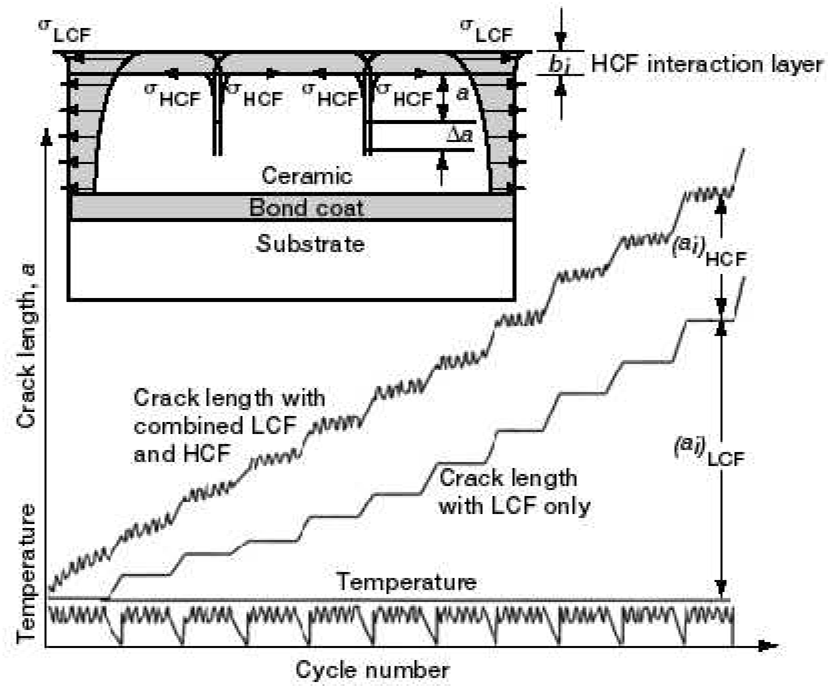
Thermal High- and Low-Cycle Fatigue Behavior of Thick Thermal Barrier Coating Systems

Ceramic thermal barrier coatings have received increasing attention for advanced gas turbine and diesel engine applications because of their ability to provide thermal insulation to engine components. However, the durability of these coatings under the severe thermal cycling conditions encountered in a diesel engine (ref. 1) still remains a major issue. In this research at the NASA Lewis Research Center, a high-power laser was used to investigate the thermal fatigue behavior of a yttria-stabilized zirconia coating system under simulated diesel engine conditions. The mechanisms of fatigue crack initiation and propagation, and of coating failure under complex thermal low-cycle fatigue (LCF, representing stop/start cycles) and thermal high-cycle fatigue (HCF, representing operation at 1300 rpm) are described.

Continuous wave and pulse laser modes were used to simulate pure LCF and combined LCF/HCF, respectively (ref. 2). The LCF mechanism was found to be closely related to the coating sintering and creep at high temperatures. These creep strains in the ceramic coating led to a tensile stress state during cooling, thus providing the major driving force for crack growth under LCF conditions. The combined LCF/HCF tests induced more severe coating surface cracking, microspallation, and accelerated crack growth than did the pure LCF test. HCF thermal loads also facilitated lateral crack branching and ceramic/bond coat interface delaminations.

HCF is associated with the cyclic stresses originating from the high-frequency temperature fluctuation at the ceramic coating surface. The HCF thermal loads act on the crack by a wedging mechanism (ref. 1), resulting in continuous crack growth at temperature. The HCF stress intensity factor amplitude increases with the interaction depth and temperature swing, and decreases with the crack depth. HCF damage also increases with the thermal expansion coefficient and the Young's modulus of the ceramic coating (refs. 1 and 3).

LCF/HCF interactions are expected to be complex. As illustrated in the figure for the proposed LCF/HCF mechanisms, alternating HCF and LCF loading (σ_{HCF} and σ_{LCF} stresses) at temperature and during cooling would increase the overall crack growth rate in the combined LCF/HCF tests. In addition, because of the ceramic-bond coat elastic mismatch, the stress intensity factor amplitudes tend to drop to zero when the crack approaches the ceramic/bond coat interface because of the relatively stiff bond coat (ref. 4). Therefore, the crack will be expected to deflect along the interface, thus leading to interface delamination under subsequent LCF and HCF loading. The thermal LCF and HCF crack growth is also greatly influenced by the HCF loading-unloading process.



Proposed thermal LCF and HCF mechanisms; a_i, crack length at any given cycle.

References

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