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Heat-Barrier Coatings for Combustion Chambers

Heat-barrier coating systems can be successful in high-temperature combustion chambers provided they are properly designed for the specific service environment (Table 1). Systems to withstand extreme thermal stressing are less of a problem than systems capable of surviving the stresses resulting from geometry and from the restraints imposed by cooled chamber walls.

Table 1. Test Results for Various Coating Systems; Arc-Plasma Deposition

Rocket engine	Coated area	Coating system[a]	Heat flux,[b] Btu/in^2-sec	Firing	Results
J-2	Combustion Chamber	Graded Inc–ZrO_2	13	7200 sec, total; 28 main-stage starts	No failure; thermal-fatigue life increased 7 times
J-2S	Film-coolant and hot-gas tap-off rings	Graded Inc–ZrO_2; W–ZrO_2	25	116 sec, total; 3 main-stage starts	Stopped oxidation, distortion, and melting of the metal component
J-2X	Film-coolant ring	W–ZrO_2	25	2502 sec, total; 62 main-stage starts	Significantly reduced deterioration of the metal component
Advanced	Chamber walls		50	10 hr; many starts; 8000° F flame temp.	

[a]Inc, Inconel [b]Through uncoated wall

A new layered coating was developed to protect an unsuccessful film-coolant ring located immediately below the injector plate of a rocket's combustion chamber. The system succeeded in a full-scale engine test although the coating spalled superficially in areas of high heat flux. The peak surface temperature of the nickel ring was reduced from 2600° to 1500°F by a coating having a thermal resistance of 200 in^2-sec-°F/Btu. Although desirable, further reduction would have required a coating thicker than 15 mils which would not have been sufficiently resistant to thermal shock.

The system was of arc-plasma-sprayed layers of graded Inconel and zirconia (Table 2); composition of graded layers was based on the thermal properties of the sprayed composite material. Unrestrained thermal expansion of selected compositions, plotted as a function of temperature, was used as an aid in selection of the compositions that resulted in the lowest buildup of stresses at interfaces between graded layers. The curves also aided determination of the necessary

(continued overleaf)

thermal resistance (thickness) required of each layer for control of the interfacial temperature—which was designed for minimum buildup of stress and to avoid melting of the metal phase in the graded layers.

Table 2. New J-2X Heat-Barrier System; Arc-Plasma Sprayed

Layer	Thickness, in.	Nature
Basic	0.002	Inconel
Second	0.002	50 Inconel–50 ZrO_2
Third	0.002	20 Inconel–80 ZrO_2
Outer	0.004	ZrO_2

A good test for comparison of coatings is to move a coated water-cooled tube in and out of an arc-plasma jet controlled at the heat flux expected in service; its shortcomings are the smallness of the test area and the low shear force of plasma gases. Although this test does not simulate all rocket-engine conditions it is very simple, efficient, and economical and yields significant data. The Inconel-zirconia coatings tested survived the following conditions without visible ill effects: total duration, 460 sec; surface temperature of coating, 4000°F; average temperature gradient, 300,000°F/in.; number of thermal shocks from 4000° to 65°F, 100.

Notes:

Requests for further information may be directed to:

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