Ablative Material Optimisation and Definition of Material Families Adaptable to Various Applications

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The development of new ablative thermal protection for atmospheric entry bodies is often a time and cost consuming effort in order to qualify the newly developed ablator towards a new set of requirements.

Ablator materials originally developed towards a specific application, but with manufacturing process reliable and robust enough, could enable rational tailoring of the composition to the needs and the entry environment of another mission application. Therefore it is important to explore and consolidate methods to rationally tailor existing (robust) ablators to new applications in an efficient way.

For rational material tailoring simple but reliable performance prediction methods or figure-of-merits are favourable. Variables of semi-empirical models should correlate with intrinsic material parameters which are controllable during manufacture.

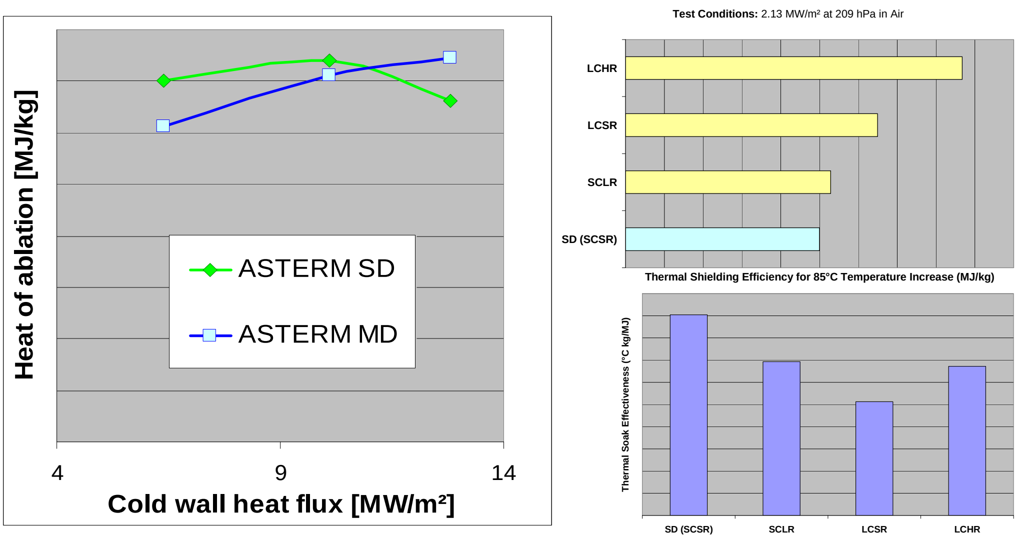

Figure 1: Semi-empirical figure-of-merits for rational material screening (left: heat-of-ablation, right top: thermal-shielding-effectiveness, right bottom: thermal-soak-effectiveness)

A robust lightweight carbon-phenolic ablator family has been developed in Europe by Airbus D&S. The ablator family trade name is ASTERM, comprising the three members SD (*standard density*), MD (*medium density*) and HD (*high density*). Two probe front-shield reference applications have been selected for ASTERM SD: A large and heavy planetary probe, the Mars Science Laboratory (MSL), and a large and heavy Earth re-entry capsule, the so called Advanced Re-Entry Vehicle (ARV).

Starting from the proven composition of SD (280 kg/m³) which is developed and pre-qualified for Marco Polo the carbon felt density is modified and, independently, the resin mass fraction. From the eight potential variations of the proven composition SD three have been selected based on surface recession and thermal conductivity material models. These three variations and the baseline SD ablator have been exposed to an arc-jet and thermal/ mechanical screening test campaign.

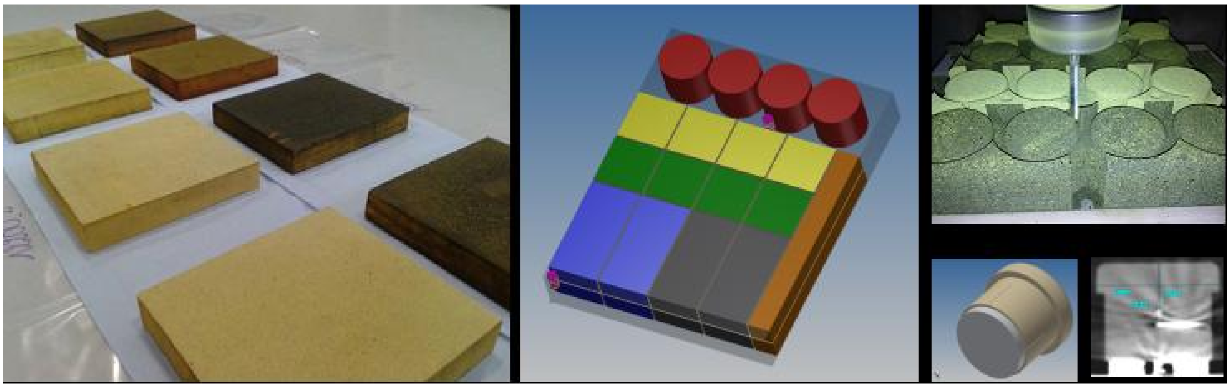

Figure 2: Ablator plates manufactured by Airbus for screening tests (left), sample cut-out plan from a plate (middle), arc-jet sample fabrication and thermo-couple integration/ position measurement at HPSP (right)

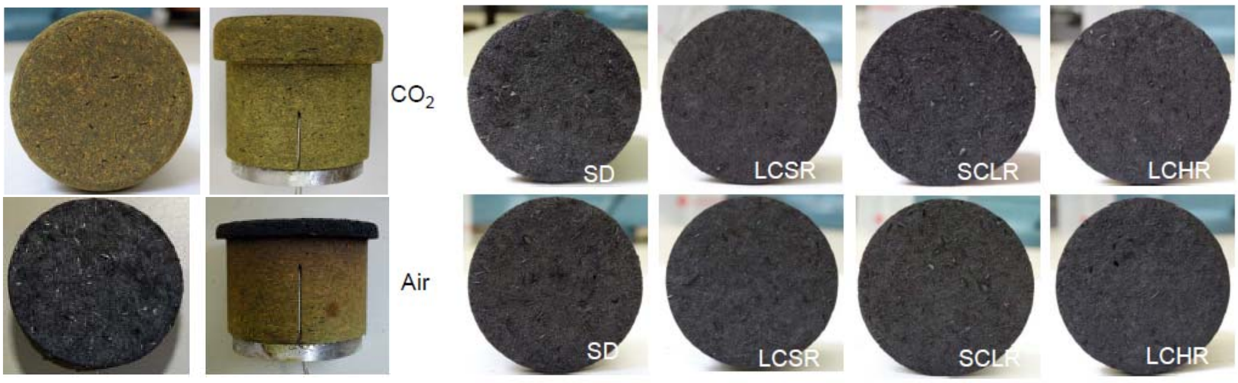

Figure 3: Front and side view of arc-jet test samples before and after test (left) and post-test appearance of arc-jet test samples (right) after screening tests in air (2.13 MW/m²) and CO_2 (2.25 MW/m²)

Based on the screening test campaign and semi-empirical model assessment an optimum ablator LCOR (***L**ow density **C**arbon felt – **O**ptimised **R**esin mass fraction*) for the MSL application was defined by using low density carbon felt with resin mass fraction between the ones of LCSR (***L**ow density **C**arbon felt – **S**tandard **R**esin mass fraction*) and LCHR (***L**ow density **C**arbon felt – **H**igh **R**esin mass fraction*). This optimum ablator was exposed to a characterisation test campaign with arc-jet tests in air and CO_2. In air/nitrogen mixtures the oxygen partial pressure was varied for constant heat flux and total pressure. This enabled to validate the surface recession model in air and its dependence on the char density.

Figure 4: Measurement of mechanical properties at AAC (from left to right: compression, shear, tensile test apparatus, shear test results and compression results compared with semi-empirical model calculations

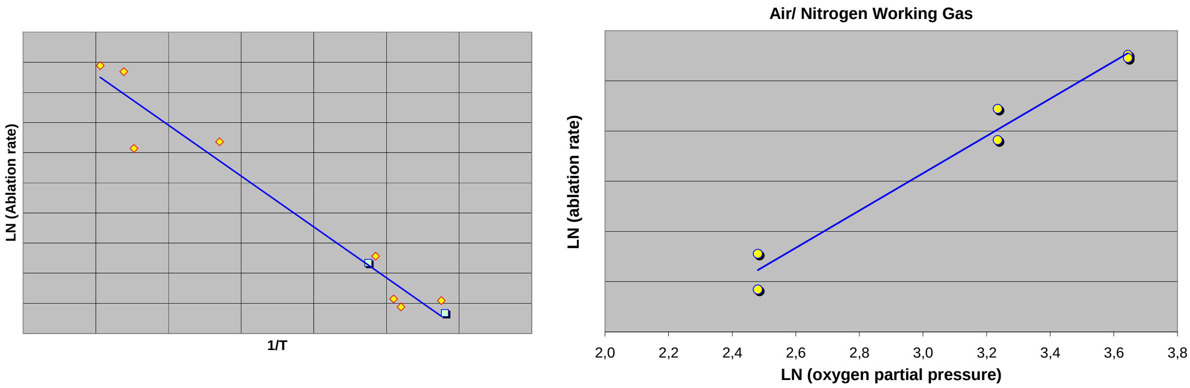

Figure 5: Surface recession temperature dependence (left) and oxygen partial pressure dependence (right)

The results of both test campaigns enabled to propose a model which correlates the thermal shielding effectiveness with ablator parameters like char density, thermal diffusivity and recession rate model. The agreement of this model with tests was good.

The characterization test campaign further demonstrated compliance of LCOR mechanical characteristics with char specifications and with virgin ablator specified tensile deformation.

The key conclusions of the TRP activity for the ASTERM ablator family are:

1.) The ASTERM manufacturing process is reliable and robust. All SD modifications showed controllable and repeatable material characteristics.

2.) All samples kept integrity in arc-jet tests. Ablation was homogeneous and predictable.

3.) For ranking performance of different modifications the thermal shielding effectiveness and the thermal soak effectiveness provides easy to use quantitative figures-of-merit.

4.) LCOR is compliant with mass, mass loss, recession loss and char strength specifications for MSL application and for ARV application. The mass reduction potential estimated from peak heating conditions of roughly 17 % for MSL application and up to nearly 50 % for ARV application needs confirmation by detailed ablator response modeling along the complete trajectory.

5.) The possibility to rationally develop from a proven ASTERM family member tailored modifications to a different application is confirmed. A guideline has been established.

During a CCN another ablator material, called conformal ablator, was produced. This conformal ablator is derived from the ASTERM material by replacing the rigid carbon fiber felt through a flexible one. This light weighted material (around 250 kg/m^3) is supposed to be used for the backside of ERC. It was tested in the same way like the other ASTERM variations and found to be a good candidate for the proposed use, following further material consolidation and potential refinement of requirements.

In summary, the technological objectives of the study have been successfully achieved. The guidelines to systematically tailor an already existing ablator composition towards a new set of requirements have been established and used for two reference applications. It was demonstrated that such systematic approach provides mass saving potential while shortening the development effort.

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