Fracture Simulation for Thermal Barrier Coatings in Rocket Engines

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ABSTRACT

The extreme heat fluxes in rocket engines require the use of materials like copper alloys with high thermal conductivity. To protect the copper from extreme temperatures, it can be coated using a thermal barrier coating comprising a nickel-base alloy top coat and a nickel-copper alloy intermediate (bond coat). During service, coatings may fail due to crack formation and spallation, buckling, or due to cracks running into the material.

To safely design such thermal barrier coatings, it is necessary to understand relevant failure modes. We use finite element simulations together with laser-shock experiments to study conditions of failure and the possible formation and propagation of cracks. The most important possible failure mode is the formation of vertical cracks: During heating, the coating deforms plastically under compression, leading to large tensile stresses upon cooling. From experiments, a critical tensile strain can be estimated. It is shown that during a rocket engine cycle, this strain will be exceeded and that the propagation of vertical cracks is thus a plausible failure mode. The energy release during crack propagation is studied. From these results, general conclusions for coating design are drawn.

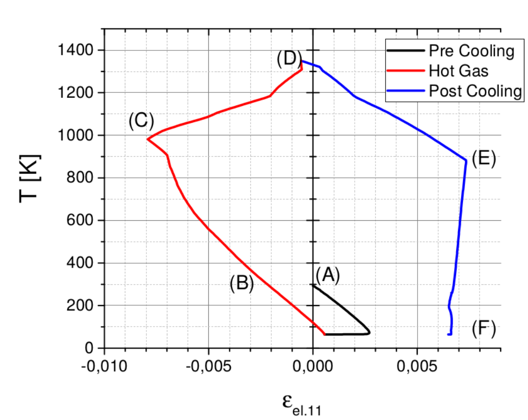

Fig. 1: Calculated strain in the coating surface for a full thermal cycle of the rocket engine. (A) Pre-cooling, (B)–(D) heating, (D)–(F) Post cooling

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