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**TESTS OF NASA CERAMIC
THERMAL BARRIER COATING
FOR GAS-TURBINE ENGINES**

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TESTS OF NASA CERAMIC THERMAL BARRIER COATING FOR GAS-TURBINE ENGINES

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1. INTRODUCTION

A NASA ceramic thermal barrier coating (TBC) system was tested by industrial and governmental organizations for a variety of aeronautical, marine, and ground-based gas-turbine engine applications. This TBC is a two-layer system with a bond coating of nickel-chromium-aluminum-yttrium (Ni-16Cr-6Al-0.6Y, in wt. %) and a ceramic coating of yttria stabilized zirconia ($ZrO_2-12Y_2O_3$, in wt. %). Tests (ref. 1) have been conducted to determine corrosion resistance, thermal protection, durability, thermal conductivity, and fatigue characteristics. The information presented herein covers some of the significant test results obtained on the first three items. The information also includes photographs of coated parts after tests, measurements of coating loss, amount of metal wall temperature reduction when the TBC is used, and extent of base metal corrosion.

2. RESULTS AND DISCUSSION

2.1 Solid, High Temperature Alloy Pins

The corrosion protection and durability of the TBC and its capability for protection of base metal parts from corrosion in marine diesel fuel products of combustion was tested with four coated, solid pin-type specimens made from Rene 80 (fig. 1). The fuel contained 1 weight percent of sulphur and 10 parts per million of sea salt. The uncoated diameter of these pins was 0.318 centimeter. The tests with a burner rig simulated coating operation in marine gas-turbine engines.

One specimen withstood 1000 hours (40 cycles) of testing. A cycle consisted of 23 hours at a gas (and metal) temperature of 978 K with a 2 hour cool-down period to 300 K. Nominal, polished zirconia thickness before testing was 0.038 centimeter (bond coating thickness was about 0.01 cm) and metallographic examination after testing showed that about 0.008 centimeter of yttria stabilized zirconia was lost during the test. The TBC on the second specimen cracked and spalled after 322 hours or 14 of these cycles. The other two specimens were heated with this rig from about 300 K to a higher temperature of 1170 K, and then cooled down to 300 K. One of these specimens ran for 450 hours before cracks appeared in the ceramic; the other specimen was tested for 800 hours before cracking and spallation occurred. Metallographic examination showed no base metal deterioration on any of the four specimens. The results of these corrosion protection and durability tests indicated to the government laboratory that the TBC is as good as some other coating systems also tested at these cyclic conditions.

This polished coating was also tested in this rig at more severe conditions; in this case a cycle consisted of 48 hours at 978 K, 24 hours at 1061 K, 24 hours at 1170 K and cooling in still air to 300 K. The duration of a full cycle was about 100 hours. These burner rig tests simulated the same marine gas-turbine environment described above, but the uncoated pin diameter was 0.953 centimeter, or three times larger. The TBC on the larger diameter pin did not crack after 10 cycles of operation for a test duration of 1000 hours. These tests suggest that the TBC becomes more durable as pin diameter (or analogously, as turbine vane and blade leading edge diameter) is increased. Reasons for this better durability (no cracking) are probably due to the reduced stress in the TBC on larger diam-

eter pins and to the greater ease of plasma-spray application which can give more consistent TBC deposition on larger diameters.

2.2 Turbine Vanes-Military Aircraft Engine

An uncoated vane located in a hot gas region (about 1700 K) melted and burned during accelerated cyclic endurance tests in a military aircraft engine. This occurred during the first 60 hours of bimodal cyclic operation which included 240 cycles between an average gas temperature and pressure of 1550 K and 2.2 MPa, respectively, to shutdown, and 1920 cycles at this gas condition to idle. This melted vane was replaced with a coated vane of identical design and subjected to the same test conditions. After 60 hours of these cyclic tests, there was no melting, burning or other deterioration of the base metal. But, loss of the TBC was observed at the trailing-edge pressure surface aft of the cooling-air dump holes and in small areas of the leading edge. Because the metal wall was very thin at the trailing-edge region, it could only be lightly grit blasted (about half of the normal blasting pressure) prior to application of the TBC. This could be partly responsible for the premature coating deterioration in this region. This vane was sectioned and areas were found primarily at the leading edge, where the bond coating thickness was 0.005 centimeter or less. For best ceramic coating adherence, the bond layer should have been applied to thicknesses of 0.010 centimeter (ref. 2). The ceramic coating was applied at a nominal thickness of 0.020 centimeter.

A second vane of identical design (fig. 2) was coated, vacuum heat treated for 4 hours at 1.3×10^{-3} Pa and 1450 K (ref. 3), and then tested at the same engine conditions. Visual inspection of this vane after 100 hours of testing showed no deterioration of the TBC. This test time included 400 cycles and 3200 cycles of the two types just described. Testing continued with this vane for a total of 300 hours; this included 1200 cycles and 9600 cycles at each of the two types of cycles. Visual

inspection after 300 hours showed minute coating loss at the leading- and trailing-edge region, but again no deterioration of the cooled metal wall was noted. This better durability is attributed to the vacuum heat treatment which can sinter and densify the bond coating to improve its oxidation resistance and durability (ref. 3).

Iron oxide particles were deposited on the TBC during the test. Iron oxide (Fe_2O_3) can react with yttria stabilized zirconia in the TBC (when monoclinic ZrO_2 is present) over times of 200 to 800 hours and temperatures of 1473 to 1673 K (ref. 4). Since the coating operated in this temperature range and is presumably partially monoclinic, such a reaction may be partly responsible for the minute loss of the TBC after 300 hours of cyclic operation.

2.3 Combustor Dome and Scroll and Turbine Nozzle Shroud

Tests were conducted on the TBC in an air-cooled combustor dome and scroll, and turbine nozzle shroud of a military ground-vehicle engine at gas temperatures and pressures of 1467 K and 1.5 MPa. The uncoated parts deteriorated early at these gas conditions, but after the TBC was applied the deterioration stopped. Inspection of the coated parts after 500 hours of testing showed that the metal parts remained coated and showed no visible deterioration. Inspection of the engine, however, showed that some erosion of the TBC occurred because minute deposits of yttria stabilized zirconia material were found lying the ducting recesses. Bond and ceramic coating thickness estimates are 0.013 to 0.025 centimeter and 0.038 to 0.127 centimeter, respectively.

2.4 Turbine Plenum - Vehicular Engine

The hot-spot area of the turbine plenum was plasma-sprayed with the TBC. Figure 3 shows the good condition of this patch of TBC after 50 hours of accelerated endurance testing in a burner rig. These tests consisted of 120 cycles at 5 cycle variations (ref. 1). The highest gas temperature for these cycles was

1310 K and the lowest was 530 K. The cycle consisted of 5 minutes of heating and 20 minutes of cooling. Some uncoated metal areas were badly warped after the test; however, no warping or coating deterioration occurred where the patch of TBC was applied on the plenum metal wall. Because these cyclic burner tests were so promising, two other plenums with fully coated internal surfaces are undergoing tests in full-scale vehicular engines. One coated plenum has satisfactorily accumulated 220 hours with no visible warping or coating deterioration; the TBC has lowered hot-spot metal wall temperatures by 30 to 100 K (from a temperature level of 1300 K). Testing of the TBC on these plenums is continuing. The bond and ceramic coating thickness were about 0.015 and 0.050 centimeters, respectively.

3. CONCLUDING REMARKS

The TBC lowered metal temperatures, improved corrosion resistance of metal parts, increased part life, and eliminated burning, melting and warping that occurred with some of the uncoated metal parts tested in this cooperative effort. Some loss and cracking of the ceramic layer occurred in regions where uncoated parts and specimens had previously melted or corroded. However, metallographic examination showed no base metal deterioration of coated parts. This demonstrated that coating loss will not necessarily result in damage to metal parts. Recent tests at the NASA Lewis Research Center (ref. 5) indicate that better coating system durability was obtained on a burner rig and furnace specimens when the percent by weight of yttria was reduced to 6.2 or 7.9 in the zirconia ceramic coating and when the percent by weight of yttrium was reduced to 0.15 or 0.35 in the bond coating. These ceramic and bond coatings were not used herein.

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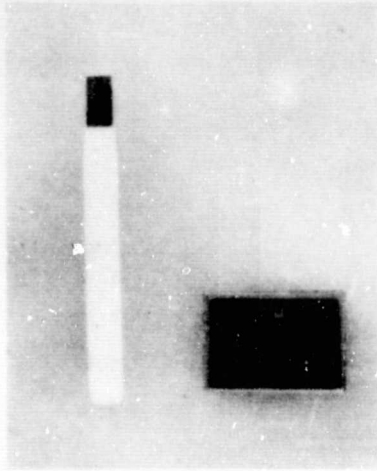


Figure 1. - Coated solid specimen for corrosion protection and durability tests in marine diesel fuel products of combustion.

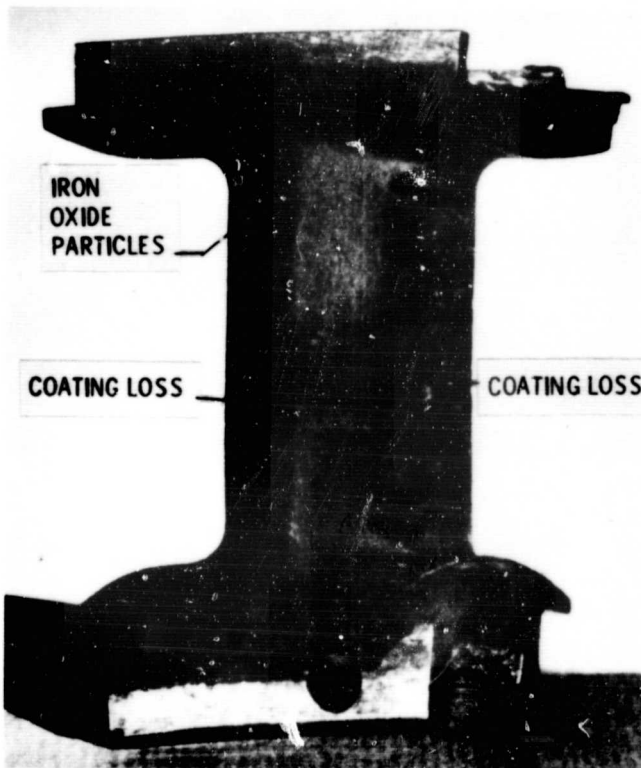


Figure 2. - Coated turbine vane after 300 hours (10,800 cycles) in a military aircraft gas-turbine engine.

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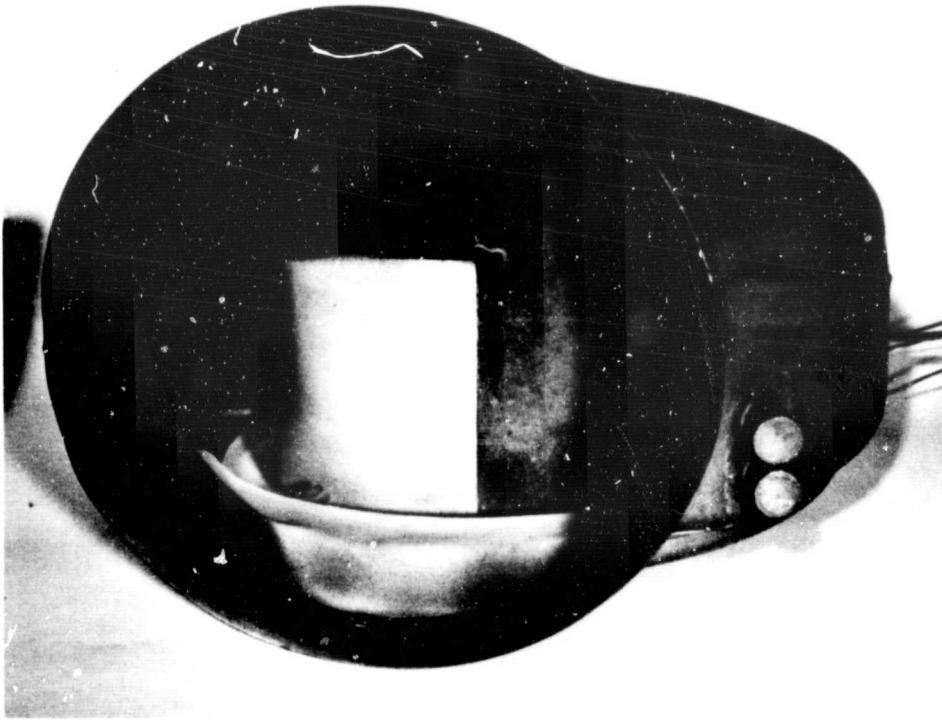


Figure 3. - TBC coating patch on turbine plenum-vehicular engine.