MONITORING DIFFUSION COATING AGING WITH MULTI-FREQUENCY EDDY CURRENT MWM SENSORS

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ABSTRACT

Diffusion coatings are widely used to protect hot gas path components in land-based gas turbines and jet engines. Effective nondestructive assessment of the aged coating and substrate condition is critical for support of refurbish/ replace/run decisions. In this paper, we present results on aging characterization of nickel aluminide and platinum aluminide coatings. The measurements were performed using a Meandering Winding Magnetometer (MWM®) eddy current sensor over a wide range of frequencies. Single-channel MWM sensors and multichannel imaging MWM-Arrays permit tracking of features of interest for a population of components and provide new capabilities for inspecting gas turbine components. These conformable sensors allow convenient manual and automated inspection on complex surfaces. Results on coating aging assessment suggest that the multiple frequency MWM technique can be implemented for characterization of diffusion coatings and base metals before and after component refurbishment.

INTRODUCTION

Diffusion coatings such as nickel aluminide (NiAl) and platinum aluminide ((Ni, Pt) Al) coating are used for high temperature oxidation protection of hot gas path components in land-based turbines and jet engines. Long-term performance of these coatings is critically affected by the available aluminum content, often referred to as the "aluminum reservoir."[1-2] As a part of condition assessment, evaluation of the coating condition is of great practical importance. Conformable eddy current MWM sensors with multifrequency methods permit nondestructive evaluation of near-surface layers such as coatings on complex geometry components. Previously, the capability of MWM eddy current sensors to characterize high-temperature coatings was demonstrated for a few as-manufactured coatings as well as aged coatings.[3-7] Current work includes characterization of aged bond coats and thermal barrier coatings (TBC). For TBC, a combination of eddy current MWM sensors and capacitive interdigitated electric dielectrometers (IDED) shows promising results. This paper describes a nondestructive evaluation method for assessment of diffusion coating condition to support decisions on continued use/refurbishment/replacement of a component.
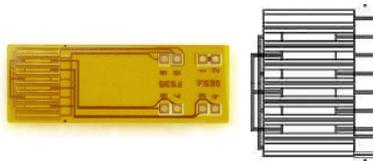
MWM SENSORS

Several examples of scanning and permanently mountable MWM-Array eddy current sensors are provided in Figure 1 (a) through (c). Each sensor has 1 drive winding, consisting of one, two or several rectangular loops, and a number of inductive sensing element rectangular loops. For these sensors, the transimpedance (sensing element voltage/drive current) is measured independently for each sensing element.

These sensors are carefully designed to enable modeling from basic physical principles and to minimize unmodeled contributions to the sensor response. Each sensing element response at one or more input current frequencies is used by a multivariate inversion routine to determine the absolute property values (e.g., electrical conductivity or magnetic permeability) at the location of the sensing element on the test specimen or component.

The sensor in Figure 1(a) has a footprint of 7 mm x 9 mm and averages the measured properties over the footprint area. It is typically used for point-by-point measurements at selected locations. The sensors shown in Figures 1(b) and 1(c) have a number of independent 1 mm x 1 mm sensing elements. These sensors are used for scanning complex geometry regions and provide images revealing special variations of measured properties/material conditions. Each of these sensors is used for measurements over a wide range of frequencies up to 32 MHz.

Databases of precomputed sensor responses are used with a table look-up algorithm to convert complex impedance data into two or more unknown property estimates at each sensing element. In a point-by-point measurement mode, data is taken at prescribed times. In a scanning mode, data is taken at each sensing element as it traverses a part to produce an image of each unknown property of interest.

(a) Single channel MWM sensor FS35
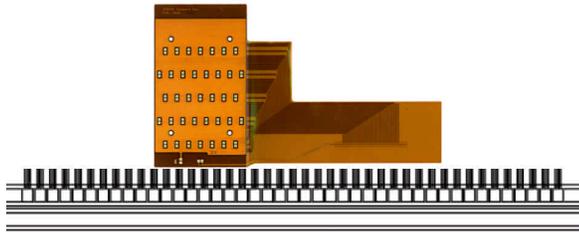
(b) Scanning 37-channel array
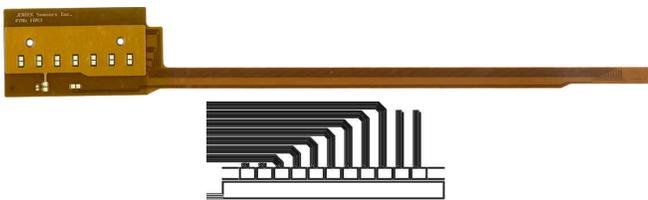
(c) Scanning 7-channel array

Figure 1: Photographs and schematics of a single channel MWM sensor and scanning multichannel MWM-Arrays.

SPECIMENS AND PROCEDURE

For this study, 28 aluminide coated specimens and 28 platinum aluminide coated specimens were examined. These were identified as Specimens A1 through A28 and P1 through P28, respectively. After baseline MWM measurements with an MWM FS35 sensor, (as shown in Figure 1(a)), four specimens were retained from each of the two sets as reference specimens. The other 24 specimens in each of the sets were exposed to a number of thermal cycles at 2000°F, including 20, 50, 100, 200, 300, and 400 cycles, with four specimens per exposure.

Both sides of each specimen were coated. MWM measurements were performed on both sides of the reference specimens and the thermally cycled specimens (the sides were identified as "top" and "bottom"). The MWM measurements were performed over a wide range of frequencies. The data presented here were obtained at frequencies between 2 and 16 MHz.

RESULTS OF MWM CHARACTERIZATION OF AGING FOR NiAl & (Ni,Pt)Al COATINGS

Figures 2 and 3 show MWM measured conductivity vs. frequency data for aluminide coated and platinum aluminide coated specimens exposed to the various thermal cycles. Figures 4 and 5 show changes in MWM frequency response for the aluminide coated and platinum aluminide coated specimens, respectively, as a function of cyclic thermal exposure. The MWM response is a multifrequency conductivity function that can capture near-surface material condition. It is used here as

one of the parameters characterizing aging of these coatings. Note that the plots in Figures 4 and 5 indicate consistent differences in the results for the "top" and "bottom" for all of the specimens.

The MWM measured conductivity at each applied frequency decreases monotonically with increased thermal exposure for both coatings. This is consistent with the expected depletion of aluminum caused by the aging of the coatings.

One of the parameters used in the analysis of the results was the "integrated available aluminum" calculated from EDS data. This parameter is a summation of "excess" aluminum content within the coating at the various distances from the surface. Each individual value of excess aluminum used in the summation was obtained as the reported aluminum content in each layer (where it exceeds 9 percent Al) minus nominal Al in the base metal. Thus, the "integrated available aluminum" accounts for both aluminum content and depth over which aluminum content is equal to or exceeds 9 percent. This parameter may be somewhat arbitrary but it does reflect a "reservoir" of available aluminum in the coating.

Figures 6 and 7 present the normalized MWM-measured conductivity response parameter and the normalized integrated aluminum content vs. thermal exposure for the 24 aluminide coated and 24 platinum aluminide coated specimens, respectively. The data are normalized relative to the mean value at 20 thermal cycles (no EDS data was available for unaged specimens). In both figures, only the data for the top are shown. The error bars correspond to ±1 standard deviation. Both the MWM response parameter and the integrated aluminum data show a similar trend with aging. In most instances, the MWM parameter scatter is significantly smaller than the scatter in the EDS-based integrated aluminum values. One possible reason is that EDS is known to provide semi-quantitative estimates of elemental composition and is more likely to vary from specimen to specimen and from one measurement to another.

While available for this study, aluminum content and its distribution with depth are not available for actual components. Note that, in the case of the platinum aluminide coated specimens, the integrated aluminum parameter tends to level off at higher exposures, whereas the MWM parameter shows continued effects of aging not captured by the aluminum parameter. This may be a very significant result for life management.
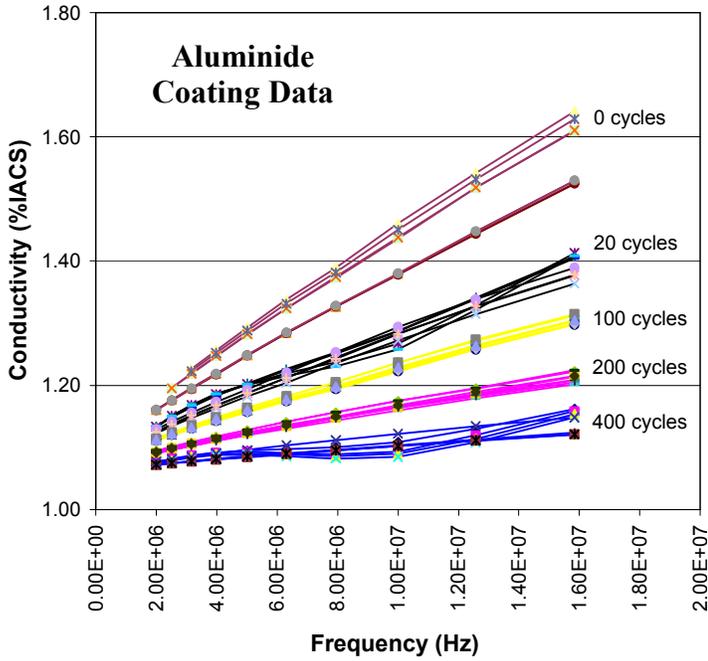
Figure 2. MWM measured conductivity vs. frequency for aluminide coated specimens exposed to various thermal cycles. Two repeated MWM measurements were taken on each specimen on different days.
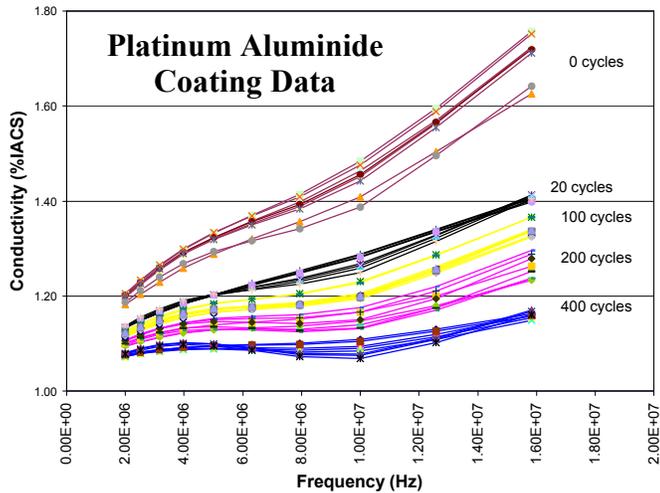

Figure 3. MWM measured conductivity vs. frequency for platinum aluminide coated specimens exposed to various thermal cycles. To show repeatability, two repeated MWM measurements were taken on each specimen on different days.
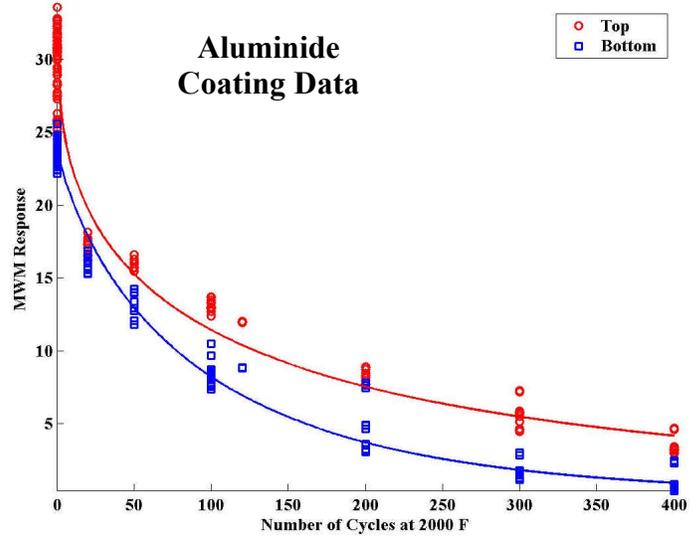

Figure 4. MWM response vs. number of thermal cycles for aluminide coated specimens ("top" and "bottom" refer to the coating on opposite sides of each specimen).
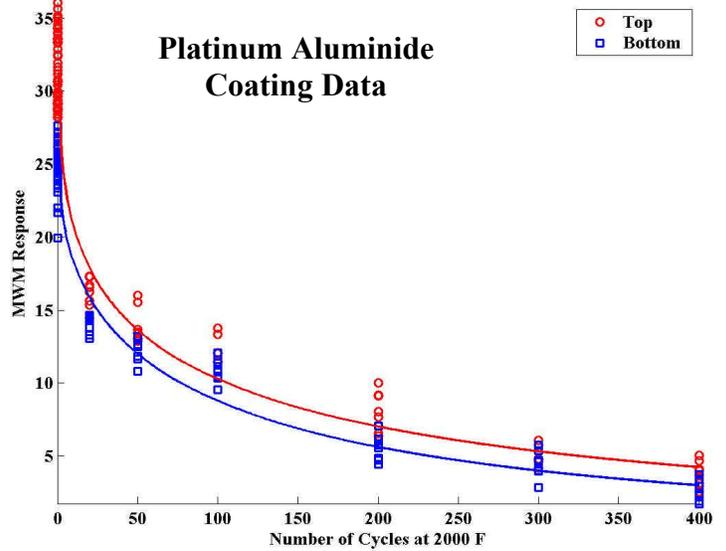

Figure 5. MWM response vs. number of thermal cycles for platinum aluminide coated specimens ("top" and "bottom" refer to the coating on opposite sides of each specimen).
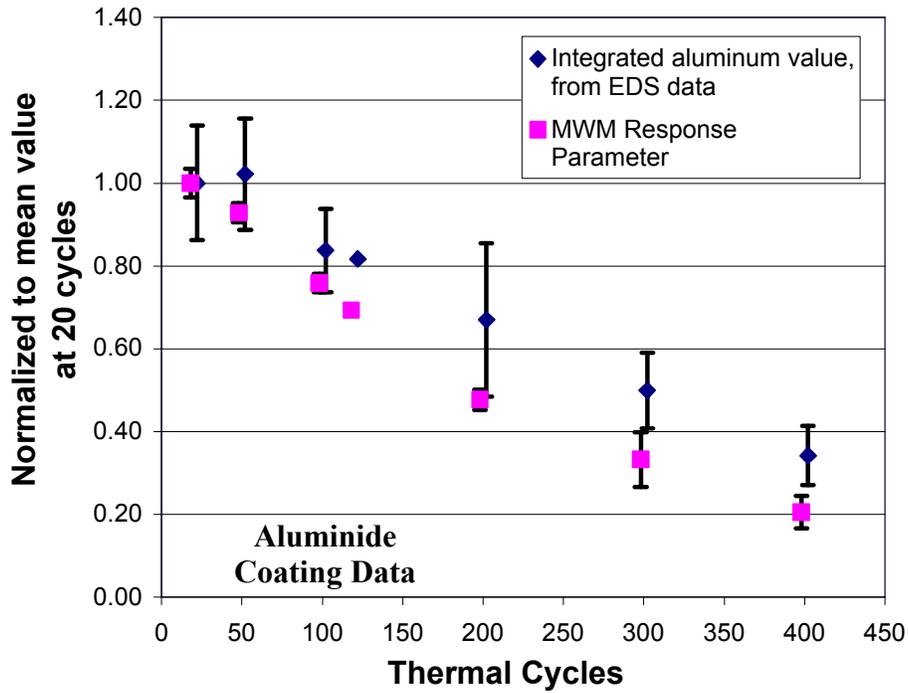
Figure 6. Normalized MWM frequency response and EDS-based integrated available aluminum content vs. thermal cycles (top only) for the 24 aged aluminide coated specimens. The error bars correspond to ± one standard deviation of the values for each exposure.
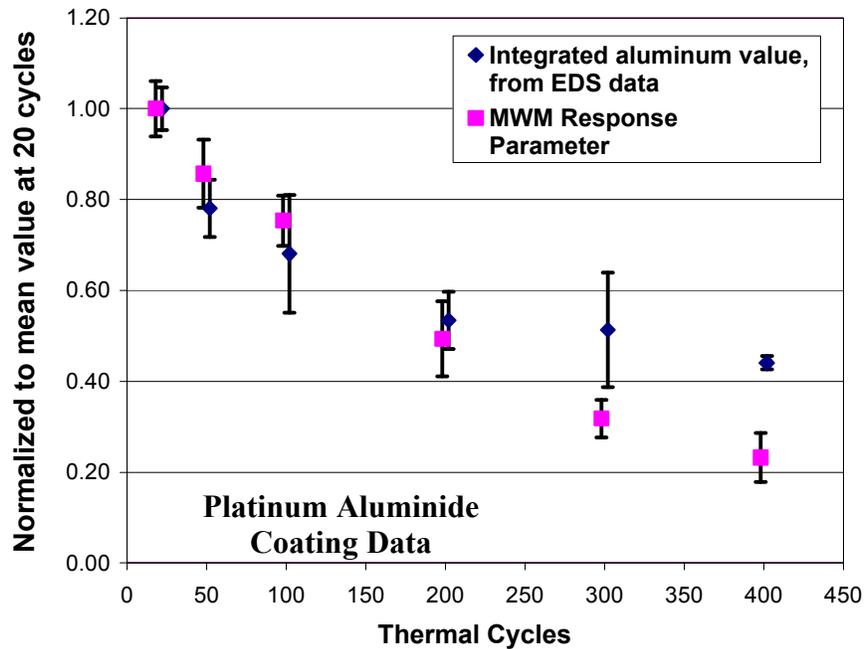

Figure 7. Normalized MWM frequency response and EDS-based integrated available aluminum content vs. thermal cycles (top only) for the 24 aged platinum aluminide coated specimens. The error bars correspond to ± one standard deviation of the values for each exposure.

CONCLUSIONS

This study suggests that the MWM technology can differentiate between as-manufactured coating condition and the conditions of the aged samples representing the various thermal cycling exposures. The results indicate that MWM sensors and MWM-Arrays should be able to provide a means of characterizing aged nickel aluminide and platinum aluminide coatings.

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