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Summary

In order to lower the thermal conductivity of Electron Beam-Physical Vapour Deposited Thermal Barrier Coatings (EB-PVD TBCs), so-called “herringbone” TBCs with a zig-zag or wavy column structure have been developed. This structure can result in more than 25 % reduction in thermal conductivity compared to a straight column TBC. This paper focuses on burner rig tests which were done to assess the service life of herringbone TBCs. Burner rig tests at 1135 °C and with a cycle length of 5 minutes showed that the number of cycles to failure of the herringbone TBCs was comparable to but lower than that of reference straight column TBCs. Furthermore, the symmetric zig-zag TBCs showed erosion at the flame-heated side. It is concluded that though the new herringbone TBCs show promising thermal properties, the production process must be optimised to improve the life and flame erosion resistance.

Contents

5 Figures

(13 pages in total)

Nomenclature

EB-PVD	Electron Beam - Physical Vapour Deposition
TBC	Thermal Barrier Coating
TGO	Thermally Grown Oxide

1 Introduction

Thermal Barrier Coatings (TBCs) are applied to the hot components of gas turbines in order to allow higher turbine entry temperature (which increases the thermal efficiency of the gas turbine) or to achieve lower substrate temperatures. For application on the most highly loaded gas turbine components, i.e. rotating blade airfoils and platforms, Electron Beam – Physical Vapour Deposited (EB-PVD) TBCs are used. Owing to their columnar microstructure these TBCs show excellent strain tolerance, but a higher thermal conductivity compared to the more conventional plasma sprayed TBCs.

Reduction of the thermal conductivity of EB-PVD TBCs can be obtained by compositional changes (Refs. 1, 2) –with the disadvantage that adding dopants most of the time changes other properties as well– or by microstructural changes (Refs. 1-4). The principle of the latter is to introduce interfaces perpendicular to the heat flow direction, but maintaining the overall columnar structure that gives the TBC its good strain tolerance.

During the present investigation a so-called “herringbone” TBC was developed (Ref. 4). The microstructure of this TBC consists of symmetrical zig-zag or wavy columns obtained by substrate manipulation during coating deposition. The thermal conductivity of these “herringbone” TBCs can be up to 25 % lower than that of a straight column TBC, depending on the microstructural characteristics (Ref. 4). Obviously, this gain in thermal barrier efficiency should not be at the expense of the coating life in service. Furnace cycle tests showed that the spallation life of herringbone TBCs was similar to that of a straight column TBCs (Ref. 4). However, burner rig tests simulate gas turbine condition more realistically, and this paper reports the behaviour of the herringbone TBCs during burner rig testing.

2 Materials and Coatings

The coating system was a PtAl bond coat and a ZrO_2–7wt%Y_2O_3 EB-PVD TBC, deposited on 5.8 mm diameter pins of the Ni-base superalloy Rene N5. Three types of coatings were produced (see also Ref. 4): a reference coating with straight columns perpendicular to the interface with the bond coat (Fig. 1a); a sinewave coating with wavy columns over the entire thickness (Fig. 1b); symmetrical coatings with zig-zag columns over the entire thickness (Fig. 1c & d). The herringbone coatings were produced with a deposition angle of 40° and a half wavelength time of 2 minutes (sinewave and symmetrical) or 4 minutes (symmetrical).

3 The Burner Rig and Test Conditions

The burner rig experiments were done with a Becon LCS-4B Combustor system. More details about the burner rig test set-up can be found in reference 5. Twelve pins were mounted on a carrousel that rotated in the hot gas stream of the burner rig. The applied test cycle consisted of a heating period to 1135 °C of about 25 sec., a dwell time at 1135 °C of 300 sec., and a cooling period of 75 sec. Inspection took place every 50 cycles. After failure, which was defined as more than 2.5 mm delamination, the pins were removed from the carrousel. Cross-sections of the damaged areas were made for optical and SEM metallography.

4 Results and Discussion

Figure 2 shows the results of the burner rig tests along with those of the furnace cycle tests[1]. The test results were remarkably similar: the number of cycles to failure for the herringbone TBCs was comparable to but a little lower than that of the reference straight column TBC.

Figure 3 shows the two types of failure observed: delamination of the top coat at the suction side of the pin (all types of top coats); and erosion-like degradation at the flame-heated side of the pin (herringbone top coats). The symmetric herringbone top coats showed more erosion damage than the sinewave top coats and erosion became visible after about 150 cycles. The eroded specimens still failed by delamination at the suction side except two pins with a symmetric/4 min/40° top coat. Testing of these pins was stopped because the top coat was eroded over the entire thickness for an area larger than 2.5 mm.

Figure 4 illustrates the degradation microstructures of the reference and sinewave TBCs. Ratcheting of the bond coat occurred for all TBCs, ultimately resulting in coating delamination by TGO/ top coat interface cracking. Ratcheting is a well-known degradation mechanism for TBC systems with a PtAl bond coat, and has been attributed mainly to plastic deformation of the bond coat. This is described in detail by Mumm et al. (Ref. 6). Besides interface cracking, there were occasional cracks through the TGO or in the top coat material. These top coat cracks are in many instances associated with pinched-off material which are defective regions in the top coat (Ref. 6).

[1] Sulzer Metco carried out furnace cycle tests; The applied test cycle consisted of a heating period to 1135 °C of about 4 min., a dwell time at 1135 °C of 50 min., and a cool down of 6 min. to about 150°. Every 20 cycles there was a 4 hour inspection period at room temperature (Ref. 4).

Figure 5 shows the above mentioned degradation and the erosion damage in the symmetric herringbone TBCs. Erosion occurred step-wise over the coating thickness with a step size corresponding to the half-wavelength of the zig-zag structure. Before break-out of the coating material small transverse cracks formed near the kinks of the columns, indicating that these are relatively weak spots in the top coat and that most probably explain the lesser erosion resistance compared to the sinewave TBCs.

5 Conclusions

- The life of herringbone TBCs during burner rig testing is slightly lower than that of standard straight column TBCs.
- Herringbone TBCs showed erosion at the flame-heated side of the pins.
- The symmetrical top coats were more sensitive to erosion than the sinewave top coats: kinks in the symmetrical top coats appear to be weak spots that crack earlier.
- Delamination occurred mainly at the TGO/top coat interface, most probably due to ratcheting of the bond coat.
- Though the new Herringbone TBCs show promising thermal properties, the production process must be optimised to improve the life and flame erosion resistance.

6 Acknowledgements

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7 References

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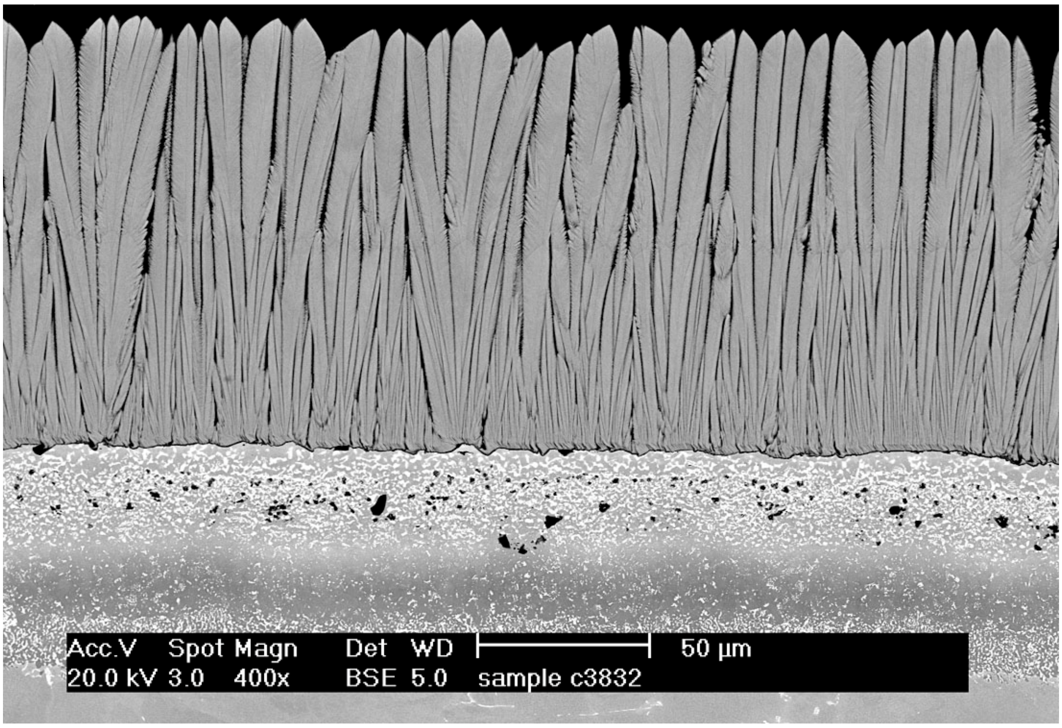
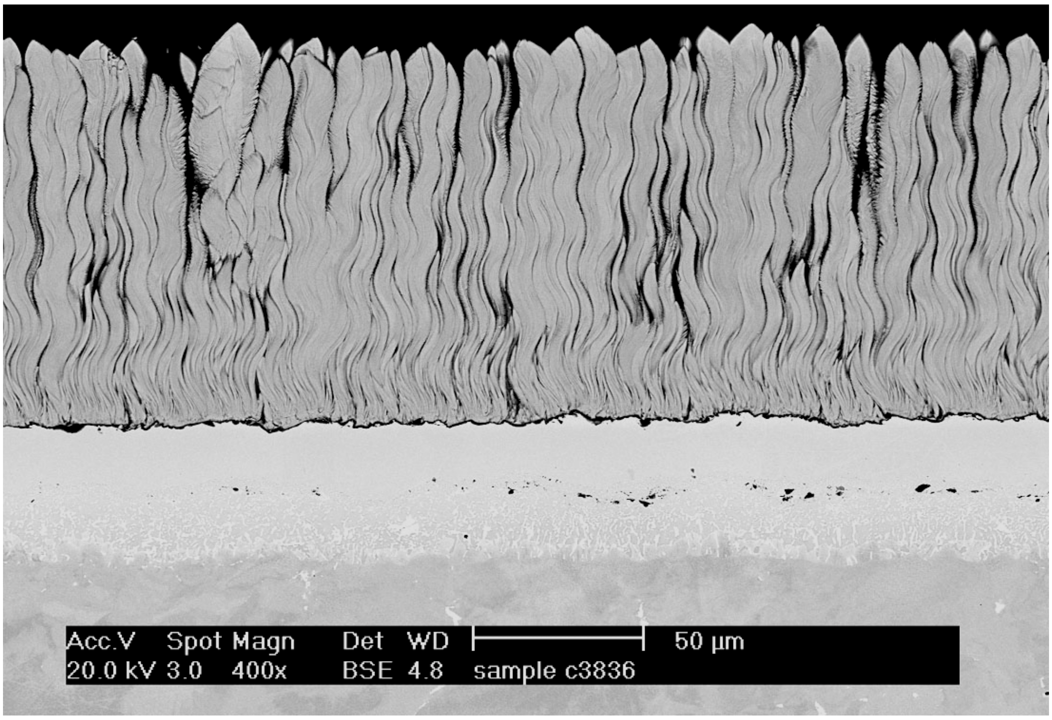
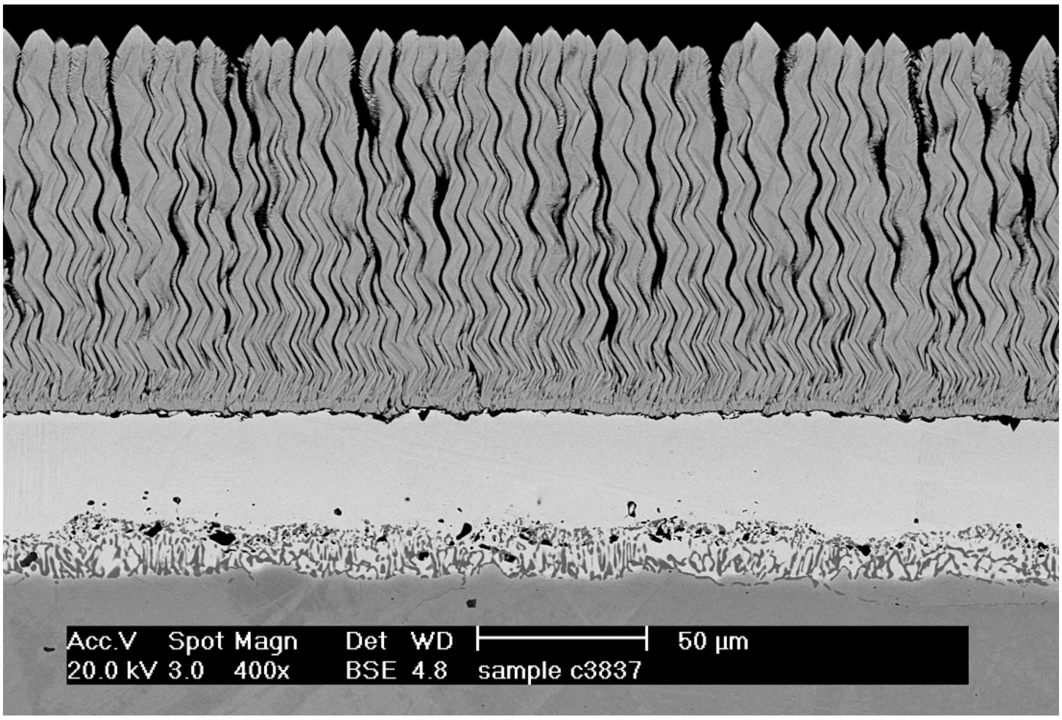


a)



b)

Fig. 1 Microstructure of herringbone TBCs a) reference b) sinewave, 2 min, 40°



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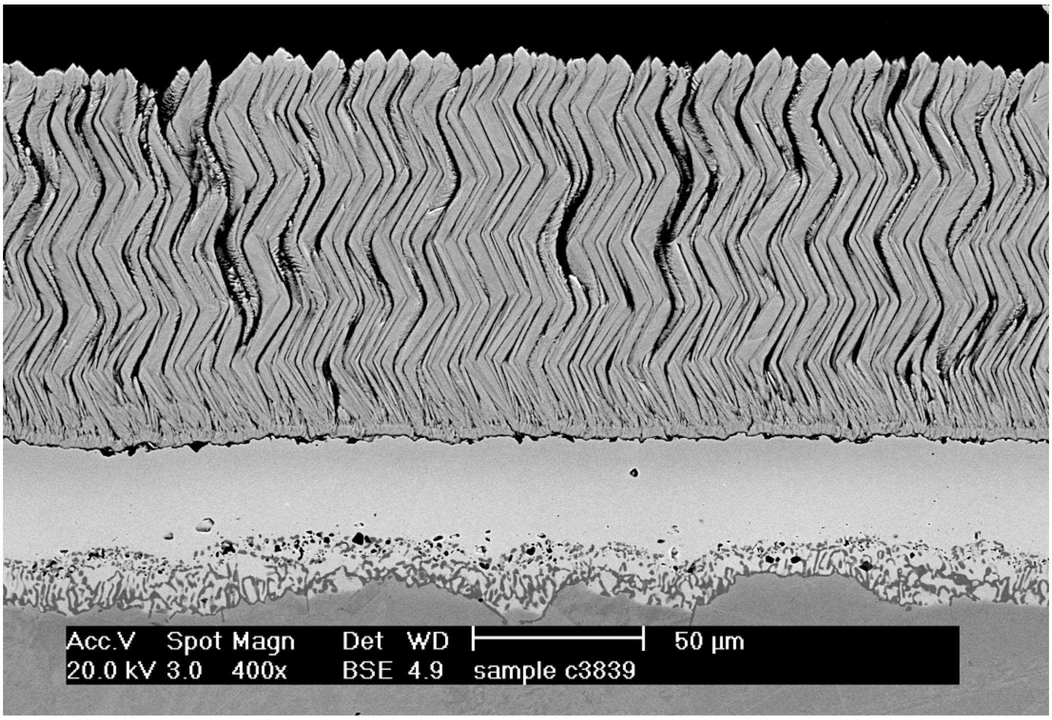


d)

Fig. 1 (continued) Microstructure of herringbone TBCs
c) symmetrical, 2 min, 40° and d) symmetrical 4 min, 40°

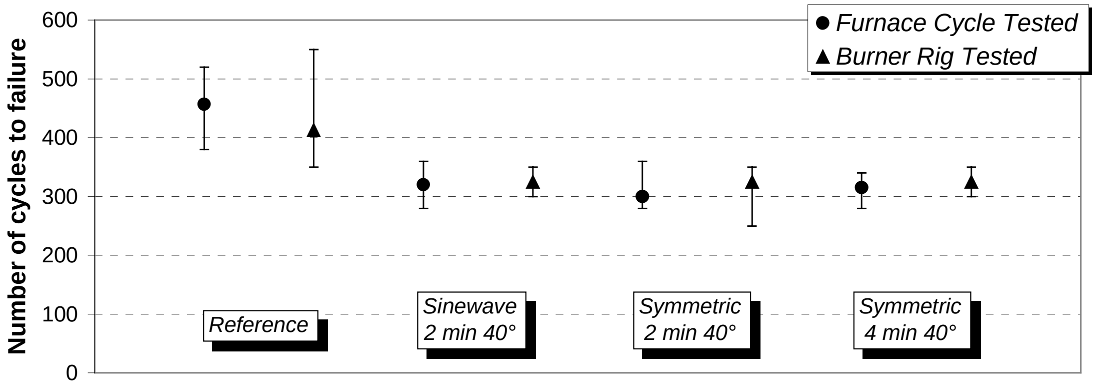
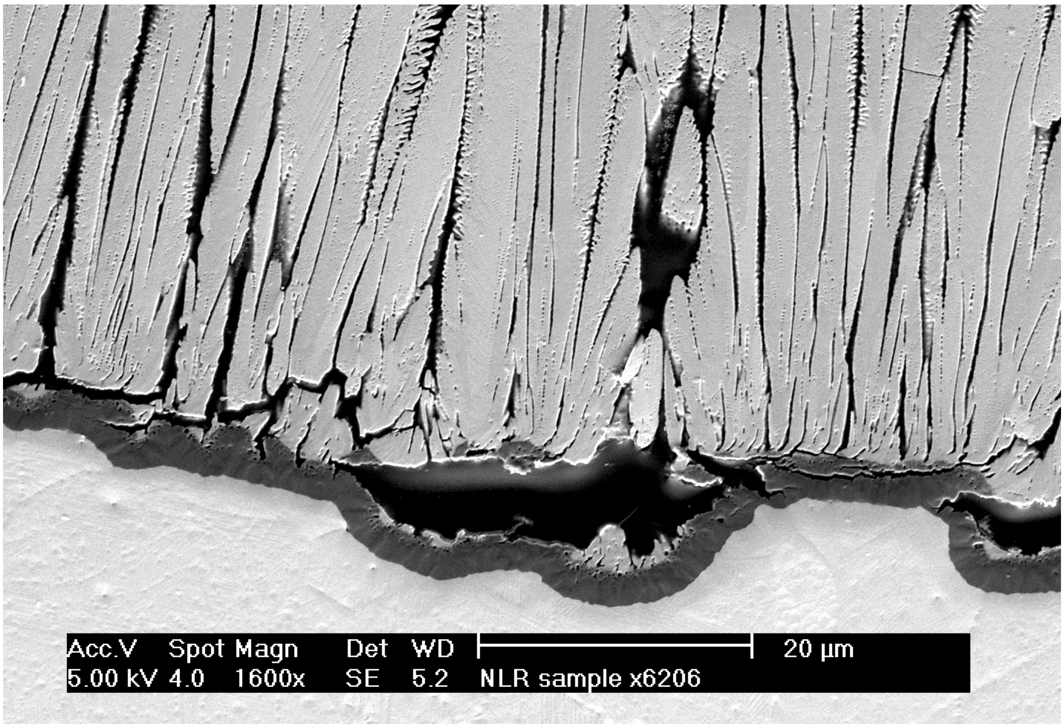


Fig. 2 Furnace cycle test and burner rig test results for reference and herringbone TBCs

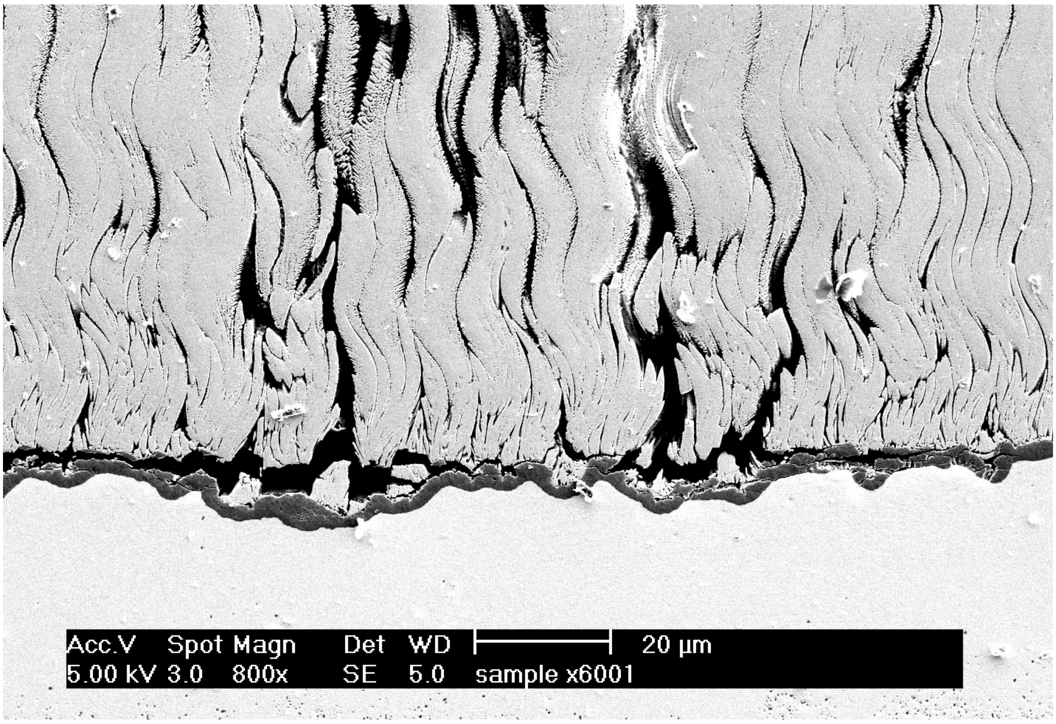
a)

b)

Fig. 3 Degradation of TBCs after 350 burner rig cycles. a) Delamination of reference coating at suction side, and b) erosion of 40° 4 min symmetric coating at flame side

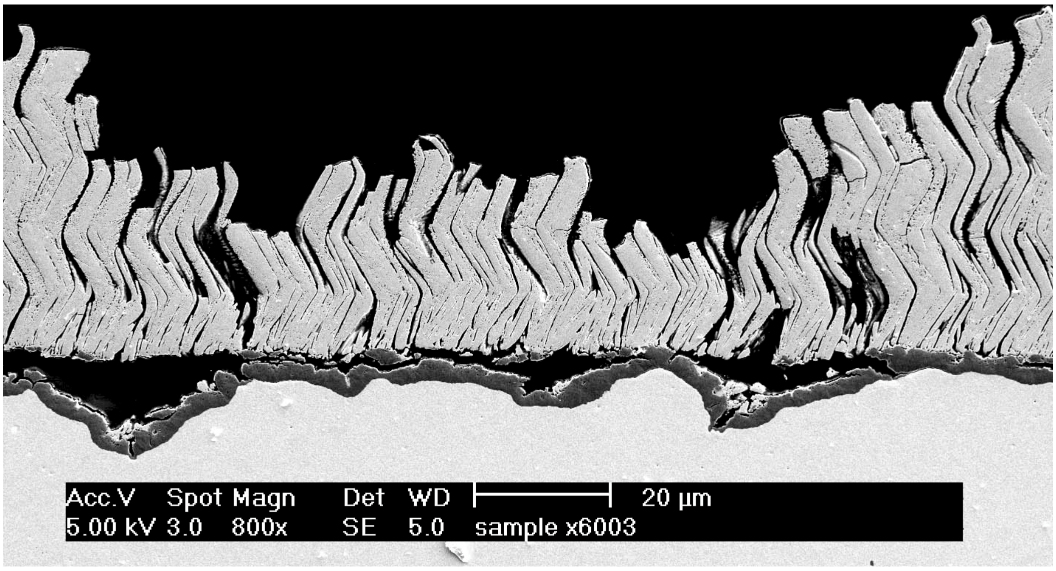


a)



b)

Fig. 4 Cross-sectional images showing the degradation after burner rig testing of a) reference and b) sinewave, 2 min, 40°



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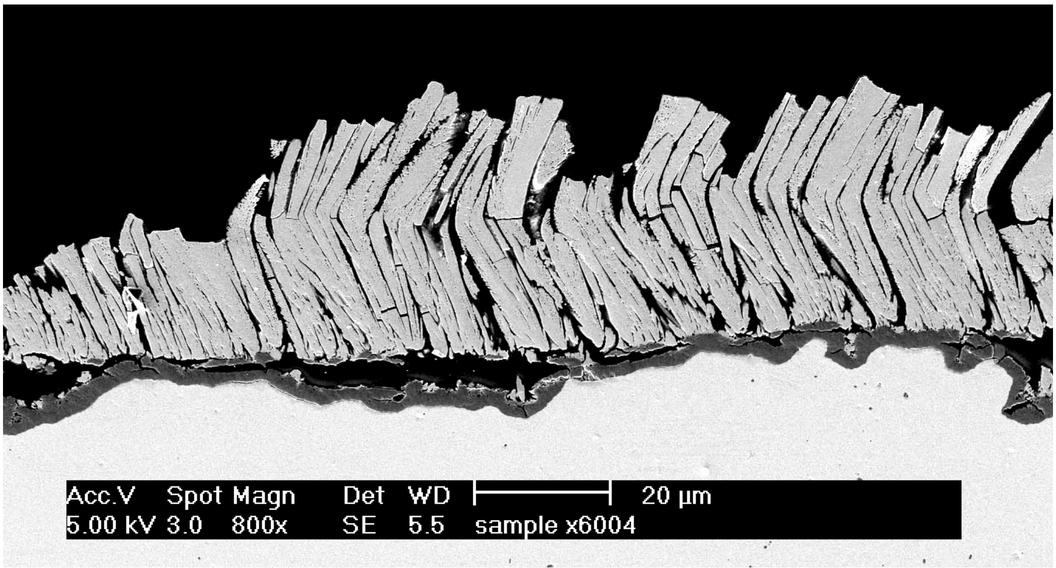

b)

Fig. 5 Cross-sectional images showing the degradation and erosion after burner rig testing of symmetrical herringbone TBCs a) 2 min, 40° and b) 4 min, 40°