Processing and Deposition of Nanocrystalline Oxide Composites for Thermal Barrier Coatings

Technical Report on ONR Grant No. N00014-95-1-0626
for the period of April 1, 2000-June 30, 2000

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1. Electrophoretic Deposition of NiCrAlY Bond Coat and Oxide Nanocomposite

As described in a previous report [1], electrophoretic deposition was used as the method in coating substrate materials for thermal barrier coating applications. In this report, we used electrophoretic deposition to deposit a NiCrAlY bond coat, and a nanocomposite Al_2O_3-YSZ coating, onto a Ni substrate. The bond coat forms a protective oxide scale that inhibits oxidation of the alloy substrate. The NiCrAlY interlayer can also provide good diffusion stability between the metallic substrate and the ceramic coating layer. We examined the thermal stability of the Al_2O_3-YSZ coatings when applied on top of the NiCrAlY-based bond coat. In particular, the effect of alumina content on the thermal stability of the nanocomposite coatings was examined.

For deposition of the bond coat, a coating solution consisting of ethanol, water, nitric acid, and the NiCrAlY powder was used. The coating composition was similar to that reported previously [1]. NiCrAlY powder was first mechanically milled for 24 hr to decrease particle size and then added to the coating solution to form a slurry. The slurry was then ultrasonicated for 15 min and aged for 24 hr. Ni electrodes were then lowered into the slurry and a DC voltage (~ 40 V/cm) was applied for 120 sec, resulting in a ~ 50 μm-thick coating of the cathode with the NiCrAlY powder. The electrodes were then removed from the slurry, and the coated Ni electrode was dried at 110 °C for 2 hr.

Next, Al_2O_3-YSZ nanocomposites were coated onto NiCrAlY-coated substrates using electrophoretic deposition. A DC voltage (~ 40 V/cm) was applied for 300 sec, resulting in a ~ 50 μm-thick Al_2O_3-YSZ coating on top of the NiCrAlY bond coat. Following drying, the coatings were cold isostatically pressed at 50,000 psi to increase mechanical stability.

2. Thermal Stability of Alumina-Zirconia Thermal Barrier Coatings

Oxide nanocomposite coatings with various Al_2O_3 contents were prepared and tested for thermal stability in the presence and absence of a bond coat (Table 1). Following electrophoretic deposition, the Al_2O_3-YSZ/NiCrAlY-coated Ni substrates were pretreated in argon at 1150 °C for 1 hr (ramp = 10 °C/min). They were then tested for long-term thermal stability by heating to 1150 °C in air (ramp =10 °C/min). In addition, the coatings were also subjected to thermal cycles of 25 °C-1150 °C-25 °C (with ramping and cooling rates of ~ 300 °C/min) to examine any failure modes due to thermal shock. The samples were inspected visually every hour for spallation of the coating and oxidation of the Ni substrate. All experiments were repeated three times.

The addition of the bond coat did not significantly increase the thermal stability of the thermal barrier coatings. Coatings prepared with and without the intermediate bond coat layer had similar thermal stability, in both coating lifetime and thermal cycling studies (Tables 1 and 2).

The addition of a small amount of Al_2O_3 to the coatings had a positive effect on the coating lifetime in the presence and absence of a bond coat (Table 1). The coating without Al_2O_3 began to crack and spall after 3-4 hr of heat treatment. The most stable compositions were 5 wt% Al_2O_3-95 wt% YSZ and 10 wt% Al_2O_3-90 wt% YSZ, which lasted for 6 hr before significant spallation occurred. Coatings with higher Al_2O_3 contents (20 wt% and 100 wt%) had poor thermal stability, lasting only 2 hr and 1 hr, respectively, at 1150 °C before spallation occurred.

The reduced thermal stability when using > 10 wt% Al_2O_3 could be attributed to a difference in the thermal expansion coefficients of Al_2O_3 and YSZ, which could induce stress and subsequent failure of the coating. Thermal stabilization with the addition of 5-10 wt% Al_2O_3 could be explained by a decrease in oxygen conductivity [2].

For the thermal cycling studies, Al_2O_3 addition also had a positive effect on the stability of the coatings with and without the NiCrAlY bond coat (Table 2). The most stable compositions were 5 wt% Al_2O_3-95 wt% YSZ and 10 wt% Al_2O_3-90 wt% YSZ, which lasted 3 thermal cycles before significant spallation occurred. Other Al_2O_3 compositions lasted ≤ 1 thermal cycle before failure.

Coatings were examined with X-ray diffraction (XRD) to determine their crystal phase before and after the thermal shock treatment. Figure 1 shows the XRD patterns of 5 wt% Al_2O_3-95 wt% YSZ before and after 3 thermal cycles at 1150 °C. Prior to the thermal cycling, ZrO_2 was present in the tetragonal phase. Ni peaks were noted from the Ni substrate, after the powder was deposited onto the Ni substrate. After 3 thermal cycles, ZrO_2 retained 100% tetragonal phase. NiO peaks were observed after the heat treatment, due to cracking of the coating and oxidation of the Ni substrate. Other Al_2O_3-YSZ nanocomposite coatings had similar phases present as this system before and after thermal shock treatment at 1150 °C.

3. Future Work

Plasma Spraying of NiCrAlY Bond Coat and Coating of the Oxide Nanocomposites

NiCrAlY bond coats will be applied onto the Ni substrates using plasma spraying. Following the deposition of the plasma-sprayed NiCrAlY coatings, electrophoretic deposition will be used to deposit oxide nanocomposite coatings with various Al_2O_3 contents. The thermal barrier coatings will be subjected to several pretreatments prior to coating lifetime and thermal shock studies. Following thermal stability studies, the coatings will be examined with XRD and SEM to determine the failure mechanisms responsible for the spallation of the oxide composite and NiCrAlY bond coat. The effect of Al_2O_3 in coating stability will also be investigated.

4. References

[1] Ying, J.Y., Technical Report on ONR Grant No. N00014-95-1-0626 for the period of October 1, 1999-December 31, 1999.

[2] Ying, J.Y., Technical Report on ONR Grant No. N00014-95-1-0626 for the period of January 1, 2000-March 31, 2000.

Table 1. Coating lifetime for various alumina-zirconia nanocomposite coatings. The coating lifetime was given by the duration before spallation was first observed for a coating heat treated at 1150 °C in air.

Coating Composition	Coating lifetime without bond coat (hr)	Coating lifetime with bond coat (hr)
100 wt% YSZ	3	4
5 wt% Al_2O_3-95 wt% YSZ	6	6
10 wt% Al_2O_3-90 wt%YSZ	6	6
20 wt% Al_2O_3-80 wt% YSZ	1	2
100 wt% Al_2O_3	1	1

Table 2. Thermal shock stability for various alumina-zirconia nanocomposite coatings. The number of cycles to failure was given by the number of thermal cycles prior to the observation of spallation. A thermal cycle involved heating the sample in air from 25 °C to 1150 °C, holding at 1150 °C for one hour, and then cooling to 25 °C, with ramping and cooling rates of ~ 300 °C/min.

Coating Composition	Cycles to failure without bond coat (hr)	Cycles to failure with bond coat (hr)
100 wt% YSZ	1	1
5 wt% Al_2O_3-95 wt% YSZ	3	3
10 wt%Al_2O_3-90 wt%YSZ	3	3
20 wt% Al_2O_3-80 wt% YSZ	1	1
100 wt% Al_2O_3	<1	<1

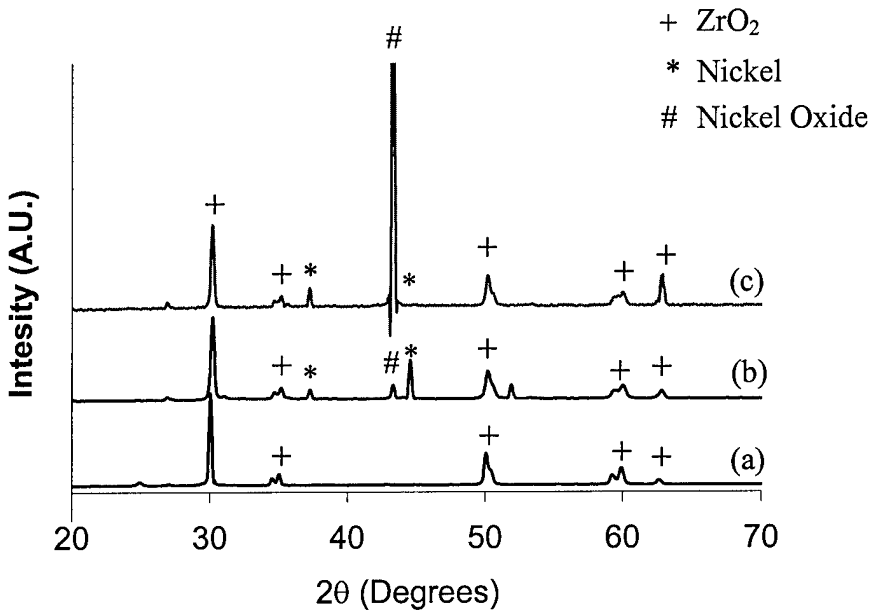

Figure 1. X-ray diffraction patterns of 5 wt% Al_2O_3-95 wt% YSZ (a) powder, (b) as deposited on Ni substrate with NiCrAlY bond coat, and (c) following 3 thermal cycles at 1150 °C.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
1 July, 2000

3. REPORT TYPE AND DATES COVERED
Progress Report: 1 April 2000 - 31 June 2000

4. TITLE AND SUBTITLE
Processing and Deposition of Nanocrystalline Oxide Composites for Thermal Barrier Coatings

5. FUNDING NUMBERS
G - N00014-95-1-0626

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8. PERFORMING ORGANIZATION REPORT NUMBER

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Office of Naval Research
800 North Quincy Street
Ballston Tower One
Arlington, VA 22217-5660

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for pulbic release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report describes the thermal stability of nanocrystalline oxide composites for thermal barrier coating applications. The coatings were tested fo long-term and thermal shock stability. Electrophoretic deposition (EPD) was used to coat the nanocomposite powders onto nickel substrates. A NiCrAlY bond coat was also coated onto the Ni substrates prior to deposition of the nanocrystalline oxide composites. It was found that a small addition of alumina (5 wt%) enhanced the thermal stability of the coatings. The NiCrAlY bond coat, when coated using electrophoretic deposition did not significantly enhance the thermal stability of the coatings. Future work will combine plasma-sprayed bond coats with oxide composites deposited via EPD.

14. SUBJECT TERMS
Nanocrystalline, Electrophoretic Deposition, Thermal Barrier Coatings

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
UL