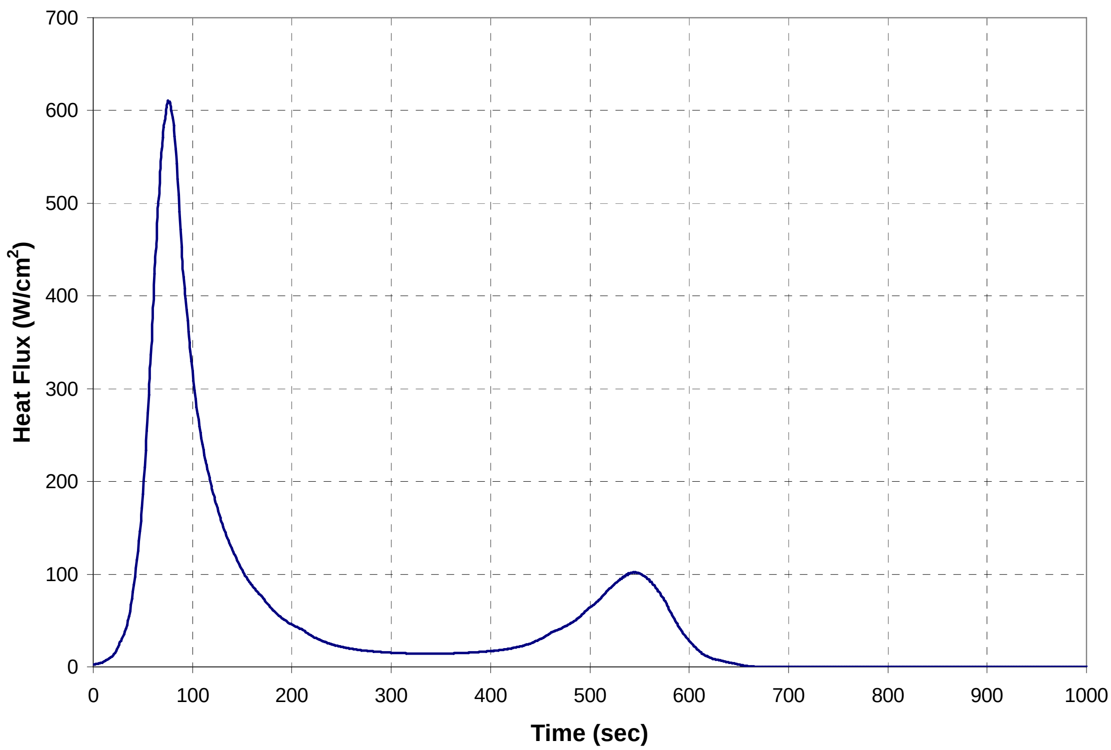

Figure 1. Lunar return heat flux as a function of time

C. <u>Manufacturability</u>

1. Geometric constraints
    a. experience base with thick parts, must be able to produce parts on the order of 7.62 cm or thicker in all proposed material forms
    b. experience base with large parts, must be able to produce billets, and or parts 30.48 cm in diameter, or 30.48 cm square
    c. RFI responses should include specific examples and dimensions achieved.
2. Relevant experience with heat shield applications
    a. Must have had some experience fabricating materials for use in heat shields within the last 10 years
3. Ability to meet customer processing and acceptance specification
    a. Minimize volatile content, desire < 2.0%
    b. Provide recommendation as to whether a post cure would be required.
    c. Cure pressures of 1000psi for shingle laminate, 3000-5000 psi and higher for chopped molded parts, best recommendation for 3D materials. IOr if experience shows otherwise, provide best recommended cure cycle pressure
    d. Minimize moisture content. State lowest achievable moisture content.
4. Minimum Technology Readiness Level (TRL) of 6 as evidenced by arc jet test data, flight test data, and or hot fire rocket test. Definition of TRL 6 – System/subsystem model or prototype demonstration in a relevant environment (ground or space). At TRL 6, a representative model or prototype system or system – which would go well beyond ad hoc, “patch-cord” or discrete component level breadboarding – would be tested in a relevant environment. At this level, if the only “relevant environment” is the environment of space, then the model/prototype must be demonstratede in space.
5. NDE/NDI and acceptance testing required. Vendors are to provide their own assessment and recommendations for NDE/NDI used during all phases of material processing. Vendors must also provide acceptance testing as part of their response. Acceptance criteria will evolve by NASA working with the vendor for each specific material system being proposed.
    a. NDE/NDI may include
        1. X-ray
        2. CT scan
        3. Ultra sound scan
        4. Alcohol wipe
    b. Acceptance criteria may include
        1. density distribution through the part
        2. % volatiles
        3. % moisture