N89-13654 S12-27 181380 11P.

EXAMINATION OF COATING FAILURE BY ACOUSTIC EMISSION*

Christopher C. Berndt
Cleveland State University
Cleveland, Ohio 44115

Coatings of NiCrAlY bond coat with a zirconia - 12 wt % yttria overlay were applied to disc-shaped specimens of U-700 alloy. A waveguide of 1-mm-diameter platinum was TIG welded to the specimen and allowed it to be suspended in a tubular furnace. The specimen was thermally cycled to 1150 °C, and the acoustic emission (AE) monitored. The weight gain per thermal cycle was also measured.

A computer system based on an IBM-XT microcomputer was used extensively to acquire the AE data with respect to temperature. This system also controlled the temperature by using a PD software loop. Several different types of AE analyses were carried out.

A major feature of these tests, not addressed by previous work in this area, was that the coatings covered 100 percent of the specimen and also that the AE was amplified at two different levels. It is believed that this later feature allows a qualitative appraisal of the relative number of cracks per AE event and also the relative size of cracks per AE event.

The difference in AE counts between the two channels is proportional to the number of cracks per AE event, and this parameter may be thought of as the "crack density." The ratio of the AE count differrence to the AE count magnitude of one channel is inversely proportional to the "crack growth." Both of these parameters allow the crack distribution and crack growth within each specimen to be qualitatively followed during the thermal cycling operation.

Recent results which used the above principles will be presented. It is shown that microcracking gave rise to a large amount of AE. However, the coating still survived more thermal cycles than a coating which exhibited macrocracking events. Data of this nature will be presented and the results discussed.

---

*Work done under NASA Cooperative Agreement NCC 3-27.

AIM

- TO STUDY THERMALLY INDUCED FAILURE PROCESSES EXPERIENCED BY THERMAL BARRIER COATINGS.

- TO ANALYSE THE FAILURE PROCESSES WITHIN COATINGS - i. e.,

    - WHAT IS THE SIZE OF ANY CRACKS?
    - HOW MANY CRACKS ARE THERE?

- TO FOCUS ON THE MICRO-MECHANICAL PROPERTIES OF COATINGS AND HOW THESE MAY VARY FROM COATING-TO-COATING.

Figure 1.

PREVIOUS WORK IN THIS RESEARCH AREA

1. D. ALMOND, M. MOGHISI AND H. REITER, " THE ACOUSTIC EMISSION TESTING OF PLASMA-SPRAYED COATINGS", THIN SOLID FILMS 108 (1983) 439-447.

2. N. RAVI SHANKAR et al., "ACOUSTIC EMISSION FROM THERMALLY CYCLED PLASMA-SPRAYED OXIDES", AM. CER. SOC. BULL. 62 NO. 5 (1983) 614-619.

3. C. C. BERNDT AND H. HERMAN, "FAILURE DURING THERMAL CYCLING OF PLASMA-SPRAYED THERMAL BARRIER COATINGS", THIN SOLID FILMS 108 (1983) 427-437.

4. C. C. BERNDT AND H. HERMAN, "FAILURE ANALYSIS OF PLASMA-SPRAYED THERMAL BARRIER COATINGS", THIN SOLID FILMS, 119 (1984) 173-184.

5. C. C. BERNDT, "ACOUSTIC EMISSION EVALUATION OF PLASMA-SPRAYED THERMAL BARRIER COATINGS", ASME J. ENG. FOR GAS TURBINES, 107 (1985) 142-146.

Figure 2.

SCHEMATIC OF EXPERIMENTAL DETAILS

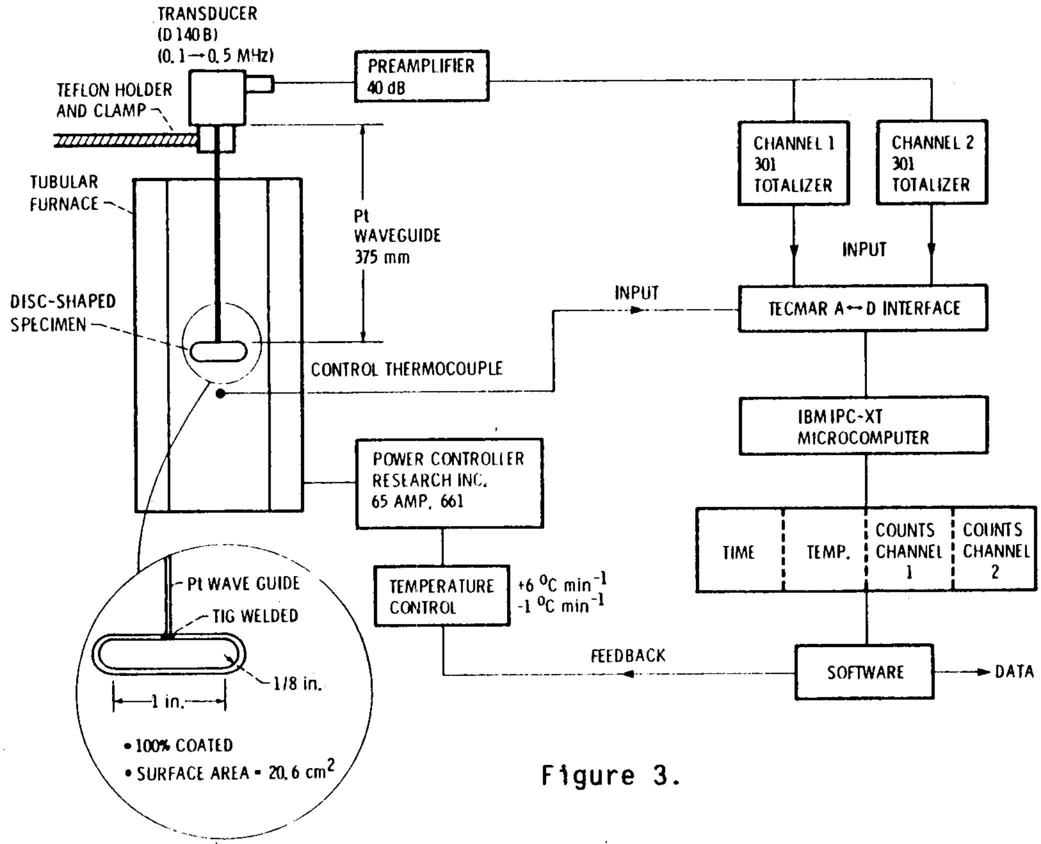


Figure 3.

SUMMARY OF EXPERIMENTAL DETAILS

1. A CLOSED LOOP DATA ACQUISITION AND CONTROL SYSTEM HAS BEEN BUILT.
2. SOFTWARE FOR DATA ACQUISITION AND ANALYSIS HAS BEEN DEVELOPED.
3. SPECIMENS PREPARED -

   BOND COAT OF Ni-16Cr-6Al-0.15Y (0.005 in.)

   CERAMIC COATING OF ZrO_2-12 wt.% Y_2O_3 (0.015 in.)

COATINGS EXAMINED

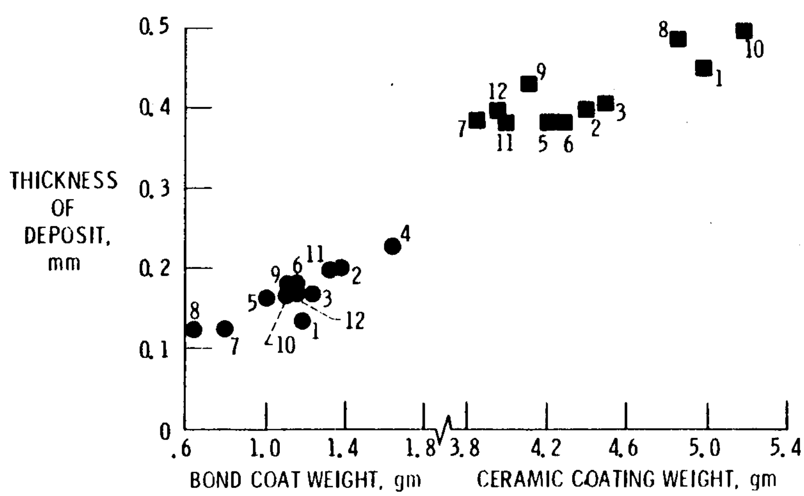
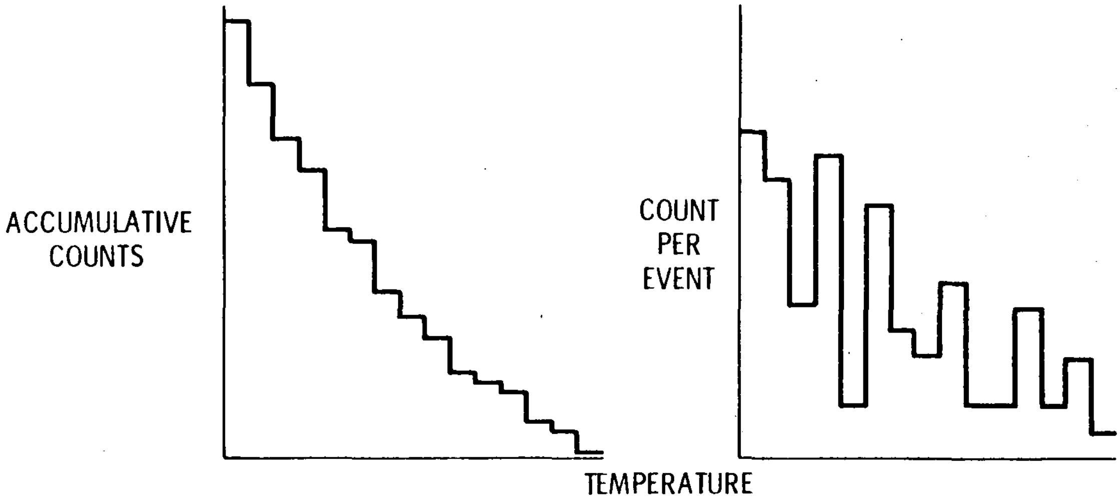


Figure 4.

THE NATURE OF THE AE DATA



AT LEAST TWO TYPES OF DISTRIBUTIONS

1. SYSTEMATIC→FROM "CONTINUOUS" EMISSIONS.
2. STOCHASTIC→FROM "BURST" EMISSIONS.

Figure 5.

METHOD 1 OF ANALYSIS

DISCOUNT SIGNALS OF A CERTAIN MAGNITUDE AND THUS SET A LOWER BOUND FOR THE BURST EMISSION. CURVE FIT THE REMAINING DATA TO FIND THE SLOPE OF ACCUMULATIVE COUNTS VERSUS TEMPERATURE.

EXAMINE: -

1. HOW THE SLOPE CHANGES WITH RESPECT TO THE BOUND LEVEL AND THERMAL CYCLE.

i. e.; $\left[\frac{\partial\,(\Sigma\ \text{COUNTS})}{\partial T}\right]_{\substack{\text{BOUND}\\ \text{LEVEL}}}$ <u>VERSUS</u> THERMAL CYCLE NUMBER

$\left[\frac{\partial\,(\Sigma\ \text{COUNTS})}{\partial T}\right]_{\substack{\text{THERMAL}\\ \text{CYCLE}\\ \text{NUMBER}}}$ <u>VERSUS</u> BOUND LEVEL

Figure 6.

ACCUMULATIVE COUNTS VERSUS TEMPERATURE ANALYSIS

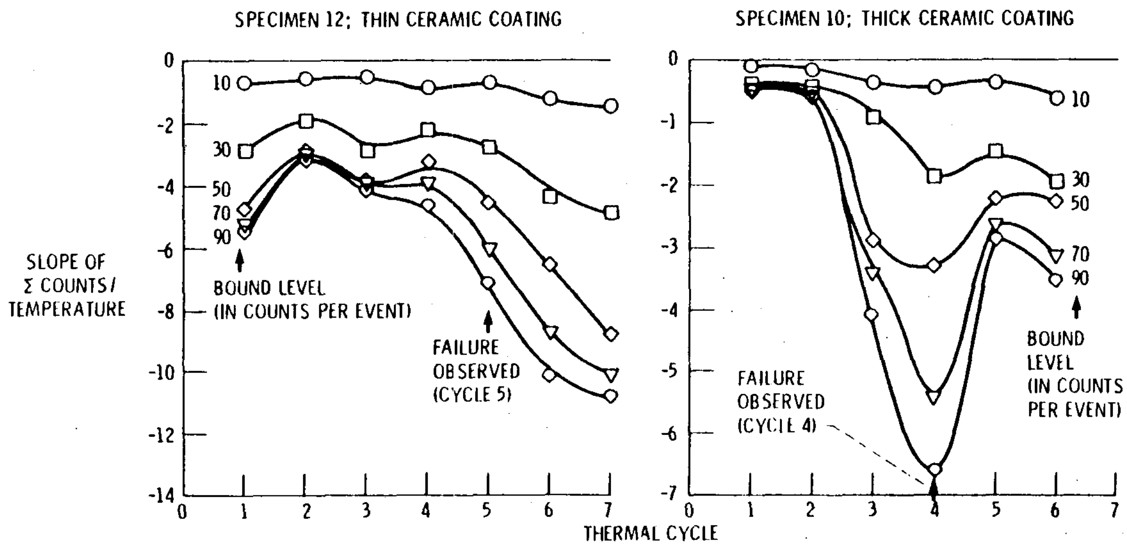
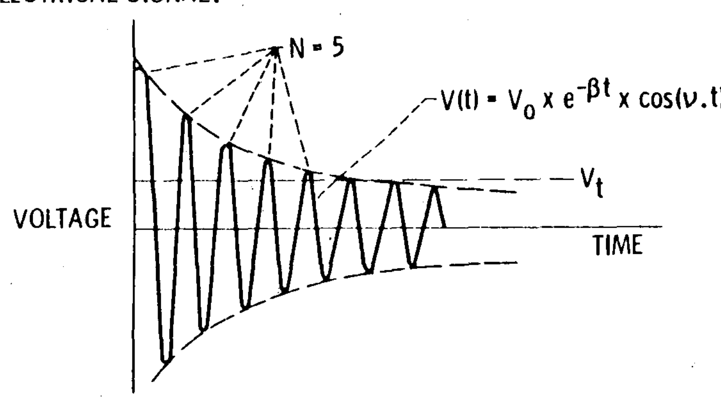


Figure 7.

THEORY OF AE

- CRACKING PROCESSES GENERATE ELASTIC WAVES i.e., MOVEMENT OF ATOMS.
- THIS ELASTIC WAVE DISTORTS A PIEZOELECTRIC MATERIAL AND GIVES RISE TO AN ELECTRICAL SIGNAL.



$V(t)$ - VOLTAGE AS A FUNCTION OF TIME
V_0 - INITIAL VOLTAGE
β - DAMPING CONSTANT
t - TIME
ν - RESONANT FREQUENCY OF THE TRANSDUCER (= 140 KHz)
V_t - THRESHOLD VOLTAGE (= 1 V)
N - NUMBER OF COUNTS ABOVE V_t

Figure 8.

AE DEFINITIONS AND EQUATIONS

$$\beta = \frac{\text{LOGARITHMIC DECREMENT}}{\text{PERIOD OF OSCILLATION}} = \frac{\gamma}{T}$$

$$\gamma = \ln\left(\frac{V_{n+1}}{V_n}\right)$$

RESULT IS: -

$$\boxed{V_{(t)} = V_0 + e^{(-\gamma.\nu.t)} \times \cos(\nu t)}$$

ALSO: -

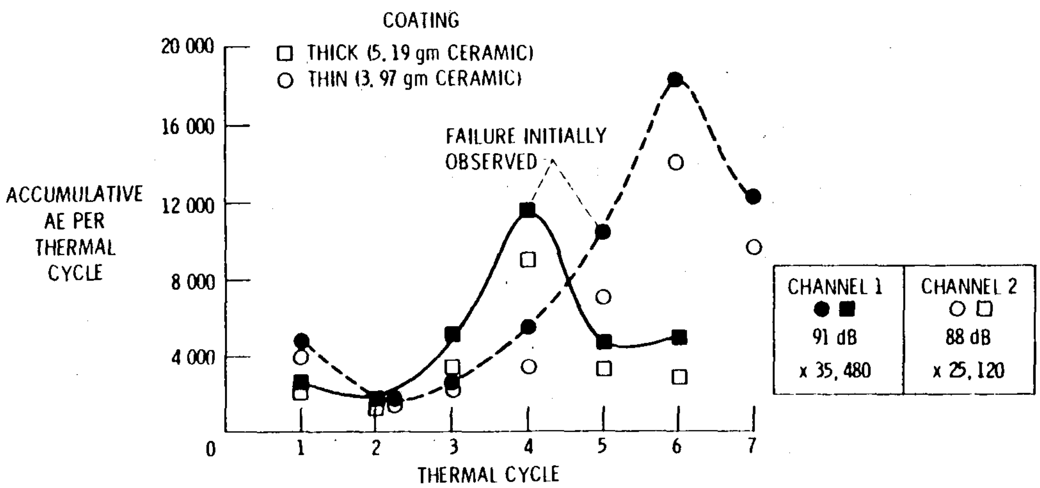
$$\boxed{N = \frac{1}{\gamma} \times \ln\left(\frac{V_0}{V_t}\right)}$$

<u>REMEMBER</u> THAT AE IS THE SUPERPOSITION OF CONTINUOUS WAVES THEREFORE BEWARE OF CONFOUNDING AE SIGNALS. DEADTIME OF THE TRANSDUCER IS ABOUT 100us. DIGITAL UPDATING OF THE APPARATUS IS 0.3us THEREFORE NO ALIASING OF THE COUNTS PER EVENT OCCURS.

Figure 9.

METHOD 2 OF ANALYSIS

EXAMINE THE ACCUMULATIVE COUNTS OF BOTH AE CHANNELS WITH RESPECT TO THERMAL CYCLING.



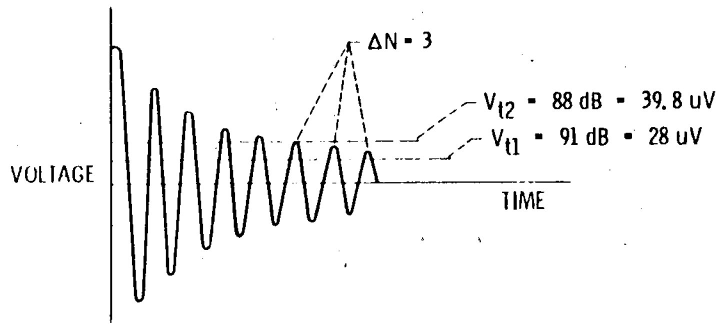
1. THE ACCUMULATIVE AE RESPONSE AFTER FAILURE IS DIFFERENT FOR BOTH SAMPLES. THE NUMBER OF COUNTS MAY EITHER INCREASE OR DECREASE AFTER VISUAL FAILURE.

2. THE DIFFERENCES BETWEEN THE CHANNELS CHANGE FOR EACH COATING.

Figure 10.

INFORMATION DERIVED FROM EXAMINING DIFFERENT AMPLIFICATIONS OF THE SAME SIGNAL

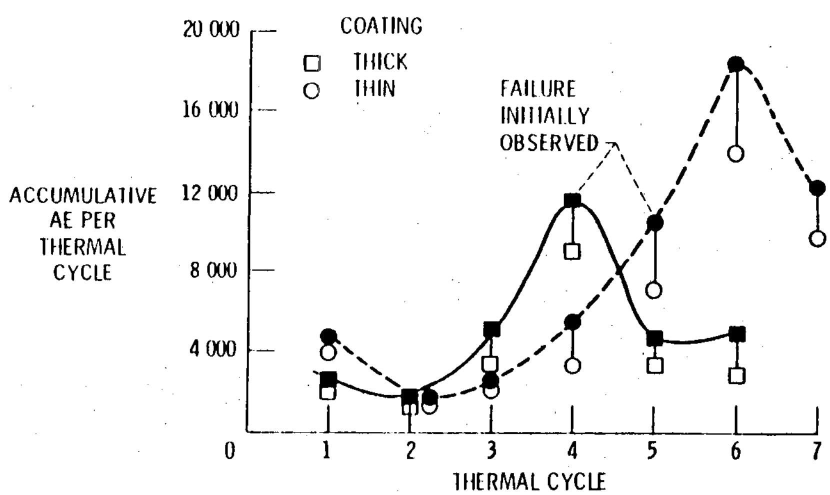
EXAMINE THE NUMBER OF PEAKS PER EVENT.



- MORE PEAKS WILL BE COUNTED AT THE LOWER THRESHOLD (i.e., HIGHER AMPLIFICATION).
- THE COUNT DIFFERENCE BETWEEN CHANNELS IS AN INDICATION OF THE RELATIVE NUMBER OF EVENTS.

Figure 11.

EXAMINATION OF COUNT DIFFERENCE DATA



IMPLICATION

1. ΔN α NUMBER OF CRACKS
2. NORMALIZED ΔN α $\frac{1}{\text{SIZE OF CRACK}}$

Figure 12.

A SIMPLE EXAMPLE

CONSIDER THAT ΔN FOR AN EVENT IS 3 COUNTS

CRACK TYPE	COUNTS CHANNEL 1	COUNTS CHANNEL 2	ΔN	$\frac{\Delta N}{N_1}$
SMALL	10	7	3	0.30
LARGE	50	47	3	.06
5 SMALL	50	35	15	.30
5 LARGE	250	235	15	.06

ASSESSMENT OF NUMBER OF EVENTS (ΔN)

ASSESSMENT OF CRACK SIZE ($\frac{\Delta N}{N_1}$)

Figure 13.

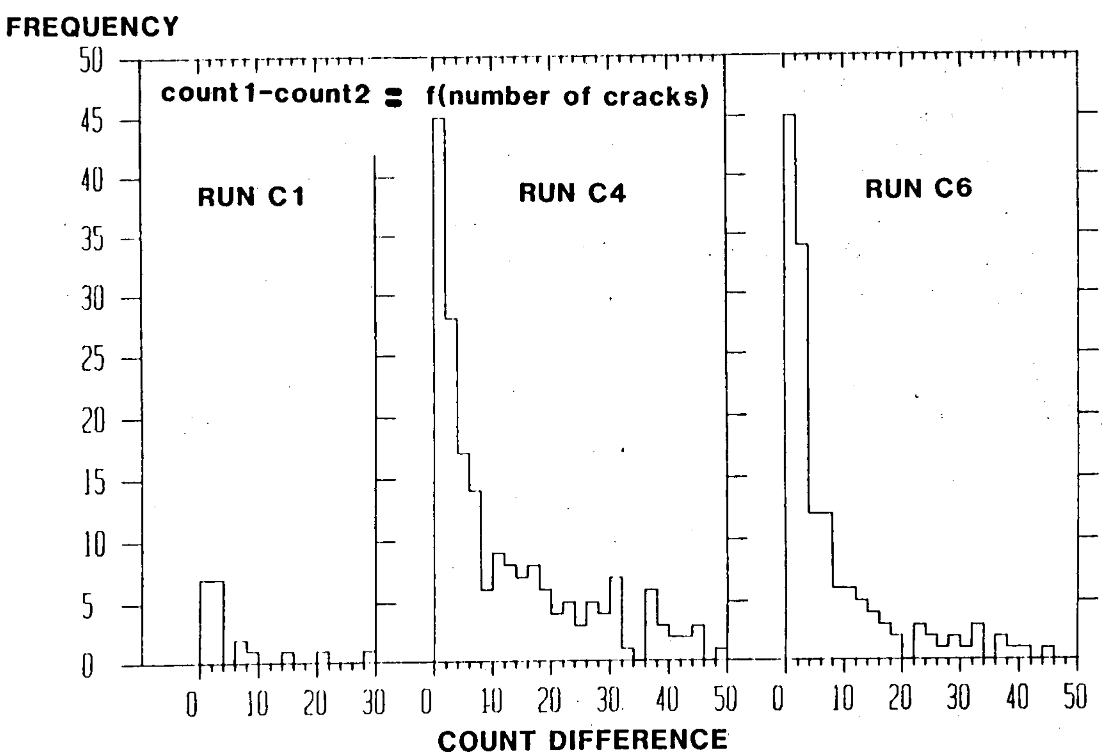


Figure 14.

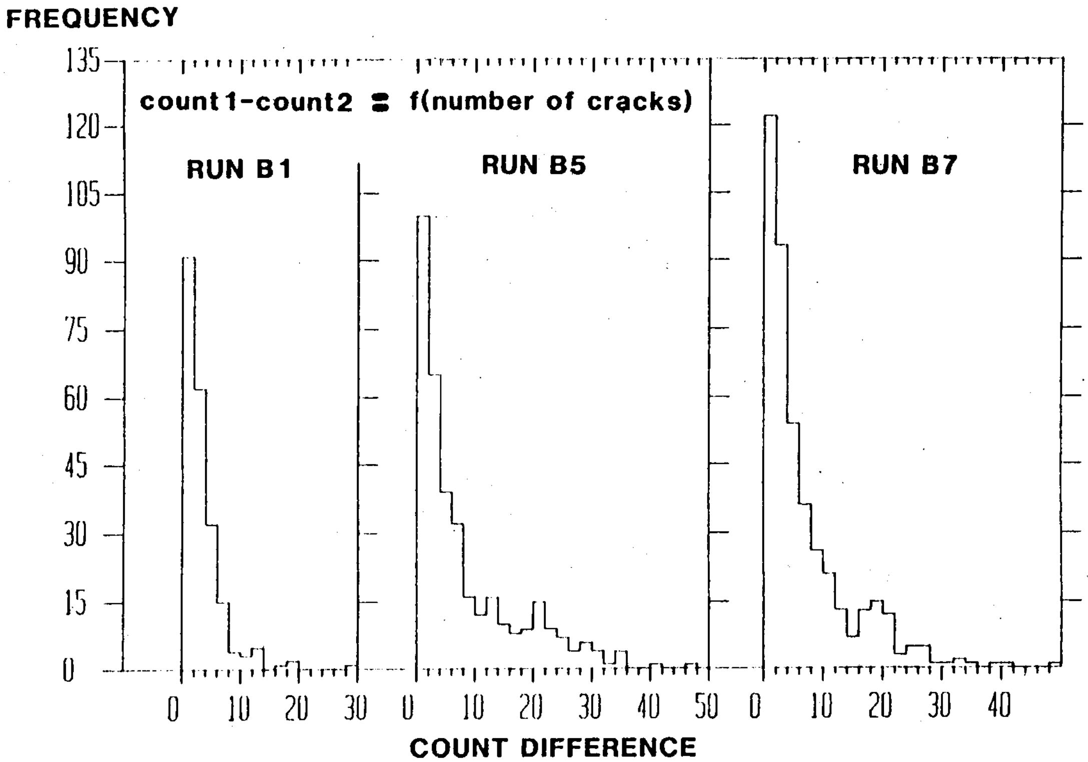


Figure 15.

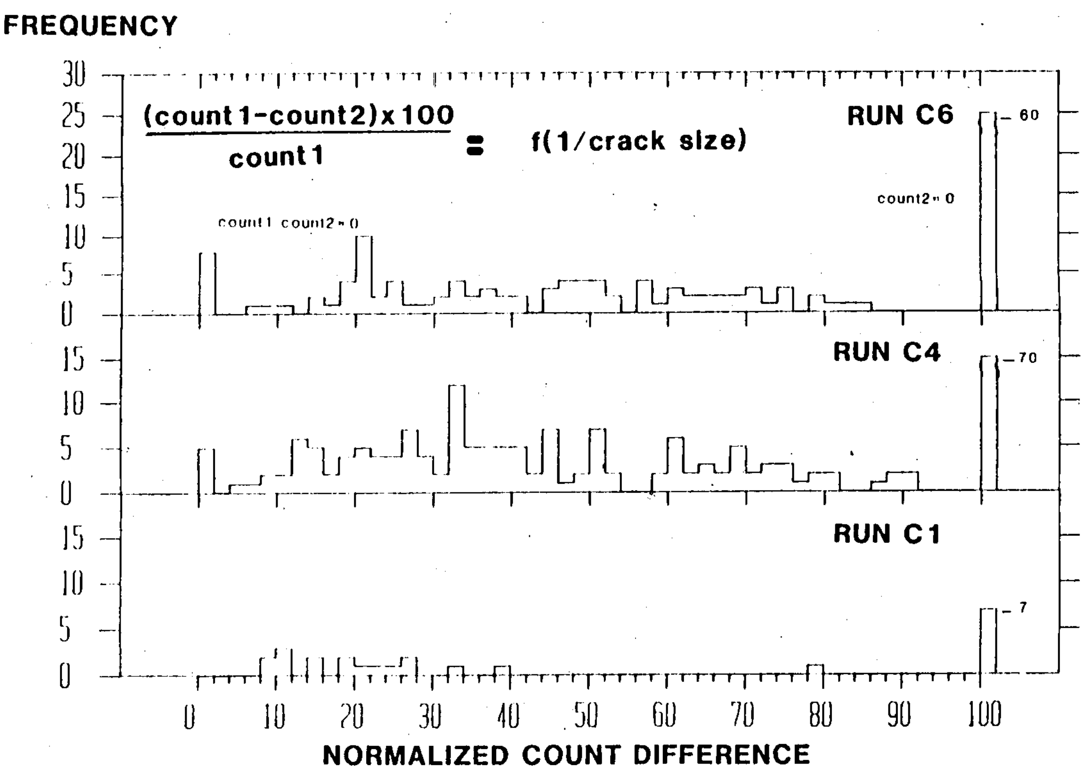


Figure 16.

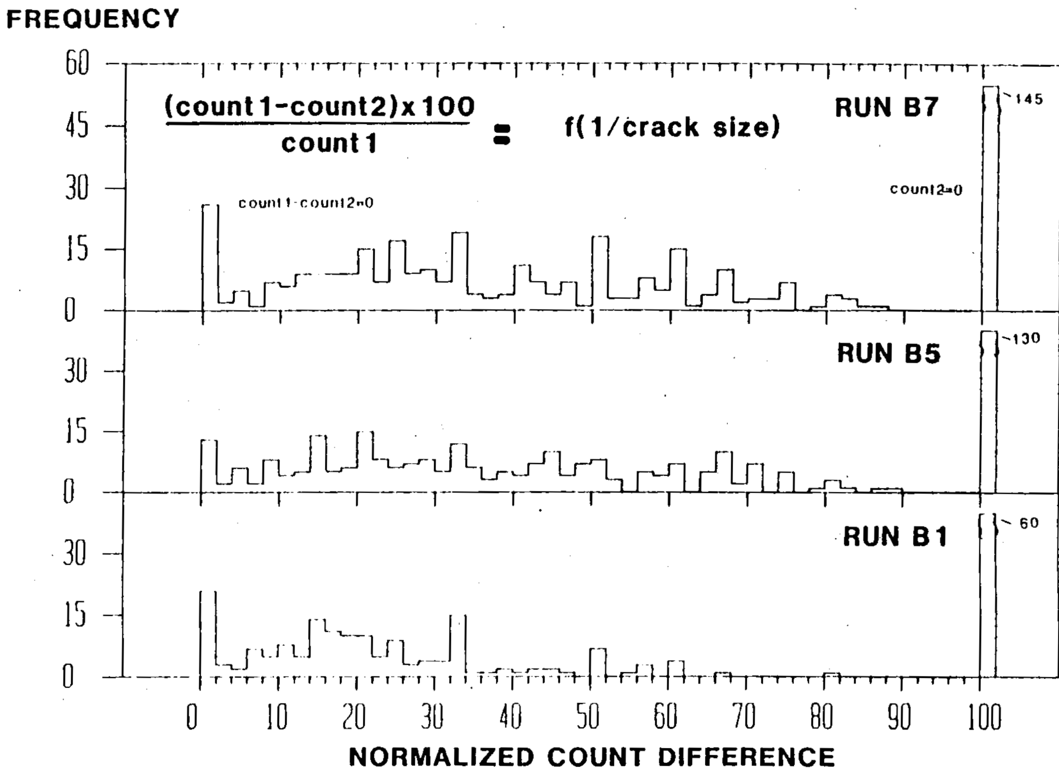


Figure 17.

SUMMARY OF "BURST EMISSION ANALYSIS"

1. The slope of Σ counts/temperature becomes more negative with respect to thermal cycle number up to the cycle where failure was first observed.

2. The sample which exhibited the least total number of AE counts also showed the greatest influence of "bound level" on "Σ counts/temperature".

3. AE burst events greater than 30 to 50 counts per event gave rise to a rapid increase in the observed accumulative AE.

4. The effect of bound level on Σ counts/temperature can be observed prior to visible failure.

Figure 18.

SUMMARY OF COUNT DIFFERENCE DATA

1. There is a wide distribution (from 1 to about 50) for the "number of cracks" which most commonly occur per AE event.

2. The crack distributions vary from cycle-to-cycle and from specimen-to-specimen.

3. The distribution for the number of cracks is greater for run C than for run B.

Figure 19.

SUMMARY OF NORMALIZED COUNT DIFFERENCE DATA

1. The distribution of the (1/crack size) function spreads on increased thermal cycling. This represents the growth (and nucleation) of cracks.

2. Generally, on thermal cycling, either;
   (i) the number of small cracks increases, or,
   (ii) the minimum growth increment of cracking decreases.

3. There is an increase in the AE activity of large cracks.

Figure 20.

EVALUATION OF THE CRACK DENSITY FUNCTION WITH RESPECT TO THE ACCUMULATIVE AE COUNTS

1. The crack density function (CDF) is not dependent on the accumulative AE counts. i.e.; different crack distributions may give rise to the same AE count for different samples.

2. An increase in the AE count will also show an increase in the CDF (for any one sample).

3. Major crack density peaks are observed between different samples and during the thermal cycling of specific samples.

Figure 21.

FINAL SUMMARY

1. AE methods have been found useful in examining the failure processes within plasma-sprayed coatings which are subjected to thermal cycling experiments.

2. A "crack density function" has been derived from the AE of the sample.

3. The CDF is qualitatively related to the crack size and number of cracks within a coating system.

Figure 22.