PARALLEL BOX-CAR IMAGING OF ADHESION DEFECTS IN PLASMA-SPRAYED COATINGS

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INTRODUCTION

Thermal wave techniques have been successfully used for the characterization of adhesion defects of plasma-sprayed coatings on metal substrates.[1-3] With the advent of thermal wave infrared video imaging,[4-6] it is now possible to image large surface areas at video frame rates using an IR video camera. In this work we describe a novel parallel box-car imaging system, using an IR video camera and WSU-designed pixel by pixel time-gating and averaging and we demonstrate the ability of this system to detect adhesion defects in plasma-sprayed coatings on metal substrates. A particular advantage of our system is that the entire image can be obtain in parallel, thus making it a much faster technique than the conventional cw thermal wave imaging techniques.

EXPERIMENTAL TECHNIQUE

A schematic diagram of our experimental set-up is shown in Figure 1. A 5 kJ flash lamp with a flash duration of about 5ms, is used as an excitation source. The flash lamp applies heat uniformly to the sample and a commercial infrared camera with a 3X telescope lens and a 6 inch close-up attachment is used to detect the infrared radiation from the surface of the sample. The camera uses a single liquid-nitrogen-cooled HgCdTe detector with an 8-12 μm spectral response and two scanning mirrors are used to form the image. The standard video signal (RS-170) from the IR camera is fed to a real-time digital image processing system and the analog signal is filtered and amplified before digitization. The timing for the frame-grabbing procedure is depicted schematically in Figure 2. The optimum repetition rate of the flashes and the time-delays for the frame-grabbing windows are determined by observing the heating and cooling curves. This is done by recording the time development of the increased surface radiation measured by the IR camera. A plot of the IR radiation as a function of time gives the time at which the maximum contrast between the defect region and the background shows up. Once the time scale for observing the maximum contrast has been determined, video frames are grabbed in two time windows, the first near the peak of the heating curve and the second near the tail of the cooling curve. The multiple frames in each of these windows are averaged, and then subtracted from each other, thereby eliminating the IR background signal. The process is repeated for several (typically 16) flashes and the resulting images are again averaged over multiple frames to enhance the signal-to-noise ratio. In this arrangement, the delay time between frame grabbing windows can be varied from a frame time to several seconds, depending upon the sample parameters. The processed images are transferred to a color work station that is

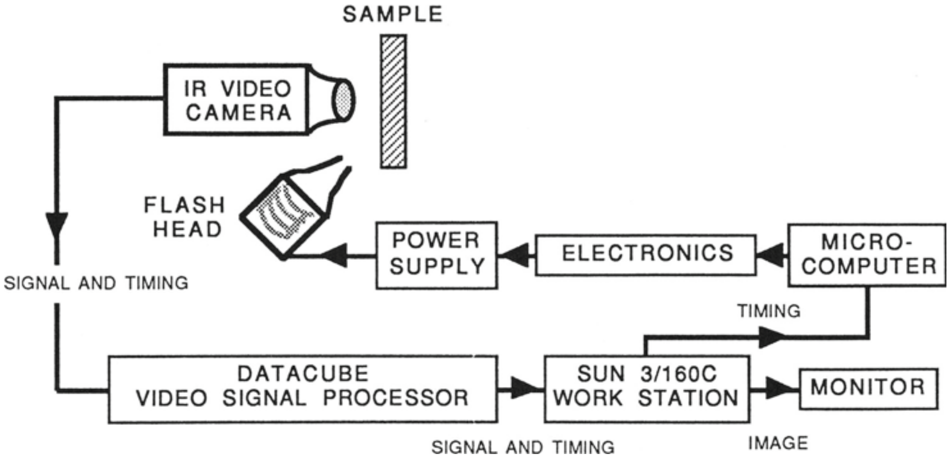

Figure 1. Schematic diagram of the experimental set-up.

used for controlling the video data acquisition and for subsequent post-processing of the images, their storage and display. The image display is done by a WSU developed custom colormap using WYSIWYG approach. The colormap composition is fully interactive using all the facilities of the window system in the Sun 3/160C color work station, and uses line adjustment mode for the red, green and blue (RGB) colors to create the colormap which gives the best visual effect for the particular image.

RESULTS AND DISCUSSION

We have applied the parallel box-car imaging technique to the detection of adhesion defects in three types of plasma-sprayed coatings on metals. The samples studied are sample A: chromium oxide coatings on steel, sample B: zirconia coatings on a nickel based super alloy, and sample C: magnesia zirconate coatings on steel. All these samples included some sort of adhesion defects or disbonds. These defects were produced in the sample preparation process by masking off a small portion of the substrate during the sand blasting of the substrates. The sand blasting of the substrates are required in order to assure proper bonding between the substrate and the coating. The thickness of the coatings used in this study were 200 to 400 μm. Figure 3 shows an infrared video image of sample A obtain by the parallel box-car imaging technique. The white (hot) vertical area is the the region of weak bonding or delamination. For this sample (chromium oxide coatings) the time-delay for best contrast was about 70 ms and 1 second after the surface reached equilibrium and the delamination was no longer visible. Two samples of chromium oxide coatings were studied, each of these samples included six regions of delaminations or weak adhesion. Using our technique all of these regions were identified. For sample B (magnesia zirconate coatings) it was a different story. The contrast between the defect and the background was observed 1 second after the flash and the maximum contrast appeared about 1.5 seconds after the flash. An infrared video image of sample B is shown in Figure 4 where the white (hot) area depicts the defect region. We studied two magnesia zirconate coatings each having four regions of weak bonding, however, we were able to identify only three regions in each sample. The third kind of sample used in this study, sample C (zirconia coatings), are known as thermal barrier coatings and are intended to be used under high temperature environment. Figure 5 shows an infrared video thermal image of sample C. For these samples a time-delay of 1-2 minutes was observed, which is consistent with the very nature of these samples. Although the three different kinds of plasma sprayed coatings had three very different time scale, it was observed very easily by using our parallel box-car thermal wave imaging technique. Also, for the thermal barrier coatings we were able to estimate the size of the flaw from the overall dimension of the image area taking into account the zoom factor used by the camera. In Table 1, a comparison of the known and measured flaw sizes for five different thermal barrier coatings are presented.

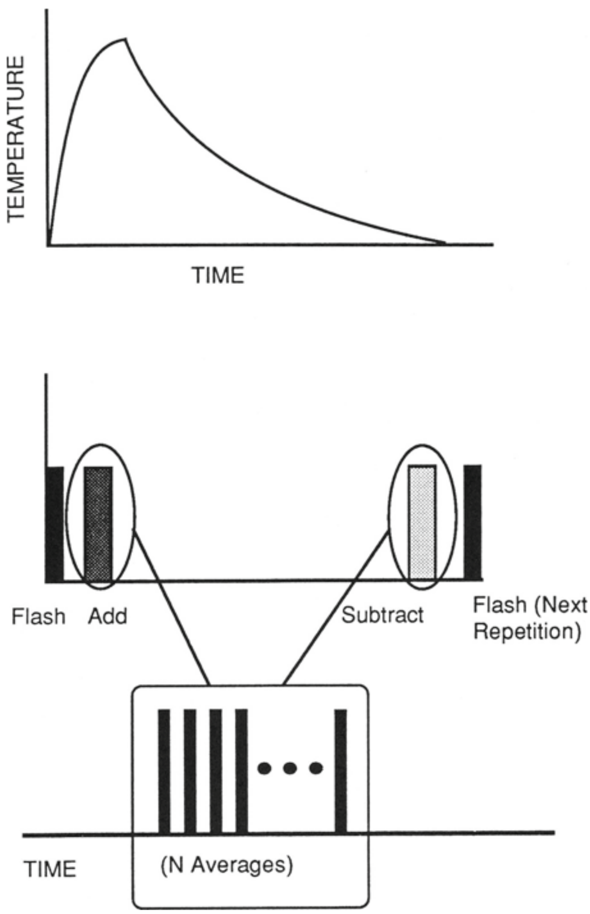

Figure 2. Timing for the frame grabbing procedure.

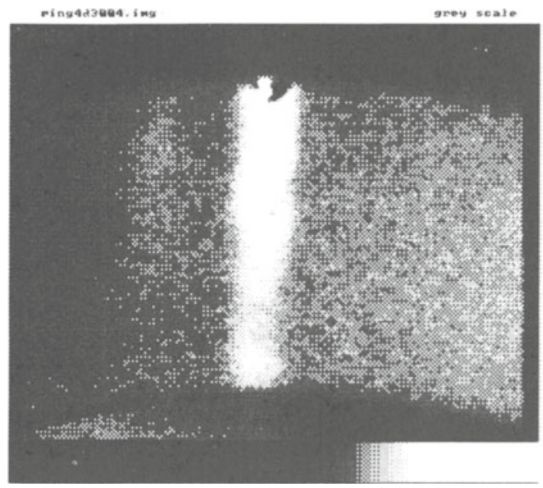

Figure 3. Infrared thermal wave video image of sample A

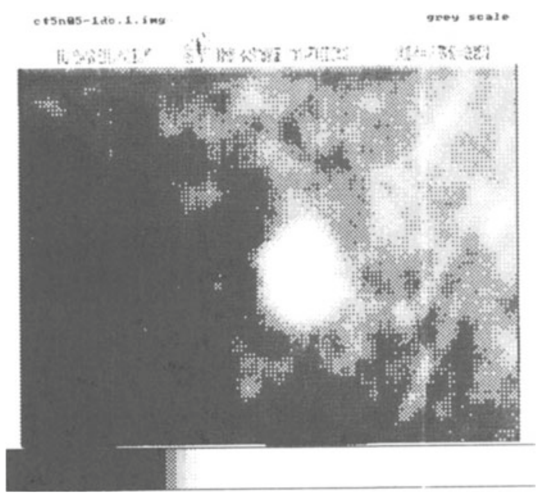

Figure 4. Infrared thermal wave video image of sample B.

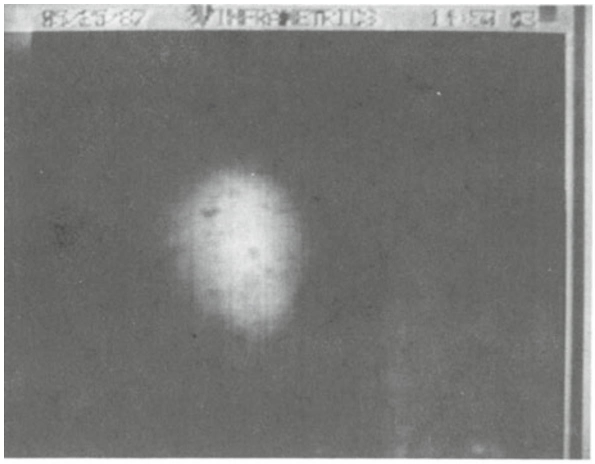

Figure 5. Infrared thermal wave video image of sample C.

Table 1. Comparison of the Known and Measured Flaw Sizes of Thermal Barrier Coatings

Sample #	Coating Thickness (μm)	Flaw Size (mm) Nominal	Flaw Size (mm) Measured
1	231	0.5	0.6
2	379	3.6	3.2
3	127/127	6.0	6.0
4	178	4.5	3.5
5	282	1.2	1.1

CONCLUSION

We have described a novel box-car thermal wave imaging technique, which can be effectively used to detect and characterize adhesion defects in plasma sprayed coatings on metals. As compared to other thermal wave imaging techniques, this method has the ability of imaging an entire area in parallel and at a much faster rate. The ability of this technique to determine the time-delay at which the maximum contrast is observed and then to image the defect in such a short time can be used as a powerful tool for characterizing plasma sprayed coatings.

ACKNOWLEDGEMENT

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REFERENCES

1. P.M. Patel and D.P. Almond, J. Material Sci. **20**, 995 (1985).
2. D.L. Balageas, J.C. Krapez and P. Cielo, J. Appl. Phys. **59**, 348 (1986).
3. P.M. Patel, D.P. Almond and H. Reiter, Appl. Phys. B **43**, 9 (1987).
4. W.N. Reynolds, Can. J. Phys. **64**, 1150 (1986).
5. P.K. Kuo, Z.J. Feng, T. Ahmed, L.D. Favro, R. L. Thomas, Springer Series in Optical Sciences, Vol. **58**: Photoacoustic and Photothermal Phenomena, Editors: P. Hess and J. Pelzl, Springer-Verlag Berlin Heidelberg 1988.
6. P.K. Kuo, J. Hartikainen, I.C. Oppenheim, L.D. Favro, Z.J. Feng and R.L. Thomas, Review of Progress in QNDE, Vol. **7A**, Edited by D.O. Thompson and D. E. Chimenti, Plenum Press, New York, 1988.