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Design and Analysis of Thermo – Vibrational Effects on Space Re-Entry Wehicle

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Abstract- **Re-entry vehicle is the part of space craft that is designed to return through earth is atmosphere. It is built to intense heating during high velocity flight through the atmosphere and to protect the crew and/or instrument until it bring them safety to earth. Aero thermodynamic analysis plays a critical role in designing a vehicle for hypersonic flight. Accurate information on the vehicle aerodynamic along the descent trajectory allows one to understand the capsule performance and therefore increase the payload and reduce the heat shield thickness on the vehicle. one of the main concerns of the aerodynamics of planetary entry is the heating rate and damage that this may cause to the vehicle at hypersonic flight speed during the reentry large fraction of the kinetic energy will be converted into heat that effect the vehicle.**

In this project we do shock wave, thermal and structural analysis of re-entry vehicle by using CFD software and by comparing the analysis results with the result of aerogel material and we conclude the application of aerogel to withstand the aerodynamic heating for future heat ablative materials in re-entry vehicle.

INTRODUCTION

Atmospheric entry is the movement of an object from outer space into and through the gases of an atmosphere of a planet, dwarf planet, or natural satellite. There are two main types of atmospheric entry: Uncontrolled entry, such as the entry of astronomical objects, space debris, or bolides; and controlled entry (or) re-entry of a spacecraft capable of being navigated or following a predetermined course. Technologies and procedures allowing the controlled atmospheric entry, descent, and landing of spacecraft are collectively termed as EDL.

Atmospheric drag and aerodynamic heating can cause atmospheric breakup capable of completely disintegrating smaller objects. These forces may cause objects with lower compressive strength to explode.

Crewed space vehicles must be slowed to subsonic speeds before parachutes or air brakes may be deployed. Such vehicles have kinetic energies typically between 50 and 1,800 mega joules, and atmospheric dissipation is the only way of expending the kinetic energy. The amount of rocket fuel required to slow the vehicle would be nearly equal to the amount used to accelerate it initially, and it is thus highly impractical to use retro rockets for the entire Earth re-entry procedure. While the high temperature generated at the surface of the heat shield is due to adiabatic compression, the vehicle's kinetic energy is ultimately lost to gas friction (viscosity) after the vehicle has passed by. Other smaller energy losses include black body radiation directly from the hot gases and chemical reactions between ionized gases.

For Earth, atmospheric entry occurs at the Karman line at an altitude of 100 km (62.14 mi / ~ 54 nautical mi) above the surface, while at Venus atmospheric entry occurs at 250 km (155.3 mi / ~ 135 nautical mi) and at Mars atmospheric entry at about 80 km (50 mi / ~ 43.2 nautical mi). Uncontrolled, objects reach high velocities while accelerating through space toward the Earth under the influence of Earth's gravity, and are slowed by friction upon encountering Earth's atmosphere. Meteors are also often travelling quite fast relative to the Earth simply because their own orbital path is different from that of the Earth before they encounter Earth's gravity well. Most controlled objects enter at hypersonic speeds due to their suborbital (e.g., intercontinental ballistic missile re-entry vehicles), orbital (e.g., the Soyuz), or unbounded (e.g., meteors) trajectories. Various advanced technologies have been developed to enable atmospheric re-entry and flight at extreme velocities. An alternative low velocity method of controlled atmospheric entry is buoyancy which is suitable for planetary entry where thick atmospheres, strong gravity, or both factors complicate high-velocity hyperbolic entry, such as the atmospheres of Venus, Titan and the gas giants.

SILICA AEROGEL

Production: Many people assume that Aerogels are recent products of modern technology. In reality, the first Aerogels were prepared in 1931. At that time, Steven. S. Kistler of the College of the Pacific in Stockton, California set out to prove that a "gel" contained a continuous solid network of the same size and shape as the wet gel. The obvious way to prove this hypothesis was to remove the liquid from the wet gel without damaging the solid component. As is often the case, the obvious route included many obstacles. If a wet gel were simply allowed to dry on it own, the gel would shrink, often to a fraction of its original size. This shrinkage was often accompanied by severe cracking of the gel. Kistler surmised, correctly, that the solid component of the gel was micro porous, and that the liquid-vapour interface of the evaporating liquid exerted strong surface tension forces that collapsed the pore structure. Kistler then discovered the key aspect of aerogel.

CONDENSATION

A condensation reaction occurs when two metal hydroxides (M-OH + HO-M) combine to give a metal oxide species (M-O-M). The reaction forms one water molecule.

GEL POINT

The point in time at which the network of linked oxide particles spans the container holding the Sol. At the gel point the Sol becomes an Alcogel.

SUPERCRITICAL FLUID

A substance that is above its critical pressure and critical temperature. A supercritical fluid possesses some properties in common with a liquids (density, thermal conductivity) and some in common with gases. (Fills its container, does not have surface tension).

AEROGEL

What remains when the liquid part of an Alcogel is removed without damaging the solid part (most often achieved by supercritical extraction). If made correctly, the aerogel retains the original shape of the Alcogel and at least 50% (typically >85%) of the Alcogel's volume.

XEROGEL

What remains when the liquid part of an Alcogel is removed by evaporation, or similar methods. Xerogels may retain their original shape, but often crack. The shrinkage during drying is often extreme (~90%) for Xerogels.

ENERGY ABSORBING MATERIAL OF SILICA AEROGEL

In very simplified terms, materials absorb kinetic energy by plastic deformation, elastic deformation, brittle fracture, or by the fluid dynamics of gases or liquids within the material. Materials used today for absorbing impacts are commonly organic foams, such as expanded polystyrene, polyurethanes, polyethers, or polyethylene. These typically show elastomeric or plastic behaviour. Silica aerogels, being an inorganic solid, are inherently brittle. A brittle material would, at first, seem to be a poor choice for a cushioning material. However, as silica aerogels are usually very low density materials, the collapse of the solid network occurs gradually, spreading the force of impact out over a longer time. Additionally, as silica aerogels are an open pored material, the gas contained within the bulk of the solid in forced outwards as the material collapses. In doing so, the gas must pass through the pore network of the aerogel. The frictional forces caused as a gas passes through a restricted opening are indirectly proportional to the square of the pore diameter.

THERMAL EFFECTS ON SPACE RE-ENTRY VEHICLE

Direct friction upon the re-entry object is not the main cause of shock-layer heating. It is caused mainly from isentropic heating of the air molecules within the compression wave. Friction based entropy increases of the molecules within the wave also account for some heating.

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It has a minimal effect when the vehicle is travelling subsonic speeds but at supersonic (beyond M=1.2) and hypersonic (beyond M=5) speeds it has a serious effects on the design, material of the vehicle structure and the incorporated systems.

The spacecraft re-enter at very high speeds (Mach number exceeding 20) which is sufficient to destroy if the vehicle, if safety measure are not taken.

Through the vehicle heats up to a high stability temperature, still the heating effect reaches the peak value at the leading edge.

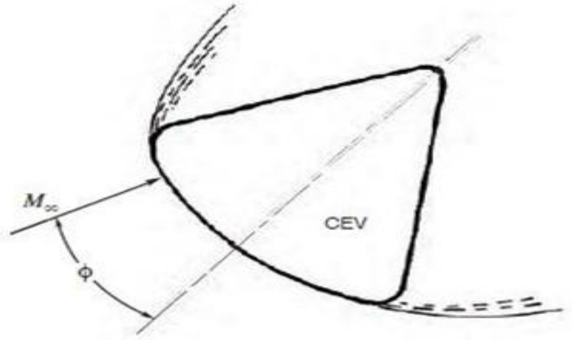


Fig [1] Thermal effects on space re-entry vehicle

MATERIAL SELECTION

Phenolics Impregnated Carbon Ablators (PICA)

Phenolics impregnated carbon ablators (PICA), a carbon fibre perform impregnated in phenolics resin, is a modern thermal production system and has the advantages of the low density (much lighter than the phenolics) coupled with efficient ablative ability at high heat flux. It is a good choice for ablative applications such as high peak heating conditions found on sample return missions or lunar return mission. Phenolics impregnated carbon ablators thermal conductivity lower than other heat flux ablative materials such as conventional carbon phenolics.

PICA was patented by NASA Ames Research centre in the 1990s and was the primary TPS material for the Stardust Aeroshell. The Stardust sample-return capsule was the fastest man-made object ever to re-enter Earth's atmosphere (12.4 km/s (28,000 mph) at 135 km altitude). This was faster than the Apollo mission capsules and 70% faster than the Shuttle. PICA was critical for the viability of the Stardust mission, which returned to Earth in 2006. Stardust's heat shield (0.81 m base diameter) was made of one monolithic piece sized to withstand a nominal peak heating rate of 1.2kW/cm2. A PICA heat shield was also used for the Mars Science Laboratory entry into the Martian atmosphere.

Phenolics impregnated carbon ablators (PICA) was an enabling TPS material for the stardust mission where it is used as a single piece heat shield. The thermal performance and ablation characteristics of PICA were evaluated in an oxidizing environment in the Ames research centre 60 Megawatts Interaction Heating Facility (IHF). Sample of PICA with and without surface densification, the carbon performance of avocet -5620 were tested at cold wall heat fluxes of 375-2960 Btu/ft² and surface pressure from 0.1-0.3 atm. Resulting heat load during this tests ranged from 55,00 to 29,600Btu/ft² surface and in-depth temperature were measured using optical pyrometers and thermocouple respectively This material also used for the solid rocket engine.

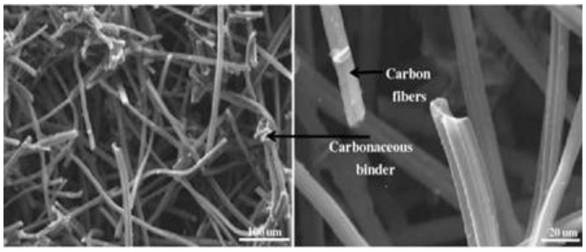


Fig [2] Phenolics impregnated carbon ablators

Properties of phenolics impregnated carbon ablator (PICA):

Property	Value
Poisson ratio	0.357
Young’s modulus	2-5.5 G Pa
Density	o.26-0.28 g/cm²(14 to 65 lbm/ft³
Temperature	2700°F(1482.22°c)
Thermal conductivity	O.188 W/MK
Isotropic resistivity	7.94-11 10^{-8} Ω m
Tensile ultimate strength	76 M Pa

Compressive ultimate strength	345 M Pa
Specific heat	697 J/kg k

Ultra high temperature ceramic material (UHTCs):

Ultra high temperature ceramic materials (UHTCs) are a class of refractory ceramics that offer excellent stability at temperature exceeding 2000°c being investigated as possible thermal production system (TPS) material coatings for material subjected to high temperature, and bulk material for heating elements. Ultra high temperature ceramics are borides, carbides, nitride, and oxides of early transition metals. Current effects have focused on heavy, early transition metal borides such as hafnium diboride (HfB_2) and zirconium diboride (ZrB_2). Additional ultra-high temperature ceramic material under investigation for thermal production system (TPS) application include hafnium nitride (HfN), zirconium nitride (ZrN), titanium carbide (TiC), titanium nitride (TiN), titanium dioxide (ThO_2), tantalum carbide (TaC) and their associated composites.

Since the late 1960s, the world of high temperature materials has focused primarily on SiC and Si_3N_4 as the material of choice. Entire industry have developed to produce ball bearing, armor, fibre, and even turbine blades But recently, there has been a revival of sorts in materials originally studied in the 1960s for potential aerospace application, driven by the need for speed with new propulsion system and the hypersonic concepts. There are 300 material with melting temperature over 2000°c,including aforementioned SiC, refractory metals (Hf,Nb,Ir,Re), oxides, a Varity of transition metal carbide, nitride, and borides as well as other compounds. Beginning in the early 1960s, demand for high-temperature materials by the nascent aerospace industry prompted the Air Force Materials Laboratory to begin funding the development of a new class of materials that could withstand the environment of proposed hypersonic vehicle such as Dyna-soar and the Space Shuttle at Manlabs incorporated. Through a systematic investigation of the refractory properties of binary ceramics, they discovered that the early transition metal borides, carbides, and nitrides had surprisingly high thermal conductivity, resistance to oxidation, and reasonable mechanical strength when small grain size were used. of these, ZrB2 and HfB2 in composite containing approximately 20% volume SiC were found to be the best performing.

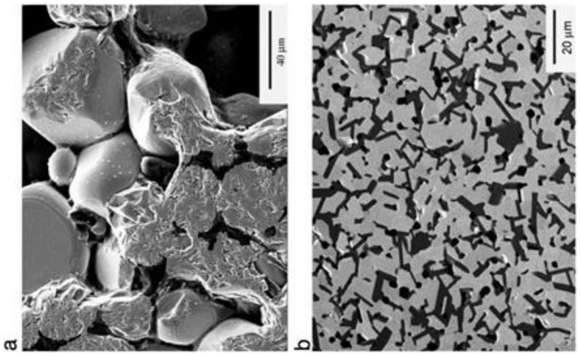


Fig [3]Ultra high temperature ceramics material

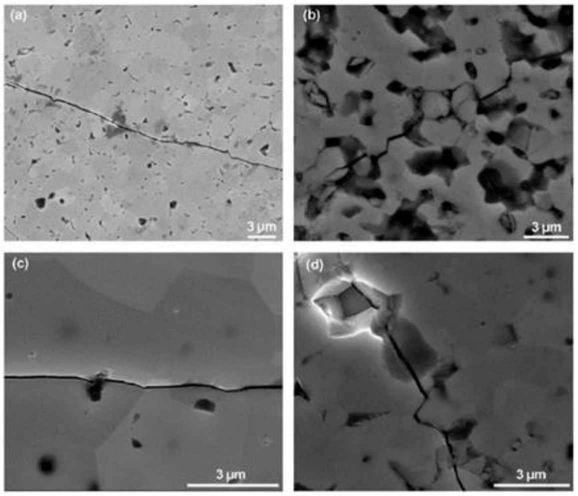


Fig [3.1] Ultra high temperature ceramics material (ZrB)

Properties of ultra-high temperature ceramics material (UHTCs):

Properties	Value
Poisson ratio	0.12-0.14
Young’s modulus	360 G pa
Density	6.10 g/cm³
Temperature	Above 2000°c
Thermal conductivity	75-105 w/mk
Isotropic resistivity	22 µ Ω cm
Tensile ultimate strength	565 M Pa
Compressive ultimate strength	6.14-12.5 M Pa
Specific heat	56-83.8Wm
Isotropic permeability	5.32
Tensile strength	60±10 M Pa
Compressive yield stress	2440±50 M Pa

Toughened uni-piece fibrous reinforced oxidation composites (TUFROC):

NASA has a new innovation that represent an exciting leap forward in reusable thermal production system (TPS) technology. The toughened uni-piece fibrous reinforced oxidation composite (TUFROC) allows for much more affordable and sustainable operation involving space launch service and other system that utilize earth re-entry vehicle. The TUFROC has an exposed surface design and appropriate materials combination that will allow a space vehicle to survive both the mechanical stresses of the initial ascent and the extreme heating and stress of re-entry. It provide a thermal production tile attachment system that is suitable for application to a space vehicle leading edge and for other uses in extreme in heating environment (up to 36000°F,and possible higher for short time intervals).

BENIFITS

- Flight tested.
- Survives high heat fluxes 3600°F and above.
- Light weight.

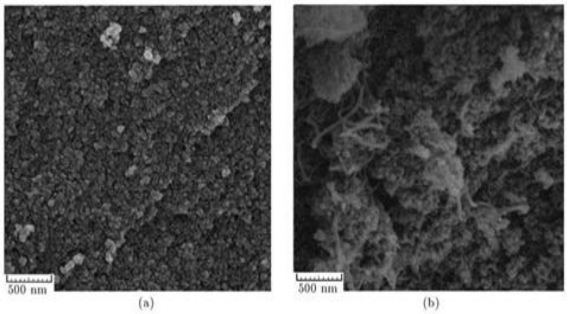
Properties of toughened uni-piece fibrous reinforced oxidation composites

PROPERTIES	VALUE
Poisson ratio	0.5
Young’s modulus	70 (or) 7GPa
Density	0.27 g/cm
Temperature	3600°F(1982.22°c)
Thermal conductivity	219 to 221w/mk
Isotropic resistivity	12 to 14Ωcm
Tensile ultimate strength	4400Mpa
Compressive ultimate strength	20.7Mpa
Specific heat	1125J/kg-k
Isotropic permeability	0.35
Tensile strength	15.9Mpa
Light weight	10 to 20 lbs/ft^3 up to 60 lbs/ft^3

Silica Aerogel material:

Silica aerogel is the most common type of aerogel, and most extensively studied and used. It is silica based and can be derived from silica aerogel or by a modified stober process. The lowest density silica nanofoam weight 1,000g/m^3, which is evacuated version of the record aerogel of 1,900g/m^3. The density of air is 1,200g/m^3(at 20°c and 1atm). As of 2013 aerographene had a lower density at 160g/m^3, or 13% the density of air at room temperature. The silica solidifies into three dimensional. Intertwined clusters that make up only 3% of the volume. Conduction through the solid is therefore very low. The remaining 97% of the volume is composed of air in extremely small Nanoporous. The air has little room to move inhibiting both convection and gas phase conduction. Silica aerogel also have a high optical transmission 99% and a low refractory index of˜1.05. It has remarkable thermal insulative properties, having an extremely low thermal conductivity from 0.03w/mk atmospheric pressure down to 0.004w/mk in modest vacuum, which correspond to R value of 14 to 105 or 3.0 to 22.2 for 3.5 inch thickness.

Silica Aerogels are materials with unique properties of such as high specific surface area (500–1200m^2g^{-1}), high porosity (80–99.8%), low density (~0.003–0.5g.cm−3),low thermal conductivity (0.005–0.1W/mk), ultra-low dielectric constant (1.0–2.0) and low index of refraction (1.05).due to their such unusual characteristic, much attention has been given to silica aerogel, in recent years for their use in several technological application including Cherenkov radiators in particle physics experiments and thermal insulation material for skylights and windows. Silica aerogel has also have been used for making heating storage devices used in window defrosting and as acoustics material. Other aerogel material have been demonstrated as battery electrodes, catalyst supports, and oxygen and humidity sensors and adsorbents for environmental clean-up due to their large surface areas and facile changing of their surface chemistry. The low value of thermal conductivity and the very low density make silica aerogel attractive coating of silica backbone via surface cross linking with a polymer and dispersing carbon nano fibres in the sol silica aerogel.



(a) (b)

Fig [4] Pure silica aerogel

Properties of silica Aerogel

Properties	Values
Poisson ratio	0.2
Young’s modulus	10^6to10^7 N/m^2
Density	0.003 to 0.35g/cm^3
Temperature	Above 1200°c

Thermal conductivity	0.5W/mk
Isotropic resistivity	
Tensile ultimate strength	45 to 155Mpa
Compressive ultimate strength	1100 to 1600Mpa
Specific heat	330K
Isotropic permeability	1000 to 1500
Tensile strength	16Kpa
Tensile yield stress	5.56Mpa

RESULT AND DISCUSSION

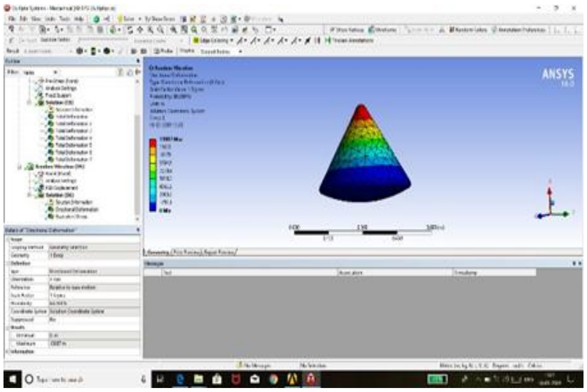


Fig [5] Directional deformation Vibration PICA

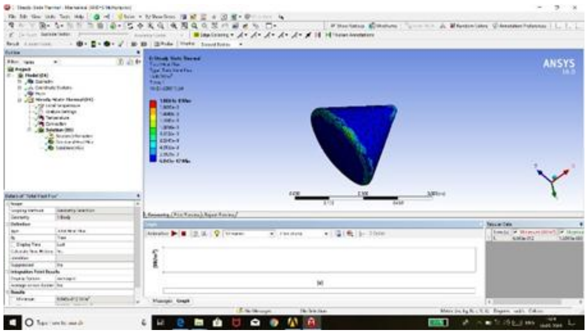


Fig [5] Total heat flux Staedy state PICA

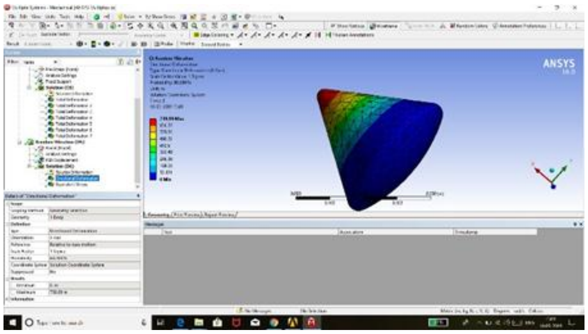


Fig [6] Directional deformation Vibration TURFUC

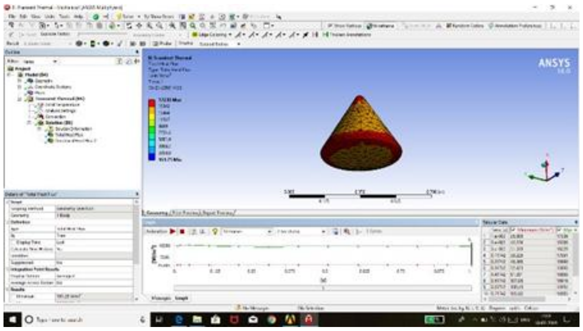


Fig [6] Total heat flux Staedy state TURFUC

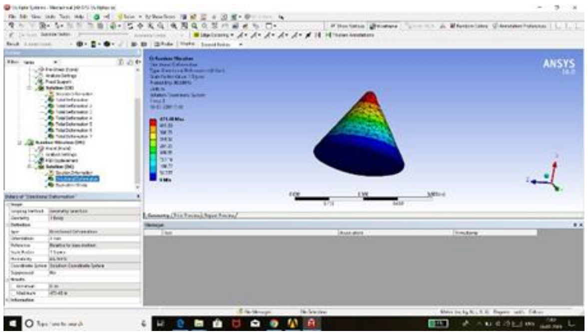


Fig [7] Directional deformation Vibration UHTC

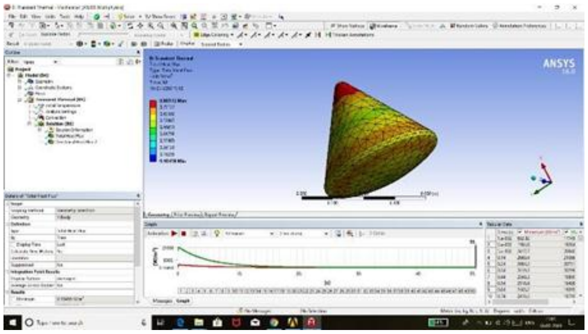


Fig [7] Total heat flux Staedy state UHTC

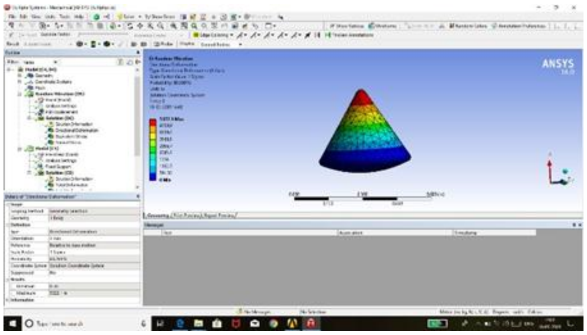


Fig [8] Directional deformation Vibration SILICA

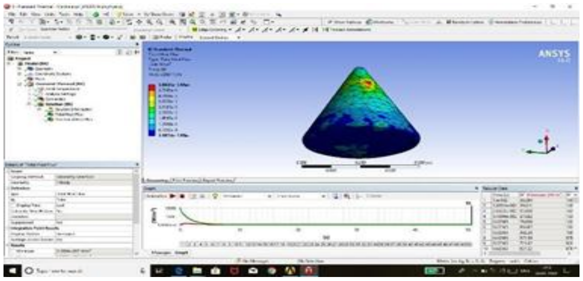


Fig [8] Total heat flux Staedy state SILICA

METERIALS	DIRECTIONAL HEAT FLUX STEADY STATE		TOTAL HEAT FLUX STEADY STATE	
	MAXIMUM(W/m2)	MINIMUM(W/m2)	MAXIMUM(W/m2)	MINIMUM(W/m2)
UHTC	7.6865e-6	- 3.8724e-6	9.806e-6	2.586e-9
PICA	5.4431e-9	-6.5759e-9	1.8061e-8	6.043e-12
TUFR OC	1.6221e-5	-1.761e-5	2.9101e-5	5.1005e-9
SILICA AEROGEL	3.7164e-8	-3.1767e-8	4.6473e-8	1.3844 e-11

Tab [1]: STEAY START THERMAL ANALYSIS

METERIALS	DIRECTIONAL DEFORMATION VIBRATION		EQUALLENT STRESS VIBRATION	
	MAXIMUM (W/m2)	MINIMUM (W/m2)	MAXIMUM (W/m2)	MINIMUM (W/m2)
UHTC	471.48	52.387	7.014e8	5.8889e7
PICA	13087	1454.1	5.237e14	2.8103e13
TUFROC	739.09	82.121	3.4328e13	3.245e11
SILICA AEROGEL	5322.1	591.34	2.8268e12	1.8457e11

Tab [2]: TRANSIENT THERMAL ANALYSI

CONCLUSION

In this paper, we have to study about the thermal effect and vibration effect on the space Re-entry vehicle during returning to the earth temperature.

These material are withstand the high temperature produced on the Re-entry vehicle. In exceeding methods. But in this case we have to added the silica aerogel material for the purpose of withstanding the very high temperature as well as the vibration effect produced on the space Re-entry vehicle and also it is used for reducing the wear and tear effects on the body of the space Re-entry vehicle silica aerogel material is not react with any other substance, so it is used for long time processes and to reduce the cost of material. The thermal effect and vibration on the space re-entry vehicle .then compare the results to form the table in about.

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