Film Adhesives EFA 1753 and EFA-1752

(Structural Adhesives for Honeycomb Sandwich Fabrication)

Vikram Sarabhai Space Centre of Indian Space Research Organization has developed an epoxy film adhesive; EFA-1753 (300 GSM) and EFA-1752 (200 GSM) (in the form of continuous film) that cures at elevated temperature 175 °C for 1 h and they possess good adhesive strength and filleting properties. Light-weight honeycomb sandwich structures are extensively made using epoxy film adhesives with precisely controlled glue line thickness. Film adhesive can also be used by shipping and boat manufacturing industries also, for fabrication of sandwich structures and other composite assemblies.

Salient Features

- One-component, heat curable, toughened, high strength polymeric film adhesive.
- Heat curable (175°C for 1 h).
- Ensures filleting during curing, leading to very high bond strength in honeycomb sandwich.
- Space qualified.

Properties	Values
Areal density, GSM [Two types]	300±20 (EFA 1753) and 200±20 (EFA 1752)
Lap shear strength at 25°C (Al/Al), MPa	≥ 25
LSS at 130°C (Al/Al), MPa	≥ 12
LSS at -196°C(Al/Al), MPa	≥ 25
Honeycomb Flat wise tensile strength at 25°C, MPa	≥ 4
TML, %	≤ 1.0
CVCM, %	≤ 0.1

Technology transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs/industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

EPG 2601[M]

ADBOND EPG 2601M is formulated for bonding of honeycomb structures and capable of working under harsh space environments such as thermo-vacuum, thermal cycling, radiation etc. The main feature of this material is that it is thermally conducting and can retain its property at very low temperatures.

ADBOND EPG 2601M is a two part chemically reactive epoxy structural adhesive system consists of polyether modified epoxide resin, filler, rheological additive and colorant in the resin part, curing agent and accelerator in the hardener part. Cure is achieved by mixing the hardener part with resin part packed separately.

Some of the specialties of this material are minimum cure shrinkage combined with excellent adhesion, superior strength & toughness and low out gassing Typical properties/ characteristics

1	Color& consistency	Part A: Black, viscous resin, Part B: Brownish yellow
2	Viscosity (ps)	1000 to 4000
3	Sp. Gravity	1.65
4	Hardness (Shore D)	≥70
5	Lap shear strength (ksc) on Alumina at RT	120
6	Thermal conductivity (cal/cm/C/s)	$8^* 10^{-4}$
7	Coeft. of thermal expansion (/ oC)	3.5×10^{-5} – 10×10^{-5}
8	Volume Resistivity (ohm- cm)	$6^* 10^{12}$
9	Out gassing	
10	- TML (%)	1
11	- CVCM (%)	0.05
12	Service temperature	93 K to 373 K

Technology transfer from ISRO

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Rocasin

Rocket case insulation (ROCASIN) is a rubber compound based on the copolymer of acrylonitrile and polybutadiene known as NBR as per ASTM code. It is specially formulated to serve as a rocket motor case insulation having compatibility to propellant grain system. This has, high strength and strain capability and excellent thermal erosion resistance properties as would be desirable in any rocket motor insulation compound. Due to its low coefficient of gas diffusion, ROCASIN finds application as impermeable liners for FRP vessels holding nitrogen at high pressures. Other than sheet form, it finds use as moulded elastomeric flight components like igniter head end insulation, igniter nozzle liners, convergent liners, insulation boot, thermal boot, head end domes etc.

Applications

Can be used as a thermal insulation barrier layer for various equipments and systems wherever required.

Technology Transfer from ISRO

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5-Aminoterazole Nitrate

5-Aminotetrazole Nitrate (ATN) is a nitrogen rich oxidizer having the empirical formula CH4N6O3. An ingredient in gas generating solid propellant/charge composition. Burns faster and yields only non--corrosive gases free from HCl upon combustion. Thus making it ideal ingredient for Green Propellant.

Salient Features

- Nitrogen rich energetic oxidizer.
- Non hygroscopic in nature, hence alternate to Ammonium nitrate. Non HCl producing, good alternate to Ammonium Perchlorate.
- Acts as monopropellant.
- Compositions made out of ATN are fast burning.

Properties

Sl. no.	Properties of Atn	
1.	Colour	Colourless
2.	State	Crystalline powder
3.	Molecular Weight	148
4.	N-content (%)	56.7
5.	O-content (%)	32.4
6.	Heat output (cal/g)	1000±50
7.	Friction sensitivity (kgf)	> 36
8.	Impact sensitivity (kg.cm)	> 50
9.	Decomposition Temperature (oC)	175

Applications

- Can be used as energetic material in power cartridges.
- Can be used as oxidizer for making cool gas generating propellant.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

BMT- Ceramics

Dielectric ceramics find application as resonators (DR), substrates, antennas etc. in terrestrial as well as space communications systems ranging from UHF to mm-band frequencies. Their advantages are small size, light weight, temperature stability etc. Globally, a few materials have been manufactured for use in specific range of microwavespectrum.

Barium Magnesium Tantalite (BMT) is a typical perovskite ceramic, which is widely used in oscillators, multiplexers, filters etc above 10GHz in satellite and terrestrial microwave communication system. The technology has been developed in collaboration with

CMET, Thrissur. This dielectric, coming in the medium permittivity materials, possesses extremely low dielectric loss (tanδ~10-5) in microwave and millimeter wave frequency ranges.

This indigenously developed BMT is equivalent to 8700 series of Trans-Tech and D series of Murata that are used in 10-25 GHz range.

Typical properties

1	Bulk density (Target)	< 8 g/cm3
	(Achieved)	7.45 ±0.1 g/cm3
	Dielectric constant (εr)(Target)	25±3
	(Achieved)	24±1
2	Unloaded Q-factor (Qu)(Target)	15,000 @ 5.6 GHz
	(Achieved)	28,000 @ 5.6 GHz
	(Achieved)	22,000 @ 7.5 GHz
3	Unloaded Q-factor (Qu)(Target)	8,000 @ 10 GHz
	(Achieved)	20,000 @ 10 GHz
4	Temp. coeff. of freq. (τf)(Target)	< 7 ppm/K
	(Achieved)	6 ±1.0 ppm/K

VSSC is willing to offer the technology of BMT ceramics to eligible interested parties who are in the field of manufacturing similar items

Interested entrepreneurs are requested to contact the address given below with all relevant particulars regarding their line of current activity, infrastructure available, market assessment of the product, financial arrangements made, turn over and sales of their products for the past years and a copy of their latest annual report.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

DK 18- Ceramics

DK-18 is a MgTiO3 based ceramic, which is widely used as Patch Antenna substrates in Satellite and GPS communication systems. This dielectric, coming in the medium permittivity materials, possesses extremely low dielectric loss (tanδ~10-5) in microwave frequency ranges.

Electronic ceramics with high permittivity (□r>20) and low dielectric loss (tan□<10±3) have a number of applications in microwave devices like filters, oscillators, multiplexers etc in terrestrial as well as Space communications systems ranging from UHF to mm- band frequencies. In such devices, it is desirable that the ceramics have high □r to confine the electromagnetic waves near them. However, when applications like antennas and substrates are considered, 10<□r<20 is desirable for better radiation field outside the ceramic and size reduction. Their advantages are small size, light weight, temperature stability etc. Globally, a few materials have been manufactured for use in specific range of microwave spectrum. This indigenously developed DK18 is equivalent to Kyocera SM200 and P series of Murata that are used as substrates for GPS antennas.

Since the process temperatures are much lower than the tantalates and raw material cost is also low, the production cost of this ceramics is much lower compared to other similar products in the market. This ceramic also has the added advantage of having a low ρ, only about a half that of tantalates.

Typical properties:

Appe arance	Light cream
Bulk density (g/cc)	3.7±0.15
Open Porosity	Nil
Closed Porosity	<2%
Resistivity (Ω.cm)	10 13
Coeff. of Thermal Expansion (10−6/K)	9.2
Dielectric constant (εr)	19±1.5
Quality factor (Qu @ GHz)	12,000 (6.5)
Loss factor (tanδ, 10−5)	8.4
Temp. coeff. of frequency (τf, ppm/K)	0 ± 5
TE01□ resonator size at 5 GHz (D=2L, mm)	14

VSSC is willing to offer the technology of DK18 ceramics to eligible interested parties who are in the field of manufacturing similar items

Interested entrepreneurs are requested to contact the address given below with all relevant particulars regarding their line of current activity, infrastructure available, market assessment of the product, financial arrangements made, turn over and sales of their products for the past years and a copy of their latest annual report.

High-Permittivity Ceramic (DK36) For R F Applications

Dielectric ceramics with high permittivity (r>10) and low dielectric loss (tan <10 3) have a number of applications in microwave devices. The process technology for realizing DK36 ceramics with dielectric constant r 36-39 has been established. This is similar to imported ceramics like TE36, MDR36, SB350 and 8300 and useful for microwave filters, oscillators etc. The process technology adopted is advanced solid state ceramic route. The ceramics can be fired to full density below 1350°C. DK36 ceramics can find use in devices like filters, oscillators, diplexers, patch antennas etc. The nominal properties of DK36 ceramic are given below.

Bulk density (g/cc)	4.35 – 4.55
Coeff. of thermal expansion (10^{-6}/K)	8.8 – 9.2
Dielectric constant (εr)	36 – 38
Unloaded Quality factor (Qu @ 4 GHz)	6,000 – 8,000
Loss factor ($\tan\delta$, 10^{-4}) @ 4 GHz	1.25 – 1.5
Temp. coeff. of frequency (τf, ppm/K)	2 – 7

DK36 ceramics can find use as resonators in filters, oscillators etc. and substrates for patch antennas.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Cryo Adhesive EPIFII-9661

(Used As an Adhesive for The End Fitting Reinforcement of Polyimide Pipelines & As A Matrix Resin for The Kevlar Composite Over Wrap on Lox Feed Polyimide Pipelines)

Adhesive EPIFIL-9661 is three-part room temperature curing adhesive. Part A is a urethane modified epoxy resin, prepared by the co-reaction of epoxy, polyol and isocyanate. Part-B is a mixture of amine hardeners and Part-C is a Silane Coupling agent. This adhesive system presently finds different applications such as matrix resin for Aramid (Kevlar) composite over-wrap

on Liquid Oxygen (LOX) feed polyimide pipelines, for reinforcing the metallic end fittings made of SS-321 and the fiber glass tape to the LOX and LH2 polyimide pipe lines and as a coating material for glass phenolic composite which perform as a thermal isolator between the mix ratio controller and (MRC)/apparent velocity regulator (AVR) valve and the motor in the cryogenic stages of GSLV.

Salient Features

- Three-component, RT curable, toughened, low viscous polymer liquid adhesive
- Increased pot life [up to approx. 3hrs.]
- Good bond ability with PI film as well as SS materials
- Flight qualified

Properties	Values
Epoxy value (equivalents/kg) of Part-A	3.5 – 4.5
Viscosity at 30 ^{0}C (cps) of Part-A	450 –700
Amine Value (mg KOH/g) of Part-B	340-400
Viscosity at 30 ^{0}C (cps) of Part-B	350-500
Pot life at 25 ^{0}C (minutes)	180 (minimum
Hardness Shore D (after 7 days cure at RT (30±5 ^{0}C)	65 (minimum)
Lap Shear Strength (PI-PI on Aluminum alloy back up) at RT (at 25 ^{0}C), (in kg/cm^2)	40 (minimum)
Lap Shear Strength (PI-Fiber glass tape on SS-321 bac up) at RT (air-conditioned room, at 25^{0}C), (in kg/cm^2)	40 (minimum)

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

Matrix resin for composite application EPY PEEKTOH

Indian Space Research Organization at its Vikram Sarabhai Space Centre (VSSC) has developed EPY PEEKTOH resin which is an elevated temperature curing high performance epoxy resin matrix suitable for composite applications. The specialty of the formulation is good mechanical properties, high glass transition temperature and low outgassing properties. This is an ideal matrix resin for processing thick carbon fabric laminates (≥ 30 mm) without any micro cracks and delamination.

Salient Features

- Elevated temperature curing
- Very good mechanical properties
- High glass transition temperature
- Low outgassing properties
- Suitable viscosity at 60-70°C for processing two dimensional fabric laminates

Properties

Volatile matter at65°C for 5 hours	:	0.04
maximum Viscosity at 65°C (poise)	:	60-80
Shore D hardness at 30°C	:	> 85
Specific gravityat 30°C	:	1.1 –1.4
Flexural strength at 25°C(MPa)	:	110 –120
TML-WVR (%)	:	≤ 1.0
CVCM (%)	:	≤ 0.1
Glass transition temperature (°C)	:	210

Applications

EPY PEEKTOH resin is mainly used for fabrication of composite YOKE panel hinge insert for satellites.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

NewSpace India Limited (NSIL)
Email: contact-nsil@isro.gov.in

Guanidinium Azotetrazolate (GZT)

Guanidinium Azotetrazolate (GZT) is a nitrogen rich, carbon poor stable organic compound having the empirical formula (C4H12N16). The decomposition products of GZT are mostly gases consisting of element alnitrogenas the major product. Since the heat of formation of nitrogen is zero, the decomposition products of GZT are inherently cool and inert. GZT is highly insensitive to mechanical and thermal stimuli and is found as a good fuel additive for gas generator compositions and a good alternate to sodium azide, which is more hazardous to environment.

Salient Features

- Nitrogen rich organic energetic fuel.
- Produces cool nitrogen gases on decomposition. Insensitive to mechanical and thermal stimuli.
- Good alternate to sodium azide used in gas generators.
- Versatile energetic compositions can be made by adjusting oxygen balance.

Properties

Sl. no.	Properties of GZt	
1.	Colour	Yellow
2.	State	Amorphous solid
3.	Molecular Weight	284
4.	N-content (%)	78.9
5.	C-content (%)	16.9
6.	Heat output (cal/g)	360 ± 60
7.	Friction sensitivity (kgf)	> 36
8.	Impact sensitivity (kg.cm)	> 320
9.	Decomposition Temperature (°C)	252 ± 6

Applications

- Fuel for making cool composite gas generators.
- Fuel for making pyrotechnic charges for power cartridges.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

Polydimethylsilane (PDMS)

(Raw material for polycarbosilane, a precursor of silicon carbide)

Polydimethylsilane (PDMS) is a pre-ceramic polymer precursor developed by Indian Space Research Organisation at its Vikram Sarabhai Space Centre. PDMS finds use in the synthesis of polycarbosilane (PCS) – a well-known polymeric precursor for silicon carbide (SiC). PCS is prepared from PDMS by heating PDMS in an autoclave, or at normal pressure with a catalyst. PCS is a ceramic precursor useful in realizing C/SiC, C/C-SiC and SiC/SiC based thermo-structural components for re-usable launch vehicles, C/SiC turbine blades, and SiC fibers.

Salient Features

- Fine free flowing powder at room temperature.
- It can be stored in sealed polyethylene bags at room temperature, away from direct sunlight, and has long shelf life.
- PDMS is insoluble in water and other organic solvents such as Acetone, Cyclohexane, Ethyl Acetate, Toluene, Xylene.

Properties	Range
Appearance	White powder
Moisture content (by KF)	<1%
Silicon content (wt%)	42 – 48
Carbon content (wt%)	34 – 41
Hydrogen content (wt%)	9 – 12
Oxygen content (wt%)	<5

Technology Transfer from ISRO

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Phenolic Resin (PF-106)

Phenolic resin (PF-106) is a resol type thermosetting phenol- formaldehyde polymer used for processing high temperature resistant ablative materials such as carbon phenolic and silica phenolic composites. PF 106 is a high temperature curing resin which has excellent ablative properties and char strength.

The production of PF-106 involves the following steps:

1. Melting of Phenol.
2. Charging of formalin and molten phenol into the reactor in the desired mole ratio.
3. Addition of catalyst.
4. Condensation polymerization of phenol and formalin.
5. Neutralization of reaction mixture with acid.
6. Settling of reaction mixture.
7. Removal of water of reaction and salt.
8. Drying of resin to remove traces of water and other volatiles.
9. Addition of required quantity of alcohol
10. Filtration and product packing.
11. Storage

Salient Features

Appearance	: Yellowish brown to dark brown liquid
Viscosity	: 150 -250
Specific gravity	: 1.12 -1.16
Total solid content	: 60–65 for ½ hr. (%)
Freephenol (%)	: 6 max.
Free formalin (%)	: 3 max.
Point of trouble	: 6–10 ml of water of resin

Storage conditions

Temperature	: 10-20 °C
Shelf Life	: 3 months

Applications

The resin finds application as binder for high temperature resistant ablative composites materials such as carbon phenolic, silicaphenolic and epoxy phenolic systems.

Technology Transfer from ISRO

ISRO is willing to offer the know-how of this technology to suitable entrepreneurs/industries in India. Capable manufacturing industries interested in acquiring this know-how may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

Phenolic Matrix Resin (PF-108)

Vikram Sarabhai Space Centre has developed different types of resins catering to specific applications in Launch Vehicles and Satellites. These materials may also find various industrial applications such as bonding, sealing, coating, potting, laminating, molding,etc.

PF-108 is a special grade liquid phenolic matrix resin which is used as a precursor for production of silica phenolic throat inserts for the liquid engines of ISRO launch vehicles.

Operational steps for synthesising PF 108

1. Melting of Phenol.
2. Charging of formalin and molten phenol into the reactor in the desired mole ratio.
3. Addition of catalyst.
4. Condensation polymerization of phenol and formalin.
5. Neutralization of reaction mixture with acid to desired pH.
6. Settling of reaction mixture
7. Removal of water of reaction and sodium salt by decantation.
8. Vacuum drying of resin to remove the final traces of water and other volatiles.

Major equipments needed are phenol melting vessel and reaction vessel.

1. Melting vessel for phenol melting.
2. Jacketed SS reactor fitted with cooling coils, stirrer, motor, condenser and receiver for polymerisation and drying. The reactor is suitably linked with the utility system during operation. It is also equipped with load cell, vacuum systems, temp controllers, cooling systems pressure/vacuum gauges, etc.
3. Decanter vessel for removal of water.
4. Water jet ejector for vacuum.

PF 108 Product Specifications

Appearance	: Yellowish brown to dark brown liquid
Viscosity at 30 DC	: 400 – 600
cps Specific gravity at 30 DC	: 1.18 – 1.20
Refractive Index at 30 DC	: 1.570 – 1.575
Total solids	: 72 –75%
Free phenol (%)	: 18 –22%
Free formalin (%)	: 0.5% (max.)
Ash Contact	: 0.5% (max.)
Point of trouble	: 13 – 15.5 ml of water/10 ml solution
pH (5%solution)	: 7.3 –7.8
Sodium Content	: 0.4% (max.)
Water Content	: 14%
(max.) Storage conditions	
Temperature	: <15°C
ShelfLife	: 3 months (in above condition)

Technology Transfer from ISRO

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RTV Silicone Single Part Adhesive, Silcem R9

Indian Space Research Organisation at its Vikram Sarabhai Space Centre (VSSC) has developed a room temperature curable single part adhesive, SILCEM R9 based on polysiloxane for multipurpose bonding applications. This system contains polysiloxane, fillers and curing components mixed under dehumidified conditions and filled inside squeeze tubes for ready – to - use condition. The adhesive can be squeezed out from the tube and very conveniently applied directly on the substrates and bonded. On exposure to humid air, it hardens by itself to a solid rubbery mass.

Salient Features

- Single part siloxane-based system containing fillers and special curing components.
- Room temperature curable on exposure to humid air. Safe inside the tube
- Easy to apply. Simply squeeze andapply
- Supplied in ready-to -use squeeze tubes of 100-150 g capacity
- Meets the aerospace quality standards

Typical Properties

Density (cured product) g/cc	: 1.25 - 1.35
Tensile strength @RTksc	: 22 - 42
Tensile strength@120°Cksc	: 18 - 35
Elongation@RT%	: 225 - 350
Elongation@120°C%	: 110 - 300
Lap shear strength (Al-Al) @RTksc	: 13 - 30
Lap shear strength(Al-Al) @120°Cksc	: 13 - 28
Thermal conductivity at 100°CW/m.K	: 0.25 - 0.50
Specific heat at 100°C,J/g/°C	: 1.0 - 2.0
Hardness, ShoreA	: 40 - 55

Applications

This adhesive finds large societal applications for use as sealants to provide leak proof joints. This material can also be used as a gap filler material where high temperatures are experienced. Being a water repellant adhesive material, the bonded substrates maintain good strength even under wet conditions. It finds applications as a general-purpose adhesive for bonding / sealing materials like wood, metals, leathers, foams etc.

Technology Transfer from ISRO

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Silica Fibres

Indian Space Research Organisation at its Vikram Sarabhai Space Centre (VSSC) has developed a new technology for developing silica fibres by sol-gel process. The fibres can be used for high temperature insulation up to 1500°C.

The low temperature process (400°C) adopted for developing silica fibres is more economical than the conventional technologies and can give high purity fine fibres. In addition, the fibres are hollow as well, thereby improving the insulation property further.

Fibre Specifications:

- Composition : Silica (99.5%)
- Diameter : 1 - 20 µ
- Length : 5 - 20 mm
- Aspect ratio : 500 - 20,000
- Morphology : Amorphous (1400 °C)
- Heat Treatment : Up to 1400 °C

The technology of developing silica fibres is available for transfer to entrepreneurs working in a similar field. Interested entrepreneurs are requested to contact the address given below with relevant particulars regarding their line of current activity, infrastructure available, market assessment of the product, financial arrangements made and turn over and sales of their products for the past years.

Technology Transfer from ISRO

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Silica Granules

Indian Space Research Organisation at its Vikram Sarabhai Space Centre (VSSC) has developed a new technology for developing silica granules of fine sizes. The granules are produced from aero-gel chips and subsequently firing using microwaves. They can be used for high temperature insulation up to 1250°C. Since they are hollow and weigh very less, they can also be used as filler materials for paints, polymer/ metal and ceramic matrices to reduce density and improve thermal properties.

Product specifications:

- Product Composition : SiO_2 (99.5%)
- Diameter : <2 mm
- Bulk Density : <0.35 g/cc
- Morphology : Hollow, fibrous & Amorphous

The technology of developing silica granules is available for transfer to entrepreneurs working in a similar field. Interested entrepreneurs are requested to contact the address given below with relevant particulars regarding their line of current activity, infrastructure available, market assessment of the product, financial arrangements made and turn over and sales of their products for the past years.

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Silica Aerogel by Ambient Pressure Drying Method

Indian Space Research Organization at its Vikram Sarabhai Space Centre (VSSC) has developed hydrophobic silica aerogel in granular/powder form by a simple and cost-effective ambient pressure drying process.

SALIENT FEATURES

Silica aerogels are exotic materials with a unique combination of properties.

As a virtue of high porosity and extremely small pores, aerogels exhibit extremely low thermal conductivity, making them a 'super-insulator'. In addition to thermal insulation, aerogels are also superior sound insulators and they possess very low refractive index and an excellent dielectric medium which finds numerous applications.

VSSC has developed a conventional drying technology at ambient pressure to get rid of the solvents within the gel. This makes the process amenable to bulk-production in a cost-effective manner. The solvents used in the production can be recycled using this technology, thus making the process environmentally friendly.

PROPERTY	VALUE ACHIEVED
Bulk density, g/cm^3	0.06 – 0.20
BET surface area, m^2/g	400 – 1000
Mean pore size, nm	10 – 40
Percentage porosity	>90 %
Contact Angle	>130°
Thermal conductivity, W/mK (RT, 1 atm)	<0.05
Dielectric constant (@ 1 MHz)	1 – 1.4

APPLICATIONS

- Bulk-fill insulation (thermal and acoustic).
- As fillers in concrete, cement, paints, adhesives, foams, ablatives, rubber, coatingsetc. fordecreasing density, thermal conductivity & flammability, and increasing the heat resistance of the material.
- As precursors to produce aerogel based sheets that can be used as foot- insoles, boot / jacket insulation or as winter / Arctic apparel at areas having extremely cold climate.
- In window glazing as insulator between glass/ polyacrylate panels, which allow natural light but not heat (for hot places-where A/C is used), and in trapping heat (in cold places), which allow in significant electricity and money saving.
- As fillers in cosmetic items such as sunscreen creams, foundation, toothpastes etc.
- Carrier for drug delivery.
- Vibration/acoustic damping materials.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Silica Aerogel Based Composite Sheet

Indian Space Research Organization at its Vikram Sarabhai Space Centre (VSSC) has developed hydrophobic silica aerogel by a simple and cost- effective ambient pressure drying process. Using the developed aerogel powders, flexible, hydrophobic aerogel sheets have also been developed.

Salient Features

The composite sheets are made from Silica aerogel which is an exotic materials with a unique combination of properties. Low density and thermal conductivity coupled with high porosity and surface area make aerogel a 'super-insulator'. However, their cost, brittle and friable nature has limited its use to specialized applications.

VSSC/ISRO has developed the technology to develop flexible and hydrophobic sheets from the aerogel powder which expands a gamut of applications, making it suitable to be used as an ideal replacement for conventional insulation. The lab scale technology developed has been demonstrated in thermal protection system since PSLV C39.

Aerogel sheets are ideal to be used as wrap around insulation, which can be cut to desired size and integrated. Aerogel sheets developed in ISRO on the other hand are non-dusting and are easy to handle.

Properties

PROPERTY	VALUE ACHIEVED
Areal density, g/m^2 (gsm)	150 – 500
Thickness, mm	0.6 – 10
Thermal Conductivity (@ RT), W/mK	~0.03 (TPS method)
Dielectric Constant (@ 10 GHz)	1.3 – 1.6

Applications

- Wrap around insulation for use in pipelines/ feed-lines etc.
- For use as insulating layer in foot- insoles, boot / jacket insulation or as winter / Arctic apparel at areas having extremely cold climate.
- As low dielectric constant substrates over which circuits can be printed.
- Cryogenic thermal insulation.
- In multi-layer insulation.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Waterproofing Compound RWPC-03

RWPC-03 is a waterproofing compound developed by VSSC for the waterproofing of silica tiles and silica felt/ fabric based flexible insulations. It is an alkoxysilane based system, processed by controlled hydrolysis of siloxanes. This is an environment friendly method and imparts efficient waterproofing of the system. The treatment involves spraying the aqueous solution of an organo-polysiloxane waterproofing compound on the substrate (preferably glass and silica based) and heating them to form a waterproofed article. In the case of silica tiles and silica felt/fabrics, water absorption could be brought down from 350% to <5% and <10% respectively using this compound. It is not a conventional surface coating method and makes both surface as well as bulk of the material water resistant.

Typical properties / characteristics:

Color and consistency	: Transparent liquid
Viscosity of water proofing compound	: <5cP
Weight increase due to water proofing	: 3% max by weight
Water absorption of water proofed silicatile	: <5 % by weight
Water absorption of water proofed flexible insulation	: <10% by weight

Applications

RWPC-03 can potentially be used as general purpose water proofing compound for silica based components including composites.

Technology Transfer from ISRO

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Sealant EPY 2121N

EPY 2121N is a two-part epoxy-amine based sealant containing mica filler which impart high insulation resistance. This castable compound is designed to have pourable consistency and long work life, which result in void free filling of the cavities. Cure is achieved by the application of heat and the sealant exhibits good high and low temperature service capability.

Typical Properties / characteristics:

PROPERTY	
Colour and consistency	Grey viscous liquid
Viscosity at 30°C (ps)	5000 – 10000
Pot life	>3 hours.
Epoxy value (eq./kg)	3 – 4.5
Cure	Ambient (25-35°C) / 18-24hrs followed by 60-65°C/5hrs
Lap shear strength on A1-A1 at RT	>100 ksc.

Technology Transfer From ISRO

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Adbond EPP-3521

ADBOND EPP 3521 is a rubber based adhesive system developed for mounting various electronic systems to the structural elements. It is having very good thermal conductivity with good electrical insulation property and also possess very low out gassing characteristics.

This is an elastomer modified epoxy system consisting of insulative oxide filler in high concentration with silane coupling agent to provide electrical insulation and thermal conductivity.

ADBOND EPP 3521 will find usage in electric/ electronic gadgets manufacturing areas where potting/ bonding with good thermal dissipation and electrical insulation are warranted.

Typical Properties / Characteristics:

PROPERTY	
Color & consistency	Black & pasty
Viscosity of the resin (ps)	700 to 8000
Sp. Gravity	1.8
Hardness (Shore D)	
Lap shear strength (ksc) on Alumina at RT	> 80
Thermal conductivity (cal/cm/C/s)	$1.04^{*} 10^{-3}$
Volume Resistivity (ohm-cm)	$1.5^{*} 10^{13}$
Out gassing - TML (%) - CVCM (%)	 < 1 ≤ 0.1
Cure	Ambient
Pot Life (min.)	45
Service temperature	223 K to 338 K

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Umbilical Pads

Umbilical pads are semi-rigid foams which are developed based on polyurethane (PU) polymeric systems having energy absorbing capabilities. These are integral skin foams that can be used for absorbing shock and impact energy hence they are used for controlling vibration and for acoustic insulation. These pads are semi flexible water blown foam system produced by the polymerization reaction between hydroxyl bearing polymeric compounds called polyols and di or polyisocyanates in the presence of catalysts.

Umbilical pads are designed to absorb impact energy of the separating umbilical lines used in launch vehicles. These foam pads of required size and dimensions are moulded with clamps at the corners for assembling the pads at required locations in the launch pad. These shock absorbing pads can also be utilized for transportation of electronic packages.

Technological Highlights of the product if any

1. Semi flexible and shock absorbing foam
2. RT curable
3. Can be moulded to the required shape and size

Typical Properties

Nature of foam	Semi-flexible PU foam with blue coloured fire-retardant coating
Dimensions	1200 mm x 1200 mm x 100 mm
Density (uncoated)	55 - 80 kg/m^3
Flame test with coating	Self-extinguishing within 5-6 sec
% Ball rebound with coating	20 - 30
Shelf life	5 years

Technology Transfer from ISRO

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Low Density Epdm Based Thermal Insulation

The technology offered is for a light weight/low density solid rocket motor thermal insulation material based on EPDM rubber. The rubber compound shall be processed in the form of sheets of required thicknesses by calendaring or extrusion. The sheets shall be used of insulation laying process following the same processing temperature and conditions as followed during NBR based systems. The material interface properties: rubber-to-metal and rubber-to-propellant match with conventional NBR based systems.

The advantage over the conventional NBR system is its 15% lower density values, resulting in lesser inert mass. Also, the thermal insulation capability is 10-15% better than elsewhere similar insulations.

The material also exhibits better aging resistance and low temperature characteristics. Other than in sheet form use, it finds utility as moulded elastomeric flight components like igniter head end insulation, igniter nozzle liners, convergent liners, insulation boot, thermal boot, head end domes etc.

Applications

- Can be used as a thermal insulation barrier layer for various equipment and systems wherever required.

Technology Transfer from ISRO

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Coating Compound EPY 1061

Vikram Sarabhai Space Centre has developed different types of adhesive compounds catering to specific applications in Launch Vehicles and Satellites. These materials may also find various industrial applications such as bonding, sealing, coating, potting, laminating, molding etc. The following are some of the new formulations tailored to meet specific requirements as adhesive, sealant, coating and potting compounds. These are derived from resins and different curing agent combinations, modified with various classes of materials such as flexibilizer, toughening agent, fillers, pigments, cure accelerators etc.

EPY1061 is an amidoamine modified epoxy-based system specially developed to protect the metal surfaces from corrosion in aqueous strontium perchlorate medium. This coating and sealing system consist of two main components Part A (resin) and Part B (hardener) and a third component Part C which is a solvent. Parts A, B and C are mixed in a specified ratio and sprayed into the metal surface using spray gun to get corrosion resistant coating. The coating adheres well to the metal substrate and reaches fully cured condition at room temperature in 72 hours

Typical Properties / characteristics:

PROPERTY	
Colour and consistency	Red coloured viscous liquid
Viscosity at 25 °C (cps)	20000-40000
Pot life/ Gel time	> 25 minutes.
Flow Time, Part A, B & C mixed	35 – 50 seconds.
Cure	Ambient
Lap shear strength on Al-Al at RT	> 90 ksc.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Benzoxazine Polymer

Indian Space Research Organisation at its Vikram Sarabhai Space Centre has developed Benzoxazine Polymer, a matrix resin suitable for thermal insulations, adhesive formulations and encapsulant in PCB industry.

Polybenzoxazine is a suitable candidate matrix resin for high density ablative composites and also for light weight foam composites in aerospace applications due to excellent thermal and thermo-oxidative stability, high char yield, good chemical inertness, abrasion resistance and flame retardancy. It also finds application as an encapsulant in electronic industry.

Salient Features

- Excellent flame retardancy
- Easily processable (solventless process, moderate temperature)
- Good thermal stability

Typical Properties / characteristics:

Raw materials	Bisphenol A, Aniline and Para-Formaldehyde
Method	Solventless process
Reaction temperature:	120 °C
Product appearance	Yellowish orange powder
Solubility	Soluble in acetone, chloroform etc
Curing temperature:	210 °C/3 hrs
Polymerization temperature (°C)	200/ 2 hours
Thermal stability	>250 °C.
Shelf life	1 year
Storage	Ambient temperature, moisture-free environment
Approximate Production cost	Rs.1000/kg

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs /industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below.

Compensated Alumina (Comal) For Electronic Applications

Alumina (Al2O3) is a versatile ceramic and a 'workhorse' ceramic that finds place in a wide range of applications— mechanical, thermal, electrical, electronic and even optic. Indian industries are well- versed in alumina products for applications like refractory bricks, insulator tubes, crucibles etc. But, alumina components for electronic and similar high- tech applications are still imported. The drawback of pure alumina for electronic applications is the large temperature-coefficient of relative permittivity. Currently imported alumina ceramics suffer from high drift of dielectric constant with temperature and need firing temperature above 1600°C. But, the compensated alumina (ComAl), developed by VSSC, has near-zero temperature coefficient and can be sintered at ≤1475°C.

The ceramic has alumina as major content and a couple of additives and dopants. The powder of ComAl can be suitably processed further for making bulk products as per requirement. Bulk green bodies can be fired at ≤1475°C for less than 2h to get sintered ceramic. Sintered products can be polished, sliced or cut or machined for various applications. Typical properties of bulk ceramics are shown below

Firing temperature(°C)	1450 – 1475
Bulk density (g/cc)	3.9 ± 0.1
Resistivity (Ω.cm)	>109
Coeff. of Thermal Expansion (10^{-6}/K)	7 – 7.2
Thermal conductivity (W/m.K)	24 – 30
Dielectric constant (er) @ 5GHz	11 – 12
Loss factor (tand, 10^{-5}) @ 6 GHz	< 7
Qu of resonator @ 12GHz	> 10,000
Temp. coeff. of frequency (τf, ppm/K)	0 ± 5

APPLICATION AREAS:

ComAl ceramics can replace conventional alumina ceramics in various electrical, electronic and RF applications.

VSSC is willing to offer the technology of ComAl to eligible interested parties who are in the field of manufacturing similar items

Interested entrepreneurs are requested to contact the address given below with all relevant particulars regarding their line of current activity, infrastructure available, market assessment of the product, financial arrangements made, turn over and sales of their products for the past years and a copy of their latest annual report.

Technology Transfer from ISRO

ISRO is willing to offer the knowhow of this technology to suitable entrepreneurs / industries in India. Capable manufacturing industries interested in acquiring this knowhow may write with details of their present activities, requirements and plans for implementation, infrastructure and technical expertise available with them, their own market assessment, if any, and plans for diversification to the address given below:

Silicone Polymer Based Low Density Syntactic Foam TPS, SSF P-70

SSF P-70 is a low density thermal protection system based on silicone polymer, with microballoon and other fillers as compounding ingredients. This TPS is room temperature curable and can be applied by brushing and spraying techniques. The remarkable features of this system include lower density of 0.38 g/cc, lower thermal conductivity, high specific heat, good ageing resistance and compatibility with wide variety of substrates. Indian Space Research Organisation (ISRO) at its Vikram Sarabhai Space Centre (VSSC) has developed a technology for processing and application of different types of silicone polymer based thermal protection systems with tailored properties to meet various mission/ application requirements.

The processing involves incorporation of selected quality fillers and ingredients in specific type of silicone polymer resin and use of suitable curatives to achieve desired thermo-physical properties.

Salient Features

- Simplified and cost effective technology for processing premium quality thermal protection system.
- Room temperature curable.
- Flexibility with respect to application procedure such as spraying and brushing.
- Compatibility with wide variety of substrates including metals, composites etc.
- Excellent ageing behaviour, making it suitable for long term application with no deterioration of properties for more than 2 years.

Applications

- Useful for light weight, high quality thermal protection system for temperatures up to 3000C direct exposure with reasonable stability and capability to retain properties. The system also has good aging characteristics. The system can be applied to desired thickness depending upon the thermal environment envisaged. Reasonable mechanical strength and adhesive properties with large number of substrates has been demonstrated by the system. Ability to retain properties at temperatures up to 150 0C and low temperature flexibility are other highlights of the system owing to the low glass transition characteristics associated with silicone polymers.
- The product can be used for thermal protection application for protecting rocket hardware form aerodynamic heating where light weight TPS is required and also as moisture / water impermeable coatings.
- The system can be tailored for use as coating on metal substrates for outdoor use.

Technology Transfer from ISRO

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DK65 Ceramic for Microwave Applications

DK65 ceramic is a type of dielectric ceramic with high relative permittivity or dielectric constant (εr ~65) and low dielectric loss ($\tan\delta$ $<10^{-3}$) at microwave frequencies. VSSC has developed this ceramic technology through conventional solid state route. The ceramics can be fired to full density by firing below 1400°C in air atmosphere furnaces. The ceramic has been successfully tested as dielectric resonators and as patch antenna in L-bands. Since this ceramic possesses very small drift in dielectric constant with temperature, it is useful for applications like dielectric resonator filters, substrates for GPS, NAVIC patch antennas, dielectric resonator antennas etc., in UHF to C-band of microwave frequencies.

The nominal properties of DK65 ceramic are given
below.

Bulk density (g/cc)	5.3- 5.5
Dielectric constant (er)	64 ± 2
Unloaded Quality factor (Qu @ 3 GHz)*	3200-3600
Loss factor (tand, 10^{-4}) @ 3 GHz	≤ 2.65
Temp. coeff. of frequency in 25-75°C (τf, ppm/K)*	0 ± 5

* Properties are obtained by testing in microwave frequency range by standard resonance method

Technology Transfer from ISRO

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Low Modulus Flex Seal Compound

Flex Nozzle Control (FNC) is one among the thrust vector control system used in solid rocket propulsion. The system enables the submerged nozzle to be vectored in all directions and to a limited angle, by an actuation system, as the nozzle is connected to the main motor through a flexible joint. The flex seal is made up of alternate layers of metallic shims and elastomeric pads. Natural rubber based elastomeric pads are found to be most suitable element for this application because of its easiness with which it can be formulated to give low shear modulus coupled with high shear strength. The method is further recommended for large size flex seals for bigger size boosters of ISRO.

The technology for realization of this low modulus flex seal rubber compound using Natural rubber, ISNR grade is offered for industrial application. The complete formulation, processing/compounding, process parameter selection, specimen preparation, property evaluation, storage and shelf life are detailed, for the developed material. The material exhibits excellent rubber to metal and rubber to carbon- carbon composite interface adhesion, enabling it for use as multilayer structural element and leak free joint.

Salient Features

- Low shear modulus
- High shear strength
- Amenable for extrusion, transfer and compression moulding processes
- Good rubber to metal and rubber to carbon epoxy composite interface property

Sl. no.	Properties of Low modulus flex seal compound	
1	Tensile strength, ksc	100 (Min)
2	Elongation at break, %	600 (Min)
3	Hardness, Shore A	40 (Max)
4	Shear strength, ksc	20 (Min)
5	Shear strain, %	700 (Min)
6	Shear modulus, ksc @ 3.57 ksc shear stress	1.6-2.0
7	Compression set @ 70degC/22hrs, %	40 (Max)

Applications

- Submerged flex nozzle vectoring unit
- Anti-vibration structural element

Technology Transfer from ISRO

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NITI Based Shape Memory Alloys

Shape Memory Alloys (SMA's) are metallic materials, which have the ability to return to a predetermined shape when heated. The most common Shape Memory Metallic Material is an alloy of Nickel and Titanium called Nitinol. Indian Space Research Organisation (ISRO) at Vikram Sarabhai Space Centre (VSSC) has developed a technology for processing NiTi based Shape Memory Alloys of uniform homogeneity with good control on deleterious impurities like Carbon, Nitrogen and Oxygen contamination.

The method consists of materials arrangement inside graphite crucible, melting under argon atmosphere and finally casting.

Salient Features

- Simplified and Cost effective technology for processing premium quality billets in NiTi base SMA's and other reactive alloys
- Homogeneous product with excellent control in impurities
- Achieves economy in cost and labour and saves time by eliminating the repeated vacuum arc remelting
- Unique way of materials arrangement in the high-density graphite crucible to reduce the contamination of the NiTi melt from the crucible
- Special tailor-made vacuum induction facility for controlling carbon and oxygen contamination in making NiTi SMA's

Applications

- Useful in economical processing of high quality cast billets in NiTi SMA's with low carbon, nitrogen, hydrogen and oxygen contamination. These billets can be used to realize wrought products like Plates, Sheets, Foils, Wires, Sleeves, Forged, Rolled and extruded products through further mechanical working. Inclusion content in the billets processed through this technique is very low; hence very thin wires can be drawn without much problem from extruded rods processed from these billets.
- The products can be used for realization of collapsible antennas, collars for separation systems, couplings, stepper drive mechanism to drive flaps of satellites, etc.
- SMA's have high potential for use in biomedical industries as Bone Plates, Stents, Orthodontic Wires etc.

Technology Transfer from ISRO

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Ceramic Foam (HTFOAM-1500) by Direct Foaming Technique

HTFOAM-1500 are ceramic foams Silicon carbide (SiC)/Silicon Oxycarbide foam (SiOC) made by direct foaming technique. HTFOAM-1500 has very high operational temperature capability of 1500°C under oxidation atmosphere. The light weight ceramic foam possesses both open and closed cells with good strut density and high compressive strength. They have very low thermal conductivities and hence suitable for various applications viz., thermal insulators, micro-meteoroid and orbital debris (MMOD) shield, electromagnetic shielding and as CMC based sandwich constructions for internal multiscreen applications.

Salient Features

- Ceramic foam (SiC) foam with temperature capability of 1500°C under oxidizing atmosphere.
- Open cell porosity, closed cell porosity, strut thickness can be optimized by varying the processing parameters.
- Compressive strength and thermal conductivity can be optimized by varying the processing parameters and polymer composition.

Properties	Values
Bulk density (g/cc)	0.23-0.35
Total porosity (%)	80-95
Open porosity (%)	20-35
Closed porosity (%)	65-80
Compressive strength (MPa)	0.2-3.0
Thermal conductivity (W/mK) at RT	0.1-0.2

Technology Transfer from ISRO

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SiC Foam Tile SICTILE-1650 by Replica Technique

SICTILE-1650 (in the form of tiles of 200x200x20 mm) is an open cell SiC foam tile formed by replica technique that has very high operational temperature capability of 1650°C under oxidation atmosphere. They possess good handling strength with 80-90% open cell porosity. Light-weight SiC foam based sandwich structures are used for thermal protection systems for aerospace applications. They can be used as volumetric absorbers in the generation of large amounts of electricity by concentrated solar power (CSP) technology. They can also be used as electromagnetic wave absorbing materials and porous burners.

Salient Features

- Open cell silicon carbide foam based tile with temperature capability of 1650°C under oxidizing atmosphere.
- Open cell porosity, pore size, strut thickness can be optimized by varying the processing conditions.
- Handling strength can be improved by varying the pore size and density.
- Thermal conductivity can be optimized by varying the processing parameters and density.

Properties	Values
Bulk density (g/cc)	0.3-0.8
Open porosity (%)	80-95
Compressive strength (MPa)	1-3
Thermal conductivity (W/mK) RT	0.1-0.3 (ρ= 0.15-0.2 g/cc)
Coefficient of thermal expansion (µm/°C) (RT-800°C)	0.5- 2

Technology Transfer from ISRO

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Strontium Perchlorate

Strontium Perchlorate is produced by various process operations like Crystallization of Sodium perchlorate (SPC) crystals, Production of Perchloric Acid, Purification of Perchloric Acid, Production of Strontium Perchlorate and Concentration of Strontium Perchlorate solution.

Properties

- Purity as Strontium perchlorate (w/w) : 68 ± 3%
- Colour and appearance : Clear straw coloured
- Specific gravity at 28 oC : 1.90 ± 0.01
- Viscosity at 28 oC : 12 ± 3 centi poise
- Acid value (mg of KOH/ g) : 0.6 (max)
- pH of 10% Solution : 4.5 - 6.0
- Chlorate as ClO3- : 0.25%
- Chloride as Cl- : 0.1%
- Suspended matter : Nil

Applications

Secondary injection thrust vector control in launch vehicles

Technology Transfer from ISRO

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High Density Sintered Silicon Carbide

Silicon carbide is widely used for high temperature applications. Due to its unique characteristics like excellent low density, high thermal shock resistance, oxidation resistance SiC based materials are also extensively used in optical systems due to low CTE and high thermal conductivity. However, due to the sintering difficulty of silicon carbide, it is difficult to obtain dense SiC. A process is developed through hot pressing procedure and using small quantity of sintering aids (<5wt%) to manufacture SIC with near theoretical density and excellent combination of mechanical and thermal properties.

The nominal properties of High density SiC ceramic are given below

Density, g/cc	3.22 (99.8% of theoretical)
Flexural strength, MPa	450
Compressive strength, GPa	1.9
Fracture toughness, MPa √m	4.5
Elastic modulus, GPa	350
Thermal conductivity, W/mK	>80
Specific heat, J/Kg/^{o}C	610
Coefficient of thermal expansion (RT to 500^{o}C), $^{o}C^{-1}$	< 2.5×10^{-6}
Electrical resistivity, Ω-cm	2.6×10^{9}

Technology Transfer from ISRO

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