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THE EFFECT OF OXIDATION ON THE HIGH HEAT FLUX BEHAVIOR OF A THERMAL BARRIER COATING

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The effect of oxidation on the high heat flux behavior of a thermal barrier coating has been evaluated by cyclically exposing preoxidized specimens to a 3000°C nitrogen plasma. The thermal barrier coatings consisted of a 0.025 cm layer of air-plasma-sprayed ZrO_2-7%Y_2O_3 and a 0.012 cm layer of low pressure-plasma-sprayed NiCoCrAlY applied over 0.13 cm diameter B1900+Hf cylindrical substrates. A gradient of 800°C is produced across the ceramic layer in each 0.5 second exposure. This is much more severe than the gradient encountered on a gas turbine engine. Prior to exposure, the specimens were preoxidized at 1200°C for times from 0 to 20 hours.

These coatings were found to be tolerant to the high heat flux plasma flame for all but the most severe preoxidations. However, life degraded rapidly for preoxidation times in excess of 15 hours at 1200°C. A log-log plot of cycles-to-failure vs. estimated oxidative weight gain yield a straight or nearly straight line, and this line could be rationalized using an oxidation-based model that had been developed previously for low heat flux applications.

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TURBOFAN ENGINE

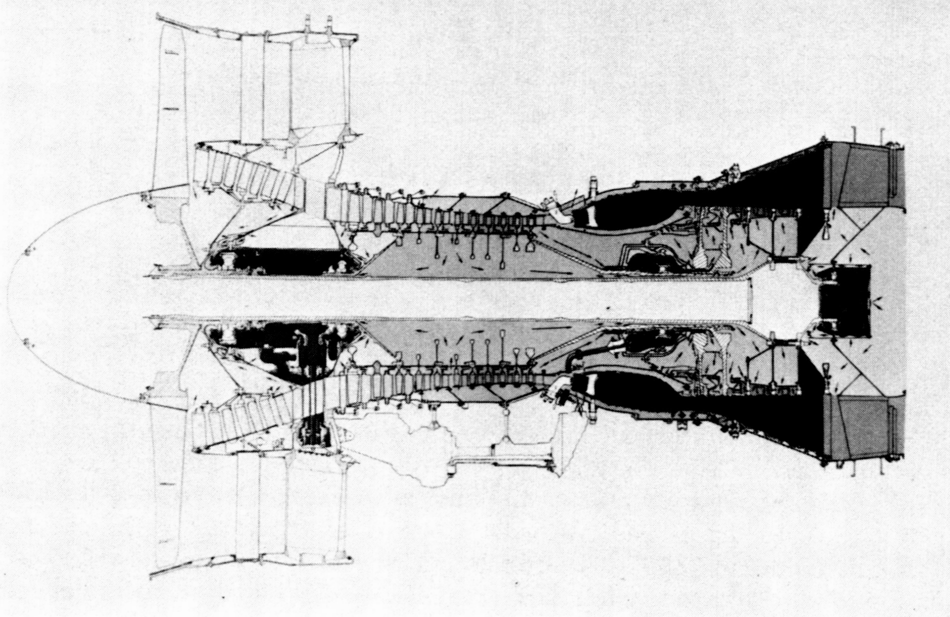

Figure 1.

FAILURE OF EARLY TBC IN JT9D ENGINE TEST

NO-COST CONTRACT WITH P&WA; 264 hr - 1424 CYCLES

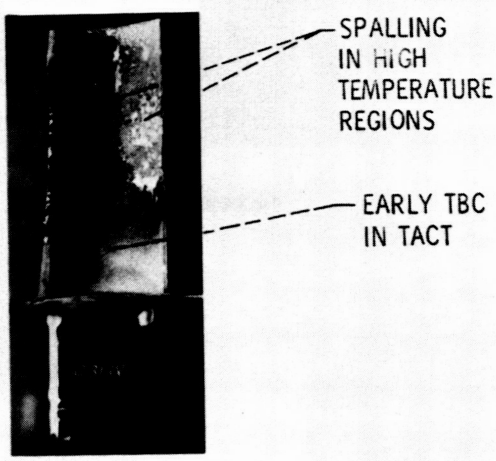

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Figure 2.

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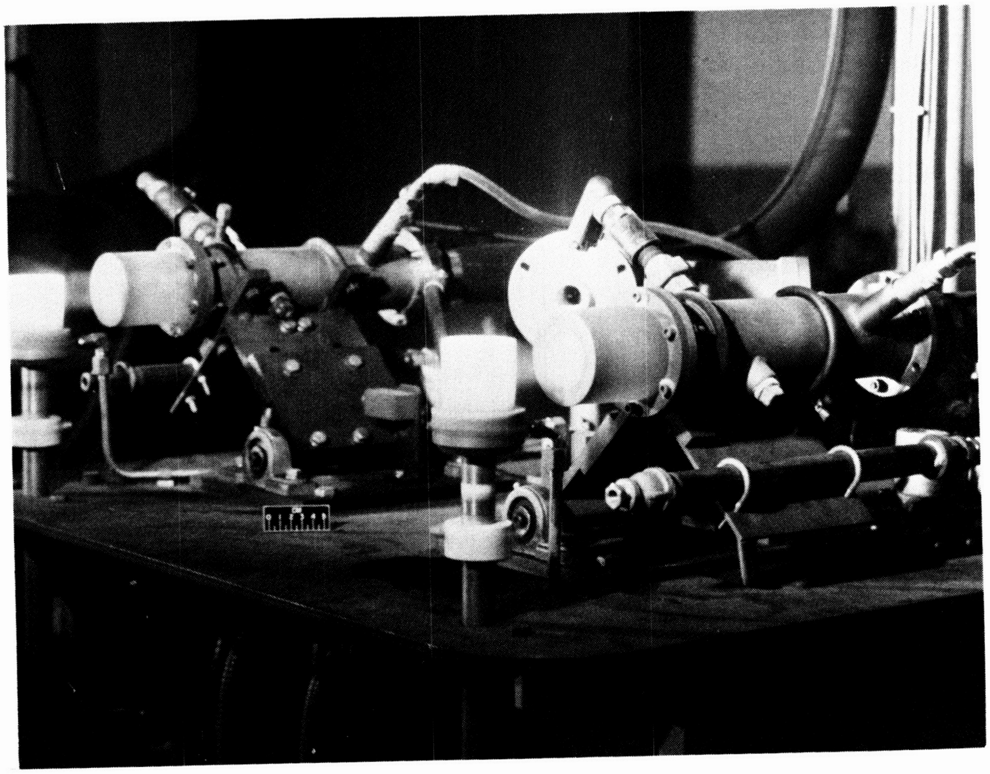

Figure 3.

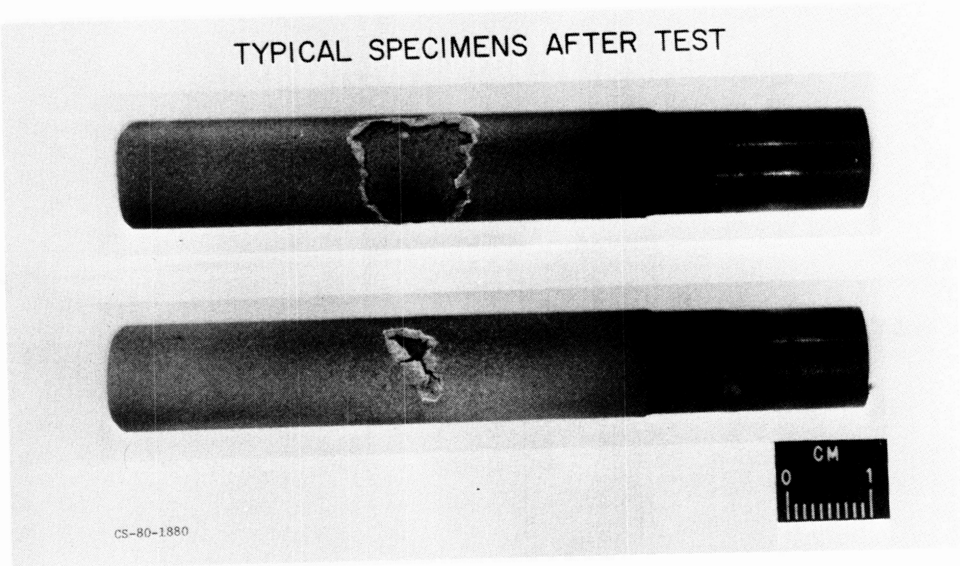

Figure 4.

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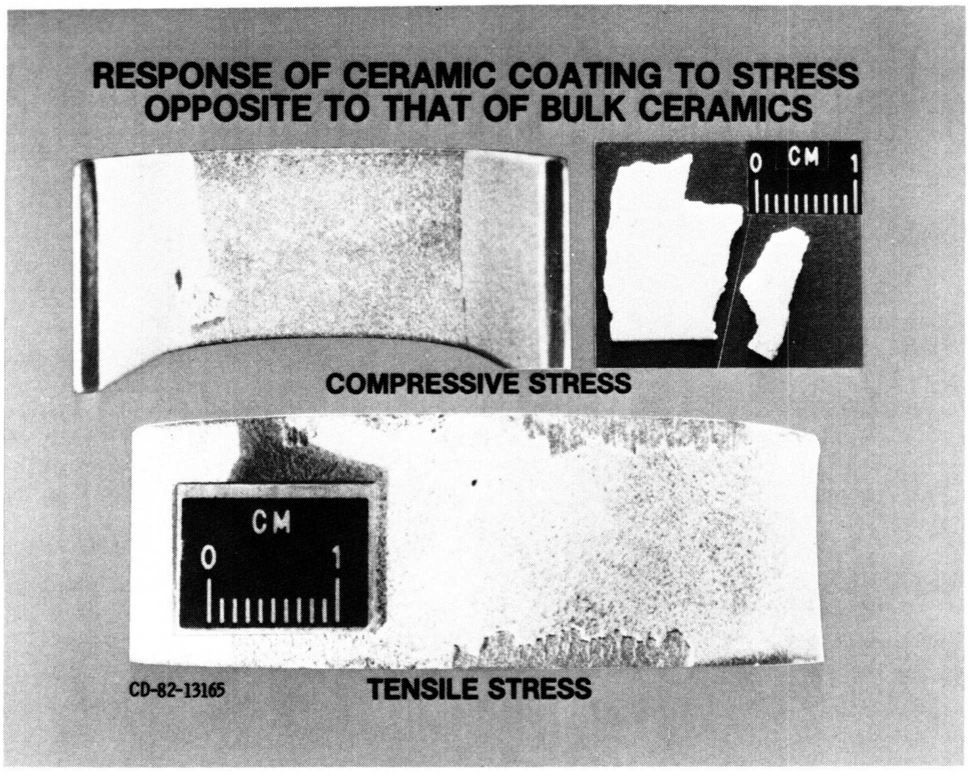

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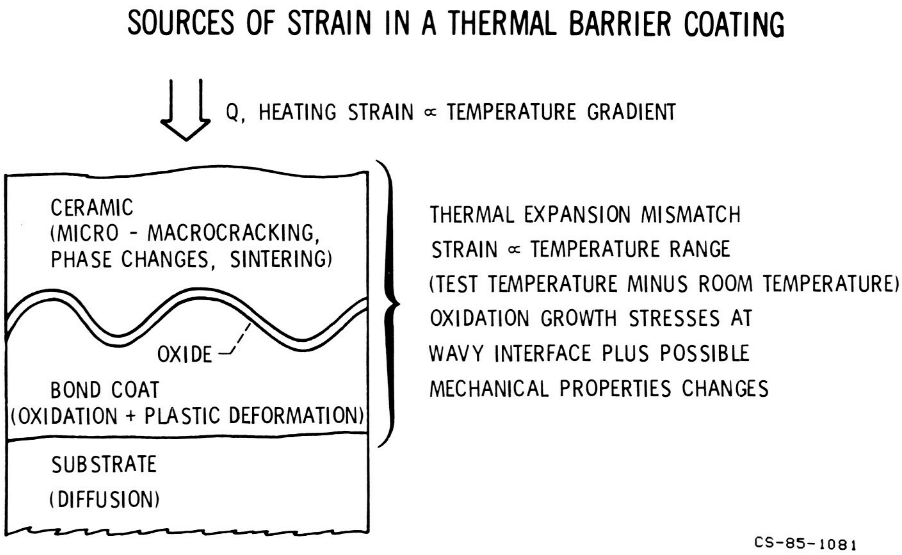

Figure 6.

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TBC'S FAIL IN OXIDIZING ENVIRONMENT

ZrO_2 - Y_2O_3/NiCrAlZr; TUBE FURNACE; 20 hr CYCLES AT 1250 °C

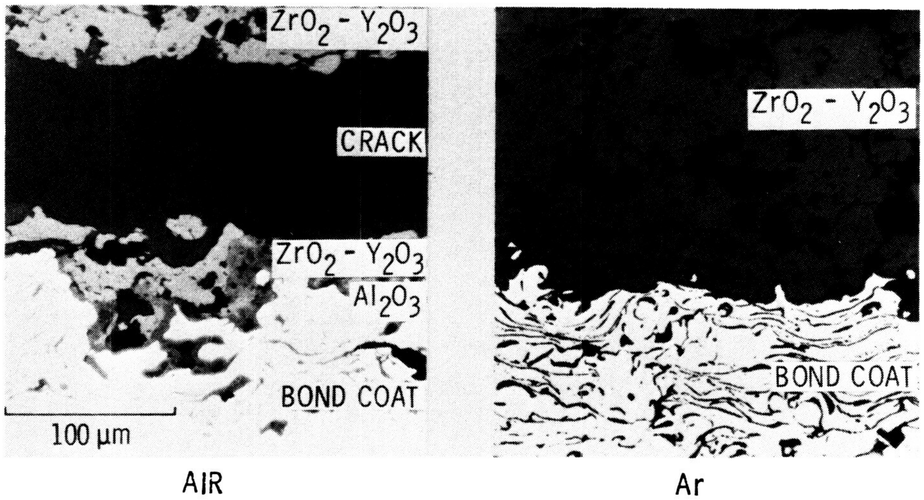

Figure 7.

PLASMA TORCH RIG (SCHEMATIC)

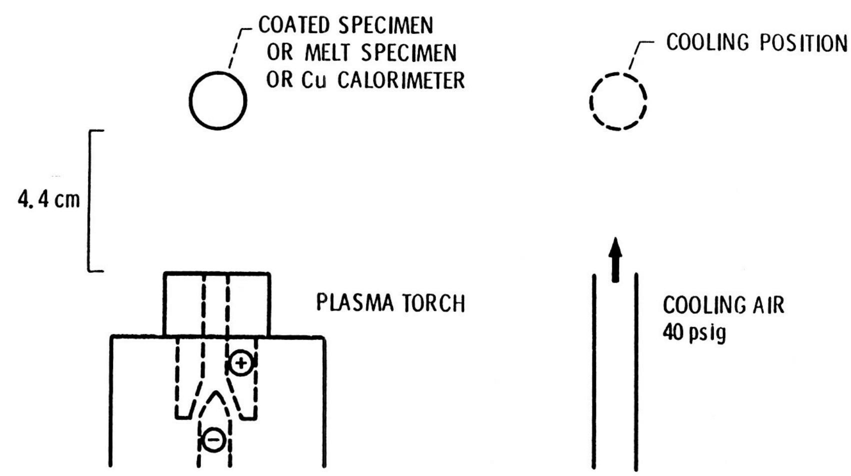

Figure 8.

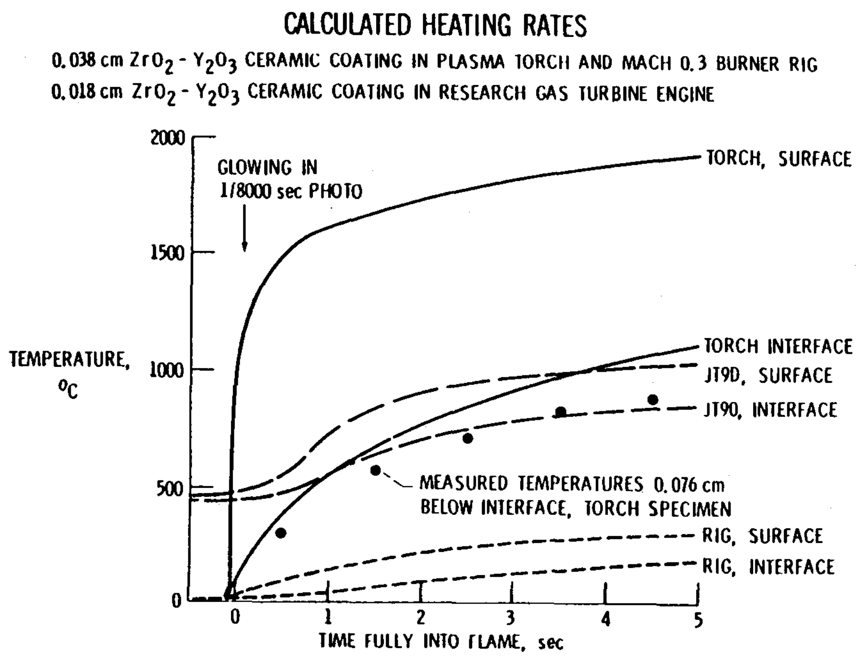

Figure 9.

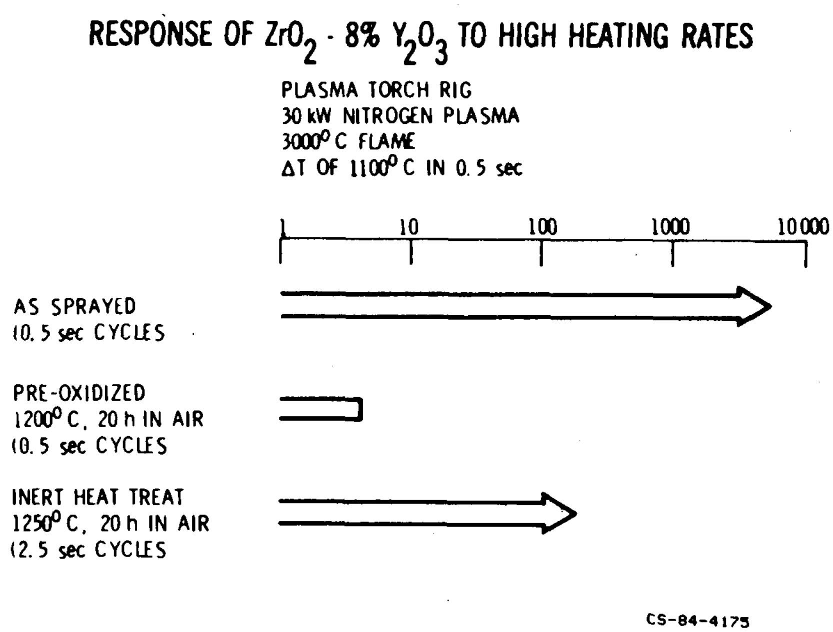

Figure 10.

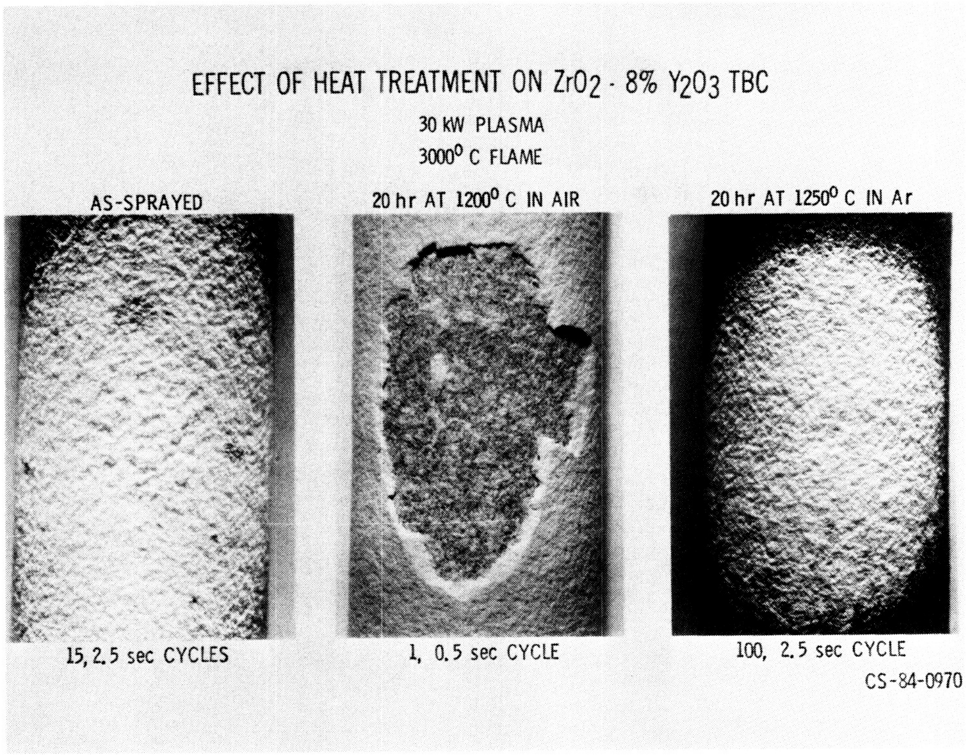

Figure 11.

THE STORY SO FAR -

- AS - SPRAYED 0.04 cm ZrO_2 - 8% Y_2O_3 TBCs TOLERATE LOCALIZED HIGH HEAT FLUX GREATER THAN EXPECTED IN GAS TURBINE ENGINE
- HIGH HEAT FLUX LIFE MAY BE SEVERLY DEGRADED BY PREOXIDATION
- INERT HEAT TREATMENT NOT HARMFUL (AND APPARENTLY BENEFICIAL, SEE THIN SOLID FILMS 119, 195 (1984).

THE NEXT STEP

- QUANTITATIVELY RELATE TBC OXIDATION TO HIGH HEAT FLUX LIFE.

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Figure 12.

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EXPERIMENTAL

SPECIMEN CONFIGURATION

CERAMIC LAYER

ZrO_2 - 7% Y_2O_3

0.025 CM THICK

ATMOSPHERIC PRESSURE PLASMA SPRAYED

BOND COAT

Ni - 22% Co - 18% Cr - 12% Al - 0.4%Y

0.012 cm THICK

LOW PRESSURE PLASMA SPRAYED

SUBSTRATE

B1900 + Hf

1.3 cm CLYINDERS

HEAT TREATMENT

4 hr AT 1080 °C IN H_2

PREOXIDATION

0 to 20 hr AT 1200 °C IN AIR

TEST RIG

30 kW N_2 PLASMA TORCH

3000 °C FLAME

0.5 sec CYCLES

800 °C GRADIENT (CALCULATED) IN 0.5 SEC

1300 °C SURFACE TEMPERATURE (CALCULATED) IN 0.5 SEC

CS-85-1075

Figure 13.

EFFECT OF PREOXIDATION ON HIGH HEAT FLUX LIFE

0.025 cm ZrO_2 - 7% Y_2O_3/NiCoCrAlY TBC

30 kW NITROGEN PLASMA

3000 °C FLAME

800 °C GRADIENT ACROSS CERAMIC IN 0.5 S

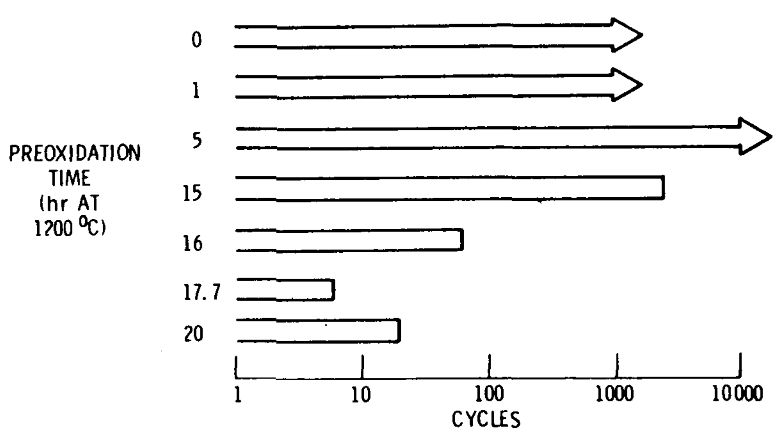

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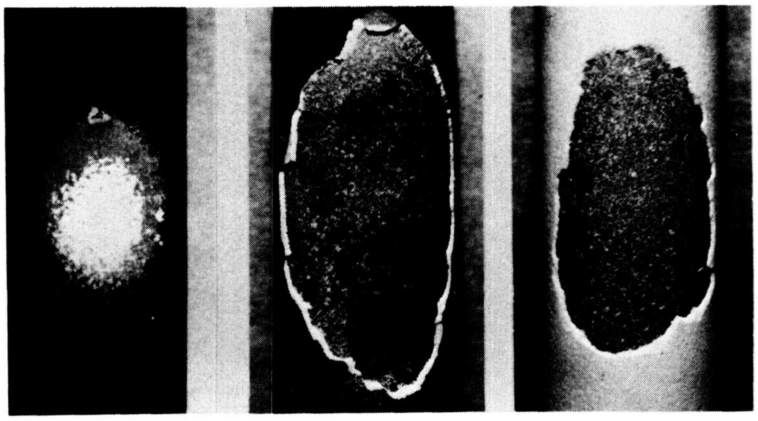
Figure 14.

EFFECT OF PREOXIDATION ON HIGH HEAT FLUX LIFE

0.025 cm ZrO_2 - 7% Y_2O_3/NiCoCrAlY
30 kW PLASMA
3000 °C FLAME
0.5 sec CYCLES

5 hr AT 1200 °C | 15 hr AT 1200 °C | 20 hr AT 1200 °C



AFTER 5000 OF 10000 CYCLES | 2350 CYCLES | 20 CYCLES

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Figure 15.

TBC LIFE MODEL DEVELOPED FOR LOW HEAT FLUX
J. CERAM SOC. 67, 517 (1984)

ASSUMPTIONS

- TIME DEPENDENCE - OXIDATION, W
- CYCLE DEPENDENCE - SLOW CRACK GROWTH DUE TO CYCLIC STRAIN
- OXIDIZED SPECIMEN BEHAVES AS IF CYCLIC STRAIN INCREASES

WORKING EXPRESSION

$$\sum_{N=1}^{N_f} [(1 - \varepsilon_r/\varepsilon_f)(w_N/w_c)^m + \varepsilon_r/\varepsilon_f]^b = 1$$

$\varepsilon_r/\varepsilon_f$ - RATIO OF THERMAL EXPANSION MISMATCH STRAIN TO FAILURE STRAIN

w_N/w_c - RATIO OF WEIGHT GAIN AFTER CYCLE N TO CRITICAL WEIGHT GAIN FOR ONE CYCLE FAILURE

m - EXPONENT EQUAL TO UNITY IF STRAIN INCREASES IN A LINEAR MANNER WITH WEIGHT GAIN

b - SUBCRITICAL CRACK GROWTH EXPONENT

N_f - CYCLES TO FAILURE

FORM OF EXPRESSION FOR PREOXIDATION

$$N_f = [(1 - \varepsilon_r/\varepsilon_f)(w_N/w_c)^m + \varepsilon_r/\varepsilon_f]^{-b}$$

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Figure 16.

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FIT OF HIGH HEAT FLUX DATA USING OXIDATION MODEL

$\omega_c = 1.95\ mg/cm^2$

$\varepsilon_r/\varepsilon_f = 0.1$

$b = 37$

$m = 1.0$

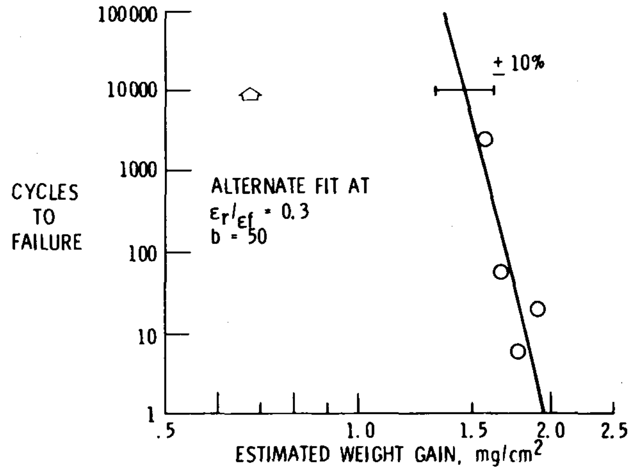

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Figure 17.

CONCLUSIONS

- MODERATELY OXIDIZED 0.025 cm ZrO_2 - 7% Y_2O_3 TBC_s TOLERATE HIGH HEAT FLUX
- TBC LIFE A VERY STRONG FUNCTION OF AMOUNT OF PREOXIDATION
- MODEL DEVELOPED FOR LOW HEAT FLUX MAY BE ADEQUATE FOR HIGH HEAT FLUX

FUTURE NEEDS

- WEIGHT GAIN MEASUREMENTS
- ADDITIONAL POINTS BETWEEN 10 AND 15 HOUR PREOXIDATION
- COMPLEMENTARY PREOXIDATION / INERT FURNACE EXPERIMENTS

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Figure 18.