06/3201 Advanced Ceramic Fibers and Matrices: Hafnium Carbide Composites

Type of activity: Medium Study (4 months, 25 KEUR)

Background and Motivation

Hafnium Carbide (HfC) is one example of advanced ceramic fiber matrices. It is a compound with the highest known melting temperature: 3890C. In theory, a part made with Hafnium Carbide fiber matrix composite would survive temperatures that would soften or melt even refractory metal-metal alloys such as rhenium-tungsten blends. HfC has about 60 percent the density of metal alloys, so critical rocket, missile and aerospace components made with HfC composites would be correspondingly lighter. Table 1 reports the main properties of the Hafnium carbide.

Table 1: HfC properties

Density	12.2 g/cm3
Melting point	3890 °C
Molecular weight	190.54 g/mol
Boiling Point	4603 °C
Thermal conductivity	292.88 W/m C
Thermal expansion coefficient	7.5-8.2 10^{-6} K^{-1}
Electrical Resistivity	109 micro-ohm cm

The fabrication process of HfC ceramic fibers is relatively complex: It is based on melting hafnium containing preceramic polymer, extruding that polymer through an orifice to form fiber, cross-linking that fiber and heating the cross-linked fiber under controlled atmospheric conditions at a temperature greater than 600°C to obtain a hafnium carbide containing ceramic fibre. [6]

Possible applications of HfC composites are:

- Liners for combustion chambers, throats and combustion chambers in rockets
- Leading-edge surfaces on vehicles entering an atmosphere to withstand the ultra-high temperatures without degrading
- Filaments in incandescent bulbs
- Field emission array cathodes for electric propulsion

Research and Study Objectives

The study shall focus on material science aspects related to the application of HfC composites to rocket combustion chambers and nozzles. HfC composites could be an interesting option to increase working temperatures of combustion chambers (thereby increasing the specific impulse to levels previously not achievable with chemical propulsion systems).

Due to zero-ablation properties, HfC composite liners may also be relevant to the development of reusable rocket engines for both launcher and spacecraft applications. However, a number of aspects related to HfC are still only partially understood and need to be evaluated further, such as the survivability of HfC composite liners to high mechanical loads arising from combustion pressure and vibration, and also thermal expansion/cycling.

The study should perform the following tasks:

- Review on state of the art HfC ceramic fibers and matrices research and development
- Identification of limitations and critical engineering issues associated with HfC ceramic fibre matrix material in general and specifically as a rocket chamber/nozzle liner, e.g. bonding, structural failure under mechanical pressure, vibration, acoustic noise, and thermal expansion/cycling environments
- Assessment of the feasibility, benefits and drawbacks of using HfC composites as liners in propulsion systems (launcher and spacecraft)
- Assessment of the feasibility, benefits and drawbacks of using HfC composites in other very high-thermal load sections of spacecraft.
- Determine eventual research, development and testing needs for the use of HfC in space systems.

References

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[3] http://www.reade.com/Products/Carbides/hafnium_carbide.html

[4] Normal spectral emittance of crystalline transition metal carbides, William A. Mackie, Pete Carleson, Janice Filion, C. H. Hinrichs, Journal of Applied Physics, Volume 69, Number 10 (May 15, 1991), pp 7236 – 7239

[5] United States Patent Application 20020165332; Kind Code A1; Pope, Edward J. A. ; et al., November 7, 2002, Preceramic polymers to hafnium carbide and hafnium nitride ceramic fibers and matrices

[6] United States Patent Application 20020142148 Kind Code A1 Hilmas, Gregory E. ; et al., October 3, 2002, Continuous composite coextrusion methods, apparatuses, and compositions United States Patent 4,825,647, Cann, May 2, 1989, Performance improvements in thruster assembly

[7] M. M. Opeka, I. G. Talmy, E. J. Wuchina, J. A. Zaykosky and S. J. Causey, "Mechanical, Thermal, and Oxidation Properties of Refractory Hafnium and Zirconium Compounds", PII: S0955-2219(99) 00129-6. E. J. Wuchina and M. M. Opeka, "Oxidation of Hf-Based Ceramics", Electrochemical Society Proceedings Volume 99-38 pp. 477-488