Introduction of innovative material solutions for demisable propellant tanks during atmospheric reentry

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Hydrazine tanks for Low Earth Orbit satellites are nowadays constituted of Ti-6Al-4V titanium alloys. The constitutive alloy is subjected to constraints of different order. First of all, it must support the inner pressure without breaking. Then, it should be demisable during atmospheric reentry. Indeed, at the end of a satellite life, an atmospheric reentry operation is mandatory to limit the total amount of space debris. The current propellant tanks are only partially demisable, which induce high casualty risks for humans and the environment.

New materials should thus be considered to fabricate the tank. Different materials families were considered in this work (Ti alloys, TiAl intermetallics, Al alloys). To evaluate their respective demisability, numerical simulations of atmospheric reentry on a critical trajectory were performed on test cases, using both DEBRISK and ARES softwares - respectively developed by CNES and ONERA. The results obtained with DEBRISK are averaged on the total mass of the tank, whereas the results obtained with ARES are local, and provides the maximum values locally reached by the tank. Consequently, simulations allow to determine some key materials parameters (melting temperature, heat of fusion, thermal conductivity and emissivity) to be adjusted for a better demisability. Moreover, previous researches have shown that developing frangible materials is a potential solution to improve the demisability of the tank.

An experimental approach was then developed to evaluate the potential of three material solutions to substitute the current Ti-6Al-4V alloy. First, Ti-6Al-4V alloy was fabricated using additive manufacturing (Electron Beam - Powder Bed Fusion), followed by a consolidation thermal treatment. The aim is to achieve an architecture made of alternated porous and dense areas. Frangibility of titanium alloys could also be obtained thanks to eutectic structures. Indeed, alloying titanium with β-eutectoids stabilizer elements like Ni, Fe, Si or Cu creates an eutectic microstructure whose melting temperature is significantly reduced compared to titanium alloys. Some eutectic alloys (Ti-Ni and Ti-Fe, with different alloying elements compositions) were fabricated by arc melting. Their characterization constitutes a necessary step to further work on architecturated titanium eutectic alloys, which could be processed via powder metallurgy routes. Finally, intermetallic TiAl alloys were considered as potential material solutions. Alloying TiAl with Nb and arc melting elaboration creates a solidification structure constituted of a refractory Nb rich squeleton, which could induce frangibility.

A material characterization campaign was then led on the fabricated samples. Mechanical behaviors were evaluated by 4-points bending tests. Thermal and thermodynamic properties (conductivity and emissivity at high temperature, heat capacity) were measured for each sample and compared with the results available in the literature. Finally, oxidation tests in laboratory air (for experimental conditions – time, temperature - representative of an atmospheric reentry) were performed. The different oxide layers have been identified as they are of primary importance for the thermal emissivity of metals. Simulations using experimental results as input for material properties are finally made for a numerical validation of the three material solutions which were considered.