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Functionally Graded Materials designed for thrusters : resistance in combustion environment and under laser thermal flux

Lisa AUDOUARD [123], Aurélie JULIAN-JANKOWIAK [1], Jean-François JUSTIN [1], Pierre BERTRAND [2], Cécile LANGLADE [2], Matthieu GARCIA [3], Lucien VINGERT [4,] Thibaut ARCHER[1]*

** Corresponding author*
[1] ONERA/DMAS-Université de Paris-Saclay, 92320, Châtillon, France (lisa.audouard@onera.fr; aurelie.jankowiak@onera.fr, jean-francois.justin@onera.fr, thibaut.archer@onera.fr)
[2] Université de Bourgogne Franche-Comté, laboratoire ICB UMR CNRS-UB-UTBM 6303, 90010 Belfort France (cecile.langlade@utbm.fr; pierre.bertrand@utbm.fr)
[3] Direction des systèmes orbitaux, CNES, Toulouse, 31410, France (Matthieu.Garcia@cnes.fr)
[4] ONERA/DMPE-Université de Paris-Saclay, 91120, Palaiseau, France (lucien.vingert@onera.fr)

Abstract

European regulations tend to limit the use of toxic propellant and especially hydrazine, which is commonly employed for chemical satellite propulsion. Thus, new "green" and more efficient propellants are developed by CNES but they induce harsher operating conditions for the materials of the combustion chamber, in terms of temperature and oxidation. Consequently, ONERA, CNES and ICB have engaged a close collaboration to develop materials able to withstand these new requirements (2700 K combined with an oxidising atmosphere). Among all, ceramic/metal Functionally Graded Materials (FGM) seems to be very promising. They are constituted of a ceramic top layer acting as a Thermal Barrier Coating, several graded layers and a refractory metal underneath [1]. This progressive evolution of the chemical composition permits to reduce stress concentrations responsible for damages.

In the present study, four FGM configurations are considered and manufactured by Atmospheric Plasma Spraying (APS) at ICB. Then, their resistance is tested on two test benches developed at ONERA: the combustion test bench MASCOTTE and the laser test bench BALI. The first one is useful to reproduce closely the environment of a real combustion chamber, with the effects of temperature and oxidising species. These tests in MASCOTTE follow a first experimental campaign led in 2019 in which the samples were placed on the wall of the combustion chamber [2]. For this new campaign, samples are now placed directly into the combustion flame. Flame mixing ratio (H_2/O_2) is chosen to obtain a 3200 K flame temperature with presence of water vapour and a pressure of 10 bar. Cumulative test durations are varying from 200 sec to 1500 sec of exposure.

This experimental campaign reveal that all the samples successfully completed the tests, as they present neither oxidation nor total spallation, except for some edges, related to side effects. This demonstrate the ability of such FGM to limit excessive stress concentrations occurring in classic coatings under extreme environmental conditions. In all cases, after the tests, the observed cracks are confined in the gradient, which confirms the suitability of the designs. Finally, the flame temperature seems to be the determining parameter considering the degradation of the materials as no evolution of the samples is observable between the different test durations. However, as the instrumentation of the MASCOTTE test bench is rather difficult, the surface temperature of the materials is not accurately known during the tests. For this reason, same FGM configurations have been submitted to laser heat fluxes. As this set up is settled under vacuum without oxidising species, the effect of the temperature on material degradation can be isolated. The FGM present very good resistance to tens of cycles up to 2600 K. However, the crack network in the ceramic part is evolving as well as the surface chemical composition. These phenomena were not observed in the MASCOTTE experiments and can be explained by the higher surface temperature achieved on the laser test bench.

References

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