ULTRA-HIGH TEMPERATURE CERAMICS FOR TRANSPIRATION COOLING APPLICATIONS IN HYPERSONIC VEHICLES

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This paper presents an overview of the work undertaken over the past four years to explore the application of transpiration cooling for hypersonic vehicles using partially sintered ultra-high temperature ceramics (UHTC). Due to the very high speeds these vehicles travel through planetary atmospheres, they are exposed to extremely high heat loads (> 1 MW/m^2). These heat loads need to be mitigated in order to protect the payload. For high flight speeds, particularly where sharp nose radii are aerodynamically desirable, these heat loads cannot be managed by passive systems. To date, the thermal protection system which has been most successfully applied is an ablative heat shield. This has extremely high heat load to mass performance. However, shape stability for aerodynamic applications and reusability requires a new cooling technology.

Transpiration cooling provides an active cooling approach that could be employed to thermally protect such hypersonic vehicles, retain shape stability, and enable re-usability. The cooling technique works by passing coolant gas through the porous skin of the vehicle which keeps the material temperature below critical values. This is mainly achieved by three mechanisms: The heat exchange from solid material to coolant while the coolant passes through the porous wall, the creation of a protective film at the outside of the vehicle that reduces boundary layer temperatures, and the reduction of catalytic and oxidation reactions at the surface due to creating an inert film that keeps the freestream radicals and oxygen away from the surface. The last feature is a key requirement to enable UHTCs as a candidate material as oxidation protection unlocks the massive re-radiation potential of these materials. Through the exclusion of oxidation, significantly higher surface temperatures can be achieved which enable a huge cooling potential through re-radiation.

This paper will present: an overview of the potential performance of the technology to key hypersonic vehicles at key trajectory points; manufacturing technologies of partially sintered ZrB_2 with designed porosity and cooling architectures; material characterisation measurements; measurements of permeability (Darcy-Forchheimer) coefficients, spatial distribution of flow; measurement of internal heat transfer coefficients; coupling of coolant ejection with a hypersonic cross flow and mixing. Finally, the paper will culminate in the experimental verification of this cooling approach through testing of an actively cooled stagnation point coupon which was exposed to a high enthalpy plasma wind-tunnel flow.