RIGID FIBROUS CERAMICS FOR ENTRY SYSTEMS

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HIGH PAYOFF AREAS WITH REUSABLE SURFACE INSULATION

- A REWATERPROOFING OR FACTORY WATERPROOFING COMPOUND WITH A 1800°F TEMPERATURE CAPABILITY
  - WOULD ALLOW REWATERPROOFING OF ABOUT 25-50% OF THE ORBITER TILES

TECHNOLOGY OPPORTUNITIES/GAPS

- LIGHTWEIGHT, INSULATING CERAMIC MATRIX COMPOSITES FOR LOAD BEARING STRUCTURE
  - RIGID FIBROUS CERAMIC (RFC) CORES
  - FACESHEETS OF HIGH TEMP (2000°F+) INORGANIC MATERIALS
  - SURFACE DENSIFICATION OF RFC CORES
- ULTRA-LIGHTWEIGHT, LOW THERMAL CONDUCTIVITY RFC, USE BEHIND C/SIC, RCC OR ACC SHINGLES/PANELS

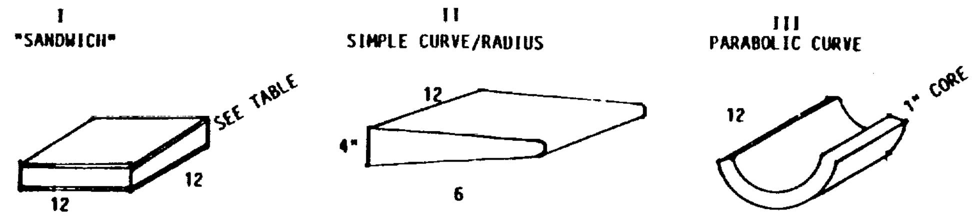
COATINGS FOR RIGID FIBROUS CERAMICS

DESCRIPTION	STATUS
CLASS 2 (RCG) BLACK BOROSILICATE GLASS	PRODUCTION; USED ON ORBITER TILES
CLASS 1 WHITE BOROSILICATE GLASS	PRODUCTION; USED ON ORBITER TILES
CLASS 1, MOD 3 BOROSILICATE, WHITE	PRODUCTION; MATCHES CTE OF HTP-12-35
CLASS 2 ON HTP-IMD-39-8, HTP-6-22 and HTP-8-22 TILES	R&D AT LMSC, SUCCESSFULLY TESTED TO 40 THERMAL CYCLES TO 2300°F AT NASA/JSC
TUFI	R&D AT NASA/ARC; VARIOUS TESTS; APPLIED TO HTP-HTP-8-22; SUCCESSFULLY TESTED TILES AT NASA/JSC FOR 20 CYCLES TO 2300°F
CLASS 2 WITH 250 MICRON SiC PLATELETS	R&D AT LMSC. APPLIED TO HTP-8-22 AND IMD HTP-39-8; SUCCESSFULLY TESTED TO 40 THERMAL CYCLES TO 2300°F AT NASA/JSC

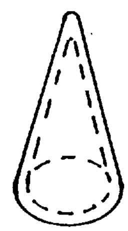
CHALLENGES FOR REUSABLE RIGID FIBROUS CERAMICS: LUNAR/MARS AEROBRAKING HEATSHIELDS

- ADVANCED FIBERS THAT CAN PRODUCE A 3000 TO 4000 °F USE-TEMPERATURE RFC MATERIAL REQUIRE THE FOLLOWING FIBER CHARACTERISTICS:
  - LOW THERMAL EXPANSION (3 TO 8 x 10^{-7} IN/IN °F)
  - SMALL AVERAGE FIBER DIAMETER (1.5 TO 3 MICRONS)
  - HIGH MELTING POINT (4000 TO 4500°F)
  - MODERATE TENSILE STRENGTH (150 TO 220 x 10^3 LB/IN^2)
  - LOW FIBER POROSITY TO ENHANCE STRENGTH
  - THERMAL STABILITY AT 3000 TO 4000°F
- ADVANCED COATINGS COMPATIBLE WITH 3000 TO 4000°F RIGID FIBROUS CERAMICS
  - CTE COMPATIBLE WITH RFC SUBSTRATE
  - HIGH EMITTANCE (≥ 0.80)
  - LOW CATALICITY, SIMILAR TO CLASS 2 (RCG) COATING

COMPOSITE CLAD HTP STRUCTURAL CONFIGURATIONS



IV
CONIC BODY



* BMI = BISMALEIMIDE

MATERIAL MATRIX FOR COMPOSITE STRUCTURES

TYPE	CLADDING	PLYS	CORE	THICKNESS	QTY
I	G/E	2	16-22	0.5"	3
I	BMI*/SIO_2	2	16-22	0.5"	3
I	G/E	2	16-22	1.5"	3
I	BMI/SIO_2	2	16-22	1.5"	3
II	S_iC/S_iOC	2	16-22	N/A	2
III	G/E	2	16-22	R_1= 12" R_2=10.75" L=12"	2
IV	BMI/SIO_2 (X2)	2	16-22	HT=16	1
	SIO_2 CERAMIC HEXCEL	2	16-22	DIA=6"	1

ENTRY SYSTEMS BACKGROUND: RON BANAS

1960-1964 (NASA/DFRC)	PLANNED, CONDUCTED AND REPORTED ON TURBULENT BOUNDARY LAYER AERODYNAMIC HEATING EXPERIMENTS ON THE X-15 RESEARCH AIRCRAFT.
1965-1972 (LMSC, INC)	AERODYNAMIC HEATING ANALYST FOR ASCENT/ORBIT/REENTRY VEHICLES SYSTEMS TEST ENGINEER FOR AEROHEATING WIND TUNNEL TESTS. • PLANNED/PERFORMED/REPORTED ON MATERIAL CHARACTERIZATION TESTS • PLANNED/PERFORMED/REPORTED ON RSI ENVIRONMENTAL TESTS - THERMAL, ACOUSTIC, ARC-JET AND ATTACHMENT TESTS
1973-1979	ANALYST PERFORMING TPS TRADE STUDIES - ACTIVE VS PASSIVE COOLING - METALLIC VS RSI (CERAMIC) EXTERNAL INSULATION - TPS SIZING
1979-1984	ENGINEERING MANAGER FOR ALL ASPECTS OF HRSI CONTRACT WITH ROCKWELL/NASA-JSC - RESPONSIBLE FOR SCALE-UP TO PRODUCTION OF CL. 2 (RCG) COATING AND FRCI-12 - RESPONSIBLE FOR TECHNOLOGY CONTRACTS WITH NASA/JSC & NASA/ARC
1985-1991	MARKETING, CUSTOMER INTERFACE/REQUIREMENTS FOR ALTERNATE USES OF RSI MATERIALS. - PROJECT LEADER ON VARIOUS EFFORTS WITH RIGID FIBROUS CERAMICS - PRODUCTION SCALE-UP OF HTP-6; HTP-16, HTP-12 & HTP-60

COMPARISON OF LI-900 AND HTP PROPERTIES

PHYSICAL PROPERTY*	LI-900	HTP-6-22	HTP-12-22	HTP-16-22	HTP-60-22
DENSITY (LB/FT^3)	8.8	6.5	12	16	60
TENSILE STRENGTH (LB/IN^2) - THRU-THE-THICKNESS - IN-PLANE	 27 68	 46 131	 88 320	 183 421	 775 1734
COMPRESSION STRENGTH (LB/IN^2) - THRU-THE-THICKNESS - IN-PLANE	 45 105	 62 95	 141 -	 259 571	 - -
COEF. OF THERMAL EXPANSION (IN/IN°F) (70 TO 1500°F) - IN-PLANE $X10^{-7}$	3.2	15.7	14.2	13.5	14.0
APPARENT THERMAL CONDUCTIVITY ($BTU\text{-}IN/FT^2\text{-}HR\text{-}°F$) - THRU-THE-THICKNESS @ 1 ATM AND 1000°F	0.79	1.02	0.80	0.90	-
DIELECTRIC CONSTANT	1.13	1.07	1.22	1.27	2.11
LOSS TANGENT	0.0004	0.0005	0.0010	0.0011	0.0017

* AVERAGE VALUES AT 70°F UNLESS NOTED

HTP: WHAT'S HAPPENED SINCE 1984

1985

- HTP-16-22 GOES INTO PRODUCTION: 200+ BILLETS, 13x13x5 INCHES
- INTEGRAL MULTIPLE DENSITY HTP DEVELOPED
- HTP-60 PROVEN AS A HIGH TEMPERATURE RADOME

1986-1987

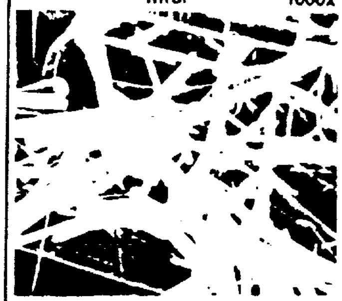
- HTP-6-22 ENTERS PRODUCTION: LOAD-BEARING CRYOGENIC INSULATOR
200 BILLETS FABRICATED, 13X13X5-INCHES.
- VACUUM FORMING FACILITY: LARGE, NEAR-NET SHAPE HTP PARTS
- BOROSILICATE GLASS COATING MODIFIED TO MATCH HTP-12-35 THERMAL EXPANSION

1988

- RCG COATED INTEGRAL MULTIPLE DENSITY HTP PASSES RAIN EROSION TESTS
- HTP-6 PASSES 2700°F ARC-JET PLASMA TEST
- HTP-6 USED FOR CRYOGENIC ULLAGE CONTROL
- FIRST LASER-MACHINED HTP PARTS

COMPARISON OF MICROSTRUCTURES

HRSI 1000X

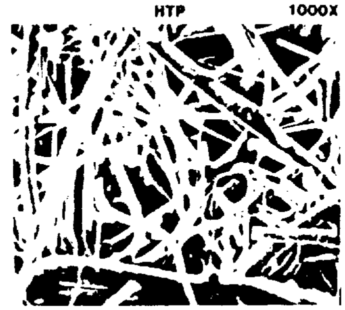


- HTP FORMULATION AND PROCESSING ACHIEVES CONTROLLED MICROSTRUCTURE OF LI-900 AND BORON FUSION MECHANISM OF FRCI WITHOUT LOSS OF SUB-MICRON SILICA FIBER.

FRCI 1000X

- SELECTIVE FIBER RATIOS ALLOW CTE CONTROL INDEPENDENT OF BORON FUSION REACTIVITY.

HTP 1000X



- HTP TECHNOLOGY
  - TAILOR FIBER COMPOSITES
    - FORMULATION
    - FIBER ORIENTATION
  - CONTROLLED FUSION
    - BINDER
    - FLUX
  - ADAPTABLE TO OTHER PROCESSING METHODS COMMON IN FIBER PRODUCTS INDUSTRY

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10.3.14 Entry Systems Technology Assessment
by Archie Gay, General Dynamics Space Systems Division