Supersonic off-stagnation point test bed for high-enthalpy material testing in Plasmatron

Sander Holum[a 1)] Bernd Helber[a)], Joseph El Rassi [a)], Olivier Chazot [a)], Louis Walpot [b)]
a) Aeronautics and Aerospace Department, von Karman Institute for Fluid Dynamics, B-1640 Sint-Genesius-Rode, Belgium
b) European Space Agency, 2200 AG Noordwijk, The Netherlands

To assess the effectiveness of tools designed for hypersonic material testing and space debris analysis, it is essential to replicate specific environmental conditions such as pressure, temperature, and shear stress in ground-based testing facilities. As part of the latest developments in space debris material research, the Plasmatron facility at the von Karman Institute now provides a unique setup enabling off-stagnation testing within a supersonic framework[1)]. In this study, ground tests were carried out on woven CFRP (Carbon Fiber Reinforced Polymer) and titanium samples using the VKI-Plasmatron to emulate the conditions encountered by these materials during reentry into Earth's atmosphere as space debris. Three samples of each material were tested in a supersonic plasma flow, either parallel to the flow or with a slight angle of attack (AoA). Various intrusive and non-intrusive instrumentation techniques were employed during testing to monitor the thermal response and oxidation growth of the materials and to visualize the temperature distribution across the surface of the samples.

The CFRP samples was made to represent rocket fuel tanks, so called wrapped COPV (Composite Overwrapped Pressure Vessel). The interaction between strong forces ripping off the carbon fibers and their simultaneous oxidation is crucial to the fuel tank's demise during re-entry. The surface temperature monitoring shows a rapid initial temperature rise until the pyrolysis of the resin starts. While the pyrolysis is ongoing the temperature stays steady, and slowly rises as the pyrolysis ends if the heat flux is sufficient. A clear increase in the recession speed was observed with an increase in angle of attack and higher flow enthalpy. The material reached a steady surface temperature under ablation, and the effect of shear was clearly pulling the fibres off the sample. The titanium samples showed a complex oxidizing behaviour, varying for different heat fluxes and shear conditions. In the low shear test case without angle of attack, a protective layer of white TiO_2 formed. This brittle later remained on the sample. With higher shear, increasing AoA, this layer was ripped off, and a complex active oxidation occurred. The oxidation could be tracked in time with the cameras. First a blue oxide layers travels from the sample front all the way to the back of the sample. As the samples heats up further, this oxidation layer degrades and is sheared off, and the active oxidation starts. More in depth material research is needed to characterize these surface oxides.

Reference:

1) J. El Rassi, S. Holum, L. Sombaert, A. Viladegut, L. Walpot, O. Chazot, B. Helber, Upgraded VKI Plasmatron Capabilities with Supersonic Nozzles for Extended Material Characterization Methods, SAMPE journal, March-April 2024, DOI: 10.33599/SJ.v60no2.02

[1]Corresponding author.
Email address: sander.holum@vki.ac.be (Sander Holum)