

# The Effect of Laser Glazing on Life of ZrO<sub>2</sub> TBC'S in Cyclic Burner Rig Tests

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

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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<sup>1</sup> 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  $\pm 0.001$  cm. The ceramic coating was deposited in two nominal thicknesses of 0.025 and 0.050 cm with deviations not exceeding  $\pm 0.002$  cm and  $\pm 0.003$  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<sub>2</sub> 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<sup>2</sup> and 150 W/mm<sup>2</sup> 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 than 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  $1050 \pm 20$  °C and then cooled with a stream of compressed

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<sup>1</sup>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<sup>2</sup> caused a weight loss of 0.00023 g/cm<sup>2</sup> while the 150 W/mm<sup>2</sup> beam caused 0.00050 g/cm<sup>2</sup> 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<sup>2</sup> 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<sup>2</sup> 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.

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

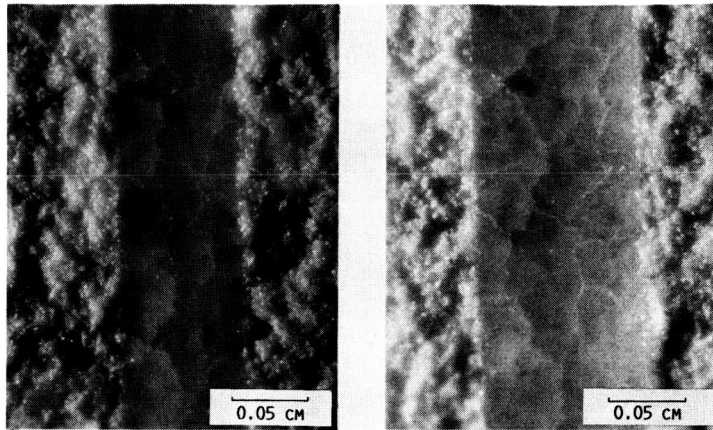
Element	Content, wt %		
	Bond coats	Zirconia	Waspalloya
Al	14	0.011	1.4
B	-----	ND <sup>b</sup>	.006
C	-----	-----	.07
Ca	-----	.078	-----
Co	-----	ND	13.5
Cr	14	ND	-----
Fe	-----	.03	2.0 max
Hf	-----	1.78	-----
Mg	-----	.031	-----
Mn	-----	ND	.75 max
Mo	-----	ND	4.3
Ni	Balance	ND	Balance
Si	-----	ND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

<sup>a</sup>Nominal composition.

<sup>b</sup>Not determined.



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

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

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

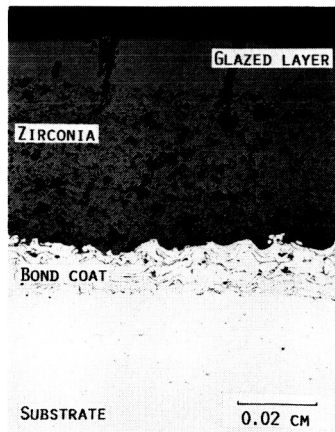


FIGURE 2. - PHOTOMICROGRAPH OF  
CROSS-SECTION OF GLAZED BUT NOT  
TESTED TBC. SCANNING SPEED  
88 CM/MIN. POWER DENSITY  $75 \text{ W/MM}^2$ .

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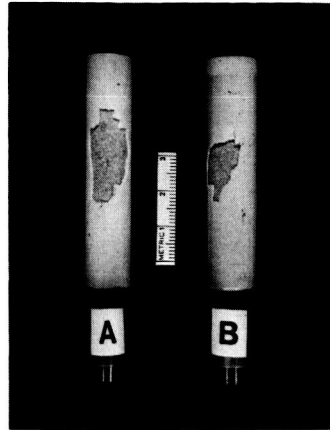


FIGURE 3. - PHOTOGRAPH OF SPECIMENS,  
WITH 0.050 CM THICK CERAMIC COAT-  
ING, AFTER TESTING.  
(A) NONGLAZED. LIFE: 150 CYCLES.  
(B) GLAZED WITH 150 W/MM<sup>2</sup> LASER  
BEAM. LIFE: 160 CYCLES.

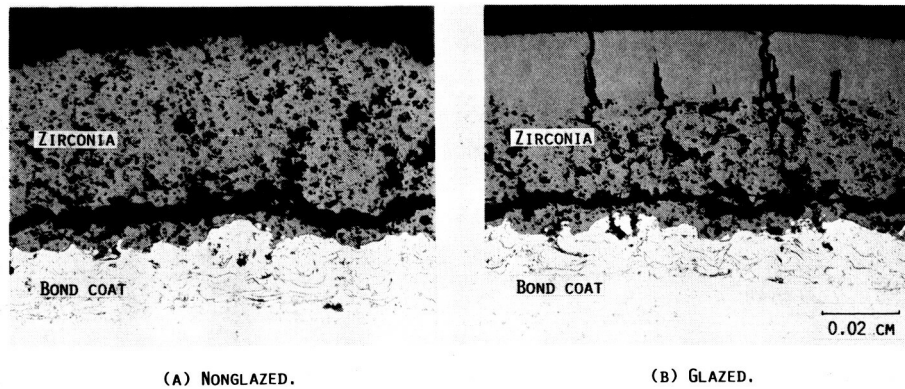


FIGURE 4. - PHOTOMICROGRAPHS OF CROSS-SECTIONS OF NONGLAZED AND GLAZED TBC'S AFTER 202 CYCLES  
AT 1000 °C.

CYCLE: 1 HR HEAT - 3 MIN COOLING

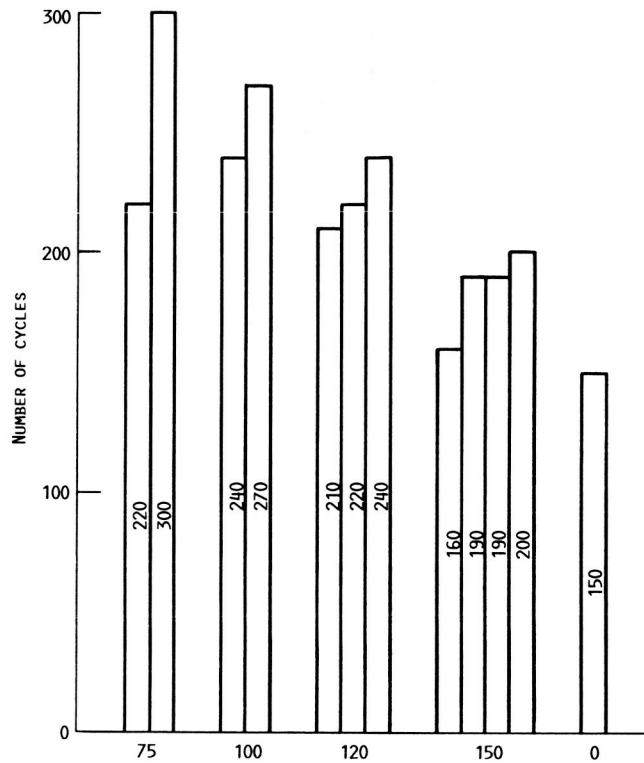
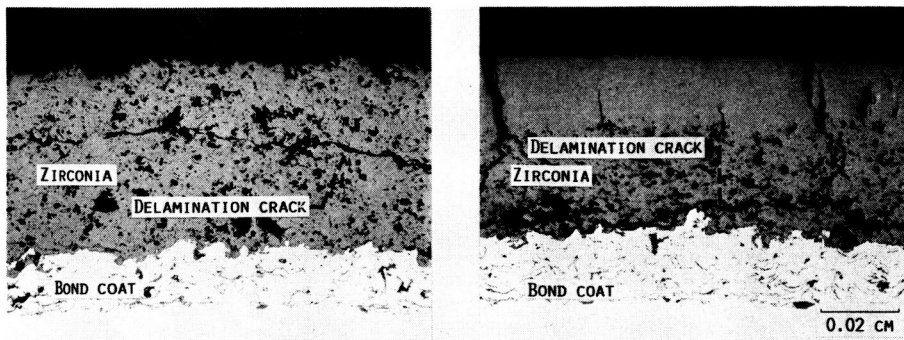


FIGURE 5.- LIFE OF 0.050 CM THICK, GLAZED AND NON-GLAZED ZIRCONIA TBC'S IN BURNER RIG CYCLIC OXIDATION TESTS AT 1050 °C.

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(A) NONGLAZED. LIFE: 150 CYCLES.

(B) GLAZED (120 W/MM<sup>2</sup>). LIFE: 240 CYCLES.

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

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