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An Investigation of blunt nose cone withUltra high temperature ceramicComposite TPS materials

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Abstract: Aerodynamic drag and heating is the valuable in the thermal steadiness of hypersonic automobiles at various speeds. The contemporary tendencies in the design of nose cone constitution needs an amazing Thermal Protection System (TPS) meets the need of the gap study technology. In this study a natural nose cone with specific ultra-high Temperature (UHT) ceramic composite TPS materials like Hafnium diboride (HfB2) and zirconium diboride (ZrB2) is analyzed and when compared for its strong protection towards switch of warmness into the constitution. A naval model is designed for from the standards of blunt nose cone and analyzed with the commercial program. A normal quad 4 node aspects is adopted to participate in thermal evaluation in ANSYS program and the simulated outcomes are validated with numerical solutions. Present ablative materials like SLA-561V, SIRCA and AVCOAT are having the warmth flux levels up to an110W/cm^2 and temperatures ranging as much as 2000°C and want of recent substances and its reliability are focused in this research.

Keywords-Thermal Protection System, Thermal stability, blunt nose cone, UHT ceramic Composite.

I. INTRODUCTION

On the base of the re-entry type previously described and the involved conditions in both of them, the thermal protection system can be divided in two main classes:Ablative TPSs support high heat loads and heating rates through phase changes and mass losses: this kind of materials are able to protect the underlying structure by absorption or dissipation of heat produced after melting, decomposition, sublimation or erosion. The ablative TPS are consequently consumed and have to be replaced or restored after using. Ablative materials have been the conventional approach to TPS used for over 40 years in a broad range of applications such as for all NASA planetary entry probes.

They represent an efficient solution to protect the vehicle and are generally cheaper than the reusable TPSs. An ablator should have a high melting/sublimation point, high specific heat and latent heat of melting/vaporization, low thermal conductivity and good strength in order to withstand vibrating and aerodynamic solicitations. Ablative thermal shield generally consists of an external part with more strictly ablative function so that it undergoes decomposition during re-entry and an inner part with insulating capability; it not suffers or only partially suffers thermal decomposition.

Their total thickness is estimated on the base of the supposed heat fluxes and temperature which the vehicle has to withstand. Most ablative TPS materials are made of reinforced composites employing organic resins as binders. When heated, the resin pyrolysis producing gaseous products (mainly hydrocarbons) that percolate toward the heated surface and are then injected into the boundary layer.

II. LITERATURE SURVEY

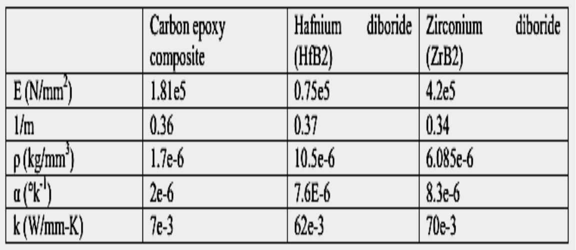
UHTCs originated in the early 1960s. Some of the earliest and most thorough work to date was performed thenby the company ManLabs, under a research program funded by the Air Force Materials Laboratory (AFML)6-7 Workon UHTCs was initiated to meet the need for high temperature materials that would allow the development ofmaneuverable hypersonic flight vehicles. Since then, despite research progress, several significant challenges remainin the use of UHTCs, and these materials have yet to be widely implemented.

Bulk UHTCs are fabricated at temperatures ranging from 1900–2100 °C and pressures of 60–100 MPa by hotpressing in either resistance- or induction-heated furnaces, using graphite dies — in processes that have not changedmuch since the 1960s. High melting temperatures make consolidating pure samples by conventional hot pressingextremely difficult. Work by ManLabs found that additives could eliminate billet cracking and make dense, fine-grained microstructures achievable.6 In particular, adding SiC from 5–30 volume percent improved UHTCdensification and oxidation resistance.

III. METHODOLOGY

The co-ordinates for the development of blunt cone profile is taken into consideration with respect to the tangency point and in which the basic size of the nose cone is given in key points as (11.55,0), (76,0), (76,37), (13.7833, 7.66), (10.95, 4.3), (76,38.5), (10.95,5.8), (9.75,4.3), (10.55,0). Base material for the nose cone is carbon epoxy and the TPS materials are Hafnium diboride (HfB2) and zirconium diboride (ZrB2) and their properties are as listed in Table: 1 [4] for performing the analysis. A layer of 1.5 mm is taken for the analysis purpose for each of the TPS material.

Table: I Material properties



	Carbon epoxy composite	Hafnium diboride (HfB2)	Zirconium diboride (ZrB2)
E (N/mm^2)	1.81e5	0.75e5	4.2e5
1/m	0.36	0.37	0.34
ρ (kg/mm^3)	1.7e-6	10.5e-6	6.085e-6
α (°k^{-1})	2e-6	7.6E-6	8.3e-6
k (W/mm-K)	7e-3	62e-3	70e-3

The FEM model is generated from the key points as furnished in the problem description. In the context of the model theactual model follows the steps of operations like from points to lines, lines to areas and free meshing methodologiesavailable in the software. An axisymmetric model is chosen for the better approach to the solution as the time and datastorage can be promisingly minimized with such model. The end boundary conditions are chosen based on the realistic nosecone structure of hypersonic vehicle and later thermal analysis is performed.

IV. MATHEMATICAL MODELING

A simple mathematical model is adopted for the validation of the actual conditions of the composite structure for its thermal analysis from the fundamentals of FEM procedures. A cantilever beam with two materials is an acceptable model to satisfy the problem. The governing equation for this condition with an isotropic body with temperature-dependent heat transfer has the form of global equations for the domain can be assembled using connectivity information. Shape functions Ni are used for interpolation of temperature inside a finite element as per equation (1) is given by[6]

$$T(x) = N_1(x)T_1 + N_2(x)T_2 \ldots\ldots\ldots\ldots\ldots (1)$$

Where T(x) is the temperature at the required position, N1 and N2 are the shape functions which will be defined in terms of temperature, T1 and T2 are the temperatures at that locations. To simplify the above equation in mathematics, evaluate the shape functions as per equation (2) is given by

$$N_1 = 1 - \frac{x}{L} \text{ and } N_2 = 1 - \frac{x}{L} \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where L is the length of the element and x is the distance from the reference point.

Finally the conduction and convection problem solution may also be able to be taken the form as,

$$[k^{(e)} = \frac{k_x A}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} + \frac{hPL}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \ldots\ldots (3)$$

The forcing function can be written as

$$\left\{f_h^{(e)}\right\} = hPT_a \begin{Bmatrix} \int_0^1 N_1 dx \\ \int_0^1 N_2 dx \end{Bmatrix} = \frac{hPT_aL}{2}\begin{Bmatrix} 1 \\ 1 \end{Bmatrix} \ldots.(4)$$

and finally the problem solution can takes the form

$$\{k\}\{T\}=\{f\}\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

V. RESULTS AND DISCUSSIONS

A 2D model is analyzed for its steady state heat transfer analysis by using Newton Raphson model at Mach number 10 for hypersonic environment and the surface temperature is taken as 2478°k and boundary temperature of 298°k [3]. A total number of 1157 elements are taken for its final solution convergence.

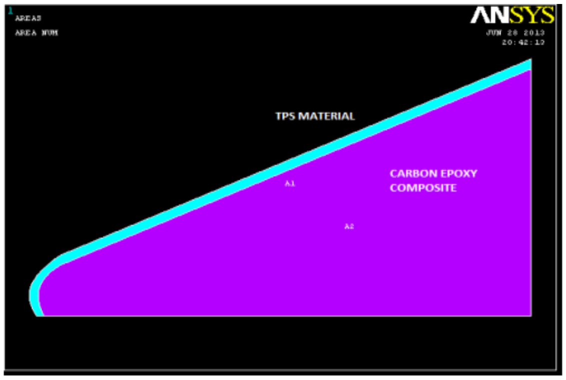


Fig. 1 A typical blunt nose cone 2D profile with TPS Layer

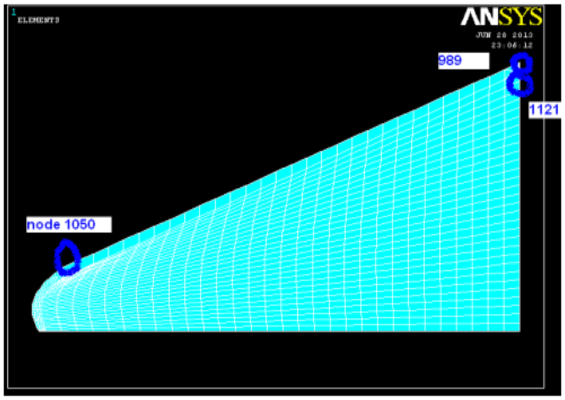


Fig. 2 Node 989,1050 & 1121 locations

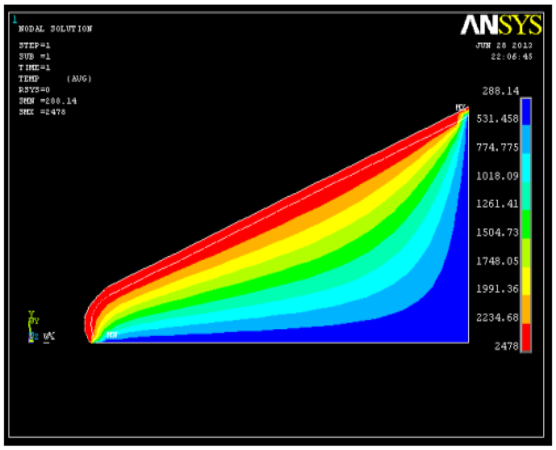


Fig. 3 Temperature distributions for HfB2 material

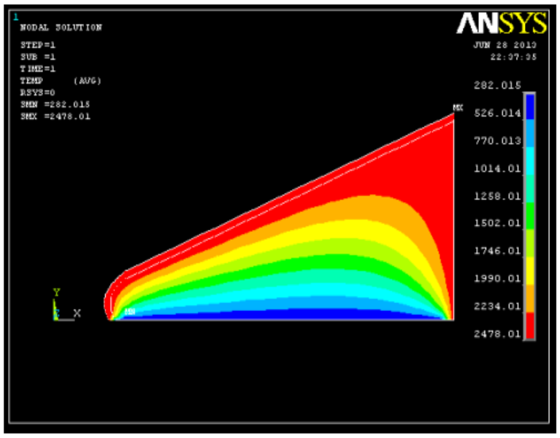
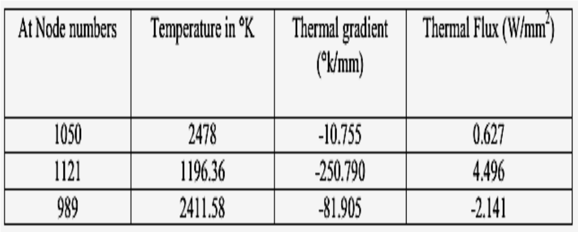


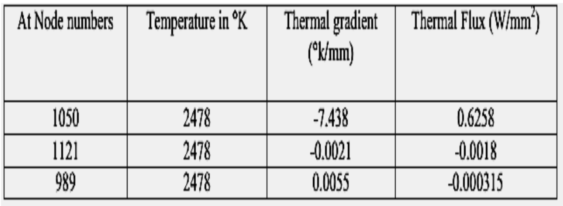
Fig. 4 Temperature distributions for ZrB2 material

Table II HfB2 material results



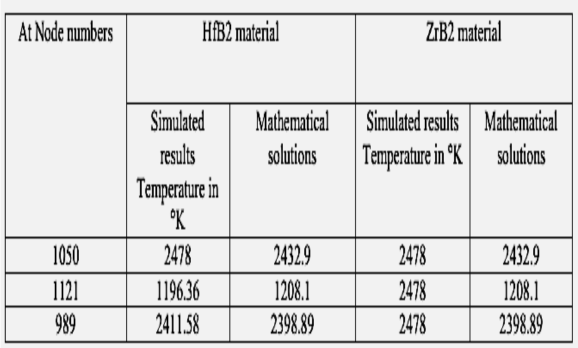
At Node numbers	Temperature in °K	Thermal gradient (°k/mm)	Thermal Flux (W/mm^2)
1050	2478	-10.755	0.627
1121	1196.36	-250.790	4.496
989	2411.58	-81.905	-2.141

Table III ZrB2 material results

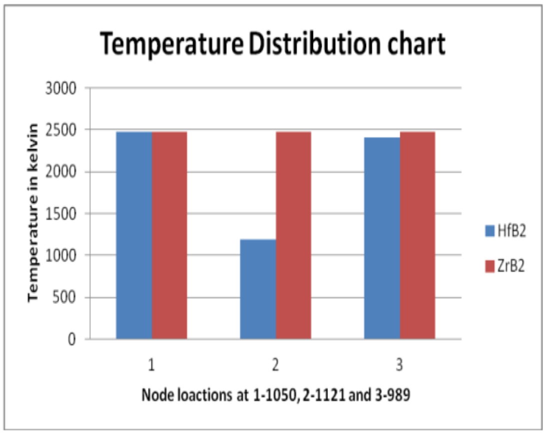


At Node numbers	Temperature in °K	Thermal gradient (°k/mm)	Thermal Flux (W/mm^2)
1050	2478	-7.438	0.6258
1121	2478	-0.0021	-0.0018
989	2478	0.0055	-0.000315

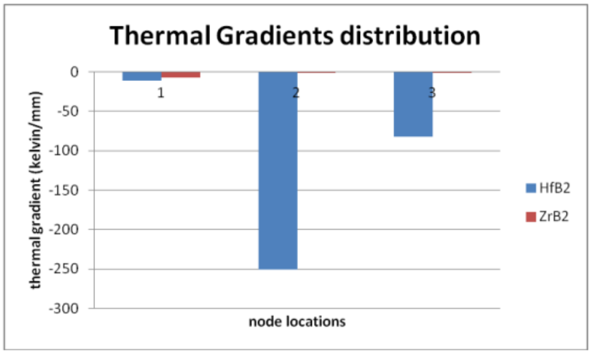
The node numbers are chosen for mathematical solutions at 1050, 989 and 1121 at the radii of the nose cone 5mm, 37mm and 38.5 mm respectively and the solutions were compared.



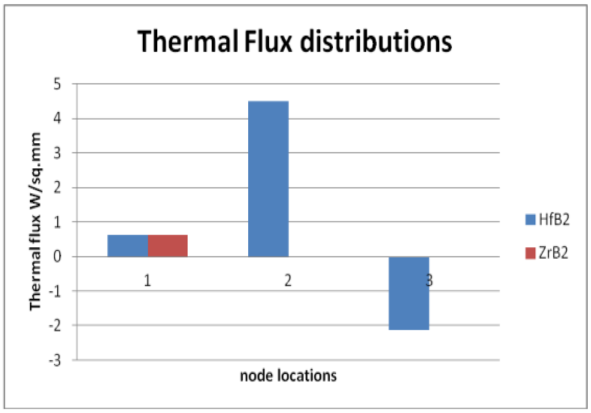
At Node numbers	HfB2 material		ZrB2 material	
	Simulated results Temperature in °K	Mathematical solutions	Simulated results Temperature in °K	Mathematical solutions
1050	2478	2432.9	2478	2432.9
1121	1196.36	1208.1	2478	1208.1
989	2411.58	2398.89	2478	2398.89



Graph. 1 Temperature distribution at nodes



Graph. 2 Thermal gradient distribution at nodes



Graph. 3 Thermal flux distributions at nodes

VI. CONCLUSION

Simulated options at more than a few nodes are validated with numerical options which can be particularly in excellent understanding and show the feasibility of the difficulty methodology.

O For the Hafnium diboride material the temperature distribution is from 2478°k to 2411.58°k and the distribution is natural showing the uniformity of the distribution over the entire nose cone.

O But for the Zirconium diboride material the temperature distribution just isn't identical and it's 2478°k at the skin of the TPS layer and indicates the resistance of the material in transferring the temperature for the remaining of the nose cone.

O From the simulated results the Hafnium diboride material shows the simpler distribution pattern and its heat flux values are also in promising stages than Zirconium diboride material.

O This can be extra evaluated for the transient thermal evaluation which will have extra options for the outlined drawback.

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