NASA Technical Memorandum 88821

The Effect of Laser Glazing on Life of ZrO_2 TBC'S in Cyclic Burner Rig Tests

I. Zaplatynsky
Lewis Research Center
Cleveland, Ohio

August 1986

(NASA-TM-88821) THE EFFECT OF LASER GLAZING ON LIFE OF ZrO2 TBCs IN CYCLIC BURNER RIG TESTS (NASA) 12 p CSCL 11F

N87-14487

Unclas
G3/26 43789

NASA

THE EFFECT OF LASER GLAZING ON LIFE OF ZrO_2 TBC'S IN CYCLIC BURNER RIG TESTS

I. Zaplatynsky
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-3026

SUMMARY

The performance of laser glazed zirconia (containing 8 wt % Y_2O_3) TBC's was evaluated in burner rig cyclic oxidation tests at 1000 and 1050 °C. It was found that the cycle duration has no effect on life of TBC's and that the increase in thickness of the glazed layer caused a slight reduction in life.

INTRODUCTION

Ceramic thermal barrier coatings (TBC's) and their potential benefits for gas turbine high temperature components have been the subject of numerous investigations. Some of the key early work, from 1950's to early 1970's was conducted at NASA Lewis Research Center (ref. 1 to 6). In the mid-1970's Stecura and Liebert (ref. 7 to 9) developed a successful zirconia-base TBC. This work stimulated further development and testing of TBC's for potential aircraft and nonaircraft applications (ref. 10 to 18). Models have been developed to explain the failure mechanisms of TBC's and to predict their life (refs. 19 and 20). Attempts were made to improve the ceramic coatings through segmentation by a laser surface fusion technique (ref. 21 to 23). However, this concept of increasing strain tolerance by segmenting the ceramic layer through exposure to a high intensity heat source, such as a laser beam, was not born out by the experimental work of the author (ref. 24), who studied the effect of laser glazing on the life of zirconia based TBC's in burner rig cyclic oxidation and corrosion tests. In this study it was found that glazed and nonglazed TBC's endured similar number of cycles of short duration in cyclic oxidation tests. However, in cyclic corrosion tests the laser glazed TBC's showed at least a four-fold improvement in life compared to nonglazed TBC's. The present investigation is an extension of this work. The duration of the heating cycle in the burner rig cyclic oxidation test was increased from 6 min to 1 hr to elucidate the effect of cycle duration on TBC's life.

EXPERIMENTAL PROCEDURE

Materials

Chemical compositions of the NiCrAlZr bond coat powder and of the yttria-stabilized zirconia powder, used in this investigation, are reported in Table I. The particle size of both powders was in the range between 200 and

325 mesh. Waspalloy[1] tubing (1.27 cm diameter and 0.124 cm wall thickness) was used as the substrate for the TBC's. Nominal composition of the Waspalloy is shown in the third column of the same table.

Coating Application

The Waspalloy tubing was cut into 18 cm long pieces. Each piece was provided with fittings to permit internal flow air cooling during plasma spraying. The procedure described in reference 8 was applied during deposition of both the bond coat and the yttria-stabilized zirconia. The nominal thickness of the bond coat was 0.020 cm and the actual thickness did not vary more than ±0.001 cm. The ceramic coating was deposited in two nominal thicknesses of 0.025 and 0.050 cm with deviations not exceeding ±0.002 cm and ±0.003 cm respectively. The coated length of the substrate tube was 6.7 cm. The diameter of each specimen was measured with micrometer in two locations after depositing the bond coat and after depositing the zirconia. Following this the specimen was cut down to 9.3 cm length, 2.6 cm of which was uncoated at one end. During cutting special precautions were taken in order to avoid contamination and mechanical damage of the ceramic coating.

Laser Glazing

A CO_2 laser was used to glaze the surface of the ceramic coatings. The laser beam was focused with a ZnSe (zinc selenide) lens (focal length 30.5 cm) to produce a circular beam area of approximately 0.10 cm in diameter. The glazing process was accomplished in an apparatus that allowed controlled rotation and translation of the specimen axis. By adjusting the speed of rotation, the cylindrical surface of the specimen could be scanned in a spiral fashion. Allowance was made to achieve 50 percent overlap of the scans. Figure 1 shows the surfaces of the zirconia coating glazed with laser beams of 75/mm^2 and 150 W/mm^2 power densities at a scanning speed of 88 cm/min. It can be seen that, although both beams had the same diameter, the trace left by the stronger beam is about 30 percent wider that the trace produced by the weaker beam. Although the glazed surface is segmented, it appears to be smooth and shiny. A typical cross section of a laser glazed zirconia TBC is illustrated in figure 2. It shows that the glazed surface layer was dense with a smooth external surface. The mud-flat cracks in the glazed layer penetrated partially into the nonglazed part of the zirconia coating.

Burner Rig Testing

The Mach 0.3 burner rig used in this study has been described in reference 25. Eight specimens were placed in a carousel holder which was rotated at 400 rpm in front of the burner nozzle. The centers of the specimens were evenly spaced on a 4.2 cm diameter circle. In this cyclic test, the specimens were heated for 1 hr at 1050±20 °C and then cooled with a stream of compressed

---

[1]Trade names or manufacturers names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by NASA.

air for 3 min. The burner rig was operated at a fuel-to-air ratio of about 0.049 using Jet A fuel and combustion air preheated to 260 °C. Test temperatures were determined with a calibrated, disappearing filament optical pyrometer by focusing on the center of the hot zone of the specimens facing the nozzle of the burner. During the test, the specimens were examined every 2 or 3 hr for the presence of bright rings, which were an indication of an incipient failure. At the same time the temperature was checked and corrected if necessary. When a failure was observed, the cycle was permitted to run to completion after which the failed specimen was removed from the carousel holder and replaced with a new specimen and the test continued. Figure 3 illustrates two typical failed specimens. All of the TBC failures occurred or apparently started on the back surfaces of the specimens where the temperature was determined to be about 100 °C higher (ref. 15). After the test, the specimens were vacuum mounted in epoxy and carefully cut with a diamond saw into sections suitable for metallographic examination.

RESULTS AND DISCUSSION

Preliminary experiments were performed for the purpose of characterizing plasma sprayed zirconia coatings and evaluating the effects of power density of the laser beam on the glazing process. The density of the plasma sprayed zirconia layer before glazing was determined to be 5.38 g/cc, which is 91.5 percent of the theoretical density. Examination of the microstructures of the plasma sprayed layer (fig. 2) revealed that the ceramic-bond coat interface was sometimes convoluted and occasionally particles of the bond coat material were found in the zirconia near the interface. This observation indicates that during the initial stages of zirconia deposition the surface of the bond coat was easily deformed. Determination of the weight and diameter of the specimens before and after glazing revealed that the specimens suffered weight loss during glazing process due to vaporization. For example, the laser beam with a power density of 75 W/mm^2 caused a weight loss of 0.00023 g/cm^2 while the 150 W/mm^2 beam caused 0.00050 g/cm^2 loss. The same beams produced 0.011 and 0.022 cm thick glazed (molten) zones, respectively. The segmentation cracks in the molten zone appeared to penetrate partially into the unglazed portion of the ceramic coating. The average size (diameter) of the "mud-flat" segments was about 0.05 cm. The surface of glazed zirconia was found to be smooth and glassy. No cracks were observed in the zirconia near the bond coat boundary as result of the glazing process.

The initial cyclic oxidation test at 1000 °C of glazed and unglazed specimens did not cause any externally visible failures or cracks in all eight specimens after 202 test cycles. However, metallographic examination of polished cross sections of these specimens revealed the presence of cracks in the zirconia near, and parallel to, the bond coat boundary (fig. 4). Results of cyclic oxidation tests on glazed 0.025 cm thick TBC's were erratic due to defective glazing. An undetected malfunction of the laser caused the whole thickness of the ceramic coating to melt and nearly all the specimens failed after only 40 cycles. This indicates that the life of zirconia TBC's is severely degraded when the whole thickness of the ceramic layer is glazed.

The results obtained with glazed and unglazed 0.050 cm thick zirconia coatings are shown in Fig. 5. All the glazed specimens exhibited longer life than the single unglazed specimen tested. It is risky to conclude that glazing extends the life of TBC's because only one unglazed specimen was tested. Nevertheless there definitely appears to be a trend which suggests some beneficial effect of laser glazing. Figures 6(a) and (b) illustrate the microstructure of unglazed and glazed 0.050 cm thick ceramic coatings after testing. Figure 6(a) shows a nontypical situation, where cracking occurred away from the ceramic/bond coat interface in a specimen that was not glazed. The glazed specimen (fig. 6(b)) exhibited a typical mode of failure, namely cracks near and parallel to the ceramic/bond coat interface. This observation brings out the fact that the glazing process does not affect the mode of failure in TBC's.

When comparing the presently obtained results with the data reported in reference 24 we can see that the life of the specimens, i.e., total time to failure with 0.050 cm thick zirconia layer, glazed with 75 W/mm^2 laser beam, expressed in terms of total exposure time, is similar to that of the specimens with 0.040 cm thick zirconia layer glazed with 50 W/mm^2 laser beam. In the present study, for 1 hr cycle length the average total life was 260 hr, i.e., 260 cycles, whereas in the former case it was 240 hr, i.e., 2400 cycles. Considering the fact that the data obtained in the experiments involving ceramic materials usually exhibit significant scatter, the obtained agreement is indeed very good. These results indicate that the time to failure of a TBC, exposed to burner rig cyclic test conditions, does not depend upon cycle duration, at least within the duration range from 6 min to 1 hr. Furthermore these results indicate that for laser glazed TBC's life is primarily a function of total time at temperature. While laser glazing improves life it apparently does not change the primary life limiting mechanism, i.e., bond coat oxidation.

SUMMARY OF RESULTS

1. The life of glazed zirconia TBC's in a burner rig cyclic oxidation test does not depend upon the cycle duration.

2. Glazing the entire thickness of the zirconia layer induces an early failure of TBC's. Apparently, the presence of a porous zone next to the bond coat is required to avoid early failure.

3. Increase of thickness of the glazed layer caused a slight reduction in life of TBC's. Seemingly there is an optimum glazed layer thickness for optimum TBC life.

4. During cyclic oxidation, the TBC's may develop cracks (delamination) near and parallel to the bond coat boundary, before any external sign of failure could be detected. This mode of cracking is responsible for ultimate failure (spallation) of the TBC.

5. Laser glazing causes a measurable amount of zirconia to be lost by vaporization.

6. The obtained data suggest that perhaps laser glazing of the ceramic coat contributes to life improvement.

REFERENCES

1. Schafer, L.J., Jr.; Stepka, F.S.; and Brown, W.B.: Comparison of Theoretically and Experimentally Determined Effects of Oxide Coatings Supplied by Fuel Additives on Uncooled Turbine-Blade Temperature During Transient Turbojet - Engine Operation. NACA RM-E53A19, 1953.

2. Bartoo, E.R.; and Clure, Y.L.: Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine, XIII - Endurance Evaluation of Several Protective Coatings Applied to Turbine Blades of Nonstrategic Steels. NACA RM-E53E18, 1953.

3. Hjelm, Lawrence N.; and Bornhorst, Bernard R.: Development of Improved Ceramic Coatings to Increase the Life of XLR 99 Thrust Chamber. Research-Airplane-Committee on Conference on the Progress of the X-15 Project, NASA TM-X-59072, 1961, pp. 227-253.

4. Nijpjes, J.M.: ZrO_2 - Coatings on Nimonic Alloys. High Temperature Materials, F. Benesovsky, ed., Springer Verlag, 1969, pp. 481-499.

5. Grisaffe, S.J.: Coatings and Protection. The Superalloys, C. Sims and W.C. Hagel, eds., John Wiley and Sons, 1972, Chapter 12, pp. 341-370.

6. Curren, Arthur, N.; Grisaffe, Salvatore, J.; and Wycoff, Kurt, C.: Hydrogen Plasma Tests of Some Insulating Coating Systems for the Nuclear Rocket Thrust Chamber. NASA TM-X-2461, 1972.

7. Liebert, C.H.; and Stecura, S.: Ceramic Thermal Protective Coating Withstands Hostile Environment of Rotating Turbine Blades. Lewis-12554, (NASA Technical Brief B75-10290) 1975.

8. Stecura, S.: Two-Layer Thermal Barrier Coating for Turbine Airfoils - Furnace and Burner Rig Test Results. NASA TM-X-3425, 1976.

9. Stecura, S.; and Liebert, C.H.: Thermal Barrier Coating System. U.S. Patent 4,055,705. Oct. 25, 1977.

10. Levine, S.R.; Miller, R.A.; and Hodge, P.E.: Thermal Barrier Coatings for Heat Engine Components. SAMPE Q., vol. 12, no. 1, Oct. 1980, pp. 20-26.

11. Stecura, S.: Effects of Compositional Changes on the Performance of a Thermal Barrier Coating System. NASA TM-78976, 1979.

12. Stecura, S.: Effects of Yttrium, Aluminum, and Chromium Concentrations in Bond Coatings on the Performance of Zirconia-Yttria Thermal Barriers. Thin Solid Films, vol. 73, 1980, pp. 481-489.

13. Gedwill, M.A.: Improved Bond Coatings for Use with Thermal Barrier Coatings. DOE/NASA/2593-18, NASA TM-81567, 1980.

14. Shankar, N.R.; Berndt, C.C.; and Herman, H.: Phase Analysis of Plasma Sprayed Zirconia-Yttria Coatings. Ceram. Eng. Sci. Proc., vol. 4, no. 9-10, Sept.-Oct. 1983, pp. 784-791.

15. Gedwill, M.A.: Burner Rig Evaluation of Thermal Barrier Coating Systems for Nickel-Base Alloys. DOE/NASA/2593-26, NASA TM-81684, 1981.

16. Miller, R.A.; Smialek, J.L.; and Garlick, R.G.: Phase Stability in Plasma-Sprayed, Partially Stabilized Zirconia-Yttria. Advances in Ceramics, Vol. 3, Science and Technology of Zirconia, N. Claussen, M. Ruhle, and A.H. Heuer, eds., American Ceramic Society, 1981, pp. 241-253.

17. Stecura, S.: Effects of Plasma Spray Parameters on Two-Layer Thermal Barrier Coating System Life. NASA TM-81724, 1981.

18. Andersson, C.A.; Greggi, J.; and Gupta, T.K.: Stabilization and Transformation of Tetragonal Zirconia. Westinghouse R&D Center, Pittsburgh, 83-1D6-Ceram-P1, Feb. 10, 1983.

19. Miller, R.A.; and Lowell, C.E.: Failure Mechanisms of Thermal Barrier Coatings Exposed to Elevated Temperatures. Thin Solid Films, vol. 95, 1982, pp. 265-273.

20. Miller, R.A.: Oxidation-Based Model for Thermal Barrier Coating Life. J. Am. Ceram. Soc., vol. 67, no. 8, Aug. 1984, pp. 517-521.

21. Bill, R.C.: Plasma-Sprayed Zirconia Gas Path Seal Technology: A State-of-the-Art Review. NASA TM-79273, 1979.

22. Gaffin, W.O.; and Webb, D.E.: JT8D and JT9D Jet Engine Performance Improvement Program. Task I: Feasibility Analysis. (PWA-5518-38, Pratt and Whiteny Aircraft Group; NASA Contract NAS3-20630) NASA CR-159449, 1979.

23. Sumner, I.E.; and Ruckle, D.L.: Development of Improved-Durability Plasma Sprayed Ceramic Coatings for Gas Turbine Engines. AIAA Paper-80-1193, June 1980.

24. Zaplatynsky, I.: Performance of Laser-Glazed Zirconia Thermal Barrier Coatings in Cyclic Oxidation and Corrosion Burner Rig Tests. Thin Solid Films, vol. 95, 1982, pp. 275-284.

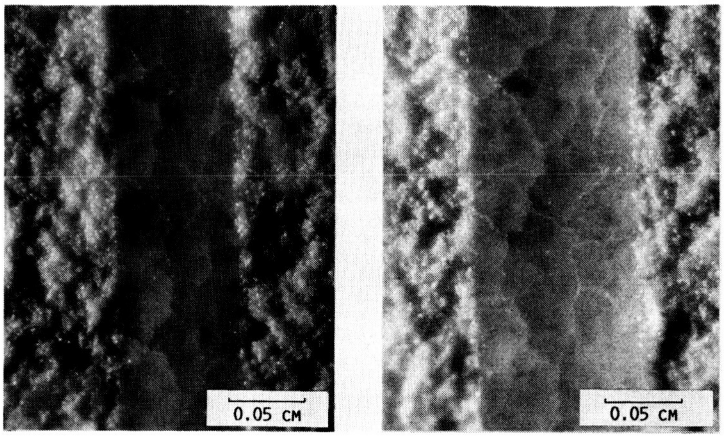
25. Gray, H.R.; Sanders, W.A.: Effect of Thermal Cycling in a Mach 0.3 Burner Rig on Properties and Structure of Directionally Solidified $\gamma/\gamma'-\delta$ Eutectic. NASA TM-X-3271, 1975.

TABLE I. - CHEMICAL COMPOSITION OF MATERIALS USED IN THIS INVESTIGATION

Element	Content, wt %		
	Bond coat[a]	Zirconia	Waspalloy[a]
Al	14	0.011	1.4
B	-------	ND[b]	.006
C	-------	-----	.07
Ca	-------	.078	---------
Co	-------	ND	13.5
Cr	14	ND	---------
Fe	-------	.03	2.0 max
Hf	-------	1.78	---------
Mg	-------	.031	---------
Mn	-------	ND	.75 max
Mo	-------	ND	4.3
Ni	Balance	ND	Balance
Si	-------	ND	---------
Ta	0.08	ND	---------
Ti	-------	.04	---------
V	-------	ND	3.0
W	-------	ND	---------
Y	-------	6.29	---------
Zr	.1	6.29	.009

[a]Nominal composition.
[b]Not determined.

ORIGINAL PAGE IS
OF POOR QUALITY



(A) TRACE OF 75 W LASER BEAM ON PLASMA SPRAYED ZrO_2 - 8 WT % Y_2O_3 SCANNING SPEED 88 CM/MIN.

(B) TRACE OF 150 W LASER BEAM ON PLASMA SPRAYED ZrO_2 - 8 WT % Y_2O_3 SCANNING SPEED 88 CM/MIN.

FIGURE 1. - PHOTOMICROGRAPH OF TRACE PRODUCED BY ONE SCAN OF A LASER BEAM.

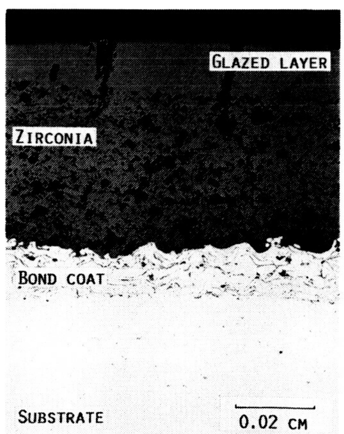


FIGURE 2. - PHOTOMICROGRAPH OF CROSS-SECTION OF GLAZED BUT NOT TESTED TBC. SCANNING SPEED 88 CM/MIN. POWER DENSITY 75 W/MM^2.

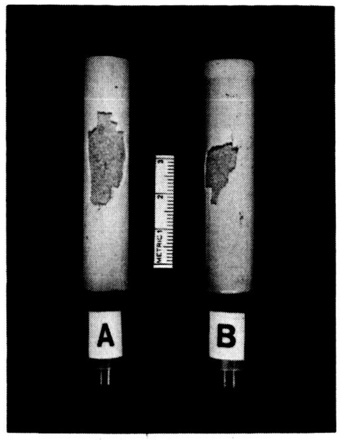
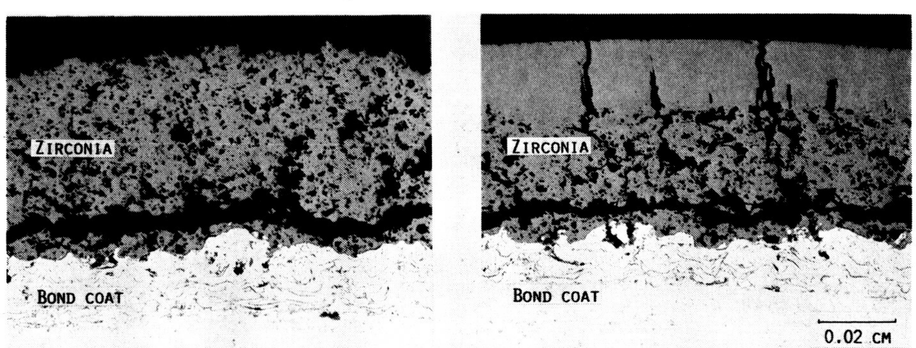


FIGURE 3. - PHOTOGRAPH OF SPECIMENS, WITH 0.050 CM THICK CERAMIC COATING, AFTER TESTING.
(A) NONGLAZED. LIFE: 150 CYCLES.
(B) GLAZED WITH 150 W/MM^2 LASER BEAM. LIFE: 160 CYCLES.



(A) NONGLAZED. (B) GLAZED.

FIGURE 4. - PHOTOMICROGRAPHS OF CROSS-SECTIONS OF NONGLAZED AND GLAZED TBC'S AFTER 202 CYCLES AT 1000 ^{o}C.

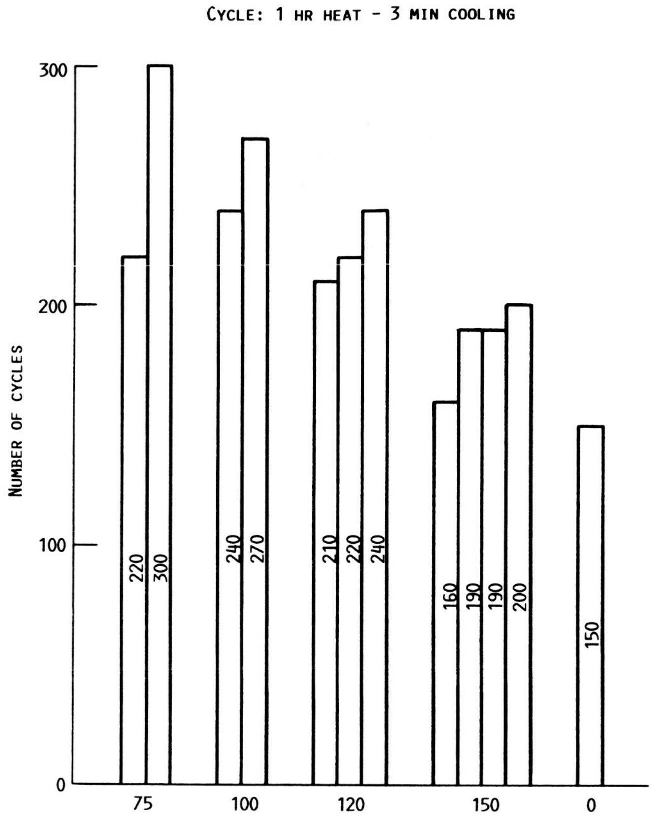
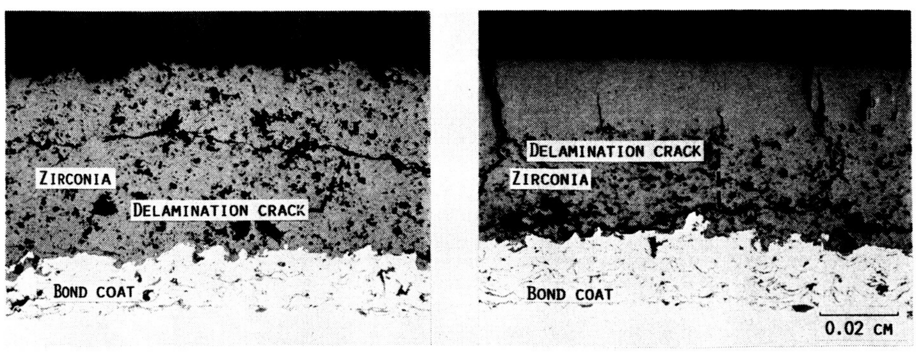


FIGURE 5.- LIFE OF 0.050 CM THICK, GLAZED AND NON-GLAZED ZIRCONIA TBC'S IN BURNER RIG CYCLIC OXIDATION TESTS AT 1050 °C.

ORIGINAL PAGE IS OF POOR QUALITY



(A) NONGLAZED. LIFE: 150 CYCLES. (B) GLAZED (120 W/MM^2). LIFE: 240 CYCLES.

FIGURE 6. - PHOTOMICROGRAPHS OF CROSS-SECTIONS OF 0.050 CM THICK ZIRCONIA TBC'S AFTER CYCLIC TESTING AT 1050 °C.

1. Report No. NASA TM-88821	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: The Effect of Laser Glazing on Life of ZrO_2 TBC's in Cyclic Burner Rig Tests		5. Report Date: August 1986
		6. Performing Organization Code: 505-63-01
7. Author(s): I. Zaplatynsky		8. Performing Organization Report No.: E-3026
		10. Work Unit No.
9. Performing Organization Name and Address: National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered: Technical Memorandum
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The performance of laser glazed zirconia (containing 8 wt % Y_2O_3) TBC's was evaluated in burner rig cyclic oxidation tests at 1000 and 1050 °C. It was found that the cycle duration has no effect on life of TBC's and that the increase in thickness of the glazed layer caused a slight reduction in life.

17. Key Words (Suggested by Author(s)): Thermal barrier system; Zirconia + yttria; Plasma sprayed coatings; Laser glazing; Cyclic oxidation		18. Distribution Statement: Unclassified - unlimited; STAR Category 26	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of pages	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161