General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA Technical Memorandum 78649

EFFECTS OF MOISTURE IN INFRARED THERMOGRAPHY OF

RESIN MATRIX COMPOSITES

(NASA-TM-78649) EFFECTS OF MOISTURE IN INFRARED THERMOGRAPHY OF RESIN MATRIX COMPOSITES (NASA) 18 p HC A02/MF A01
CSCL 14E
N78-15464
Unclas
G3/35 01861

Jag J. Singh, Andronicos G. Kantsios, Edwin A. McErlean,
Robert A. Babcock, and Richard D. Buckingham

January 1978

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

EFFECTS OF MOISTURE IN INFRARED THERMOGRAPHY OF RESIN MATRIX COMPOSITES

By

Jag J. Singh, Andronicos G. Kantsios, Edwin A. McErlean,
Robert A. Babcock, and Richard D. Buckingham*

ABSTRACT

Several multi-ply graphite polyimide composite specimens were examined by real-time infrared thermography in order to study the effects of moisture on their thermograms. Heat was injected from one side and IR emission detected on the opposite side using AGA Thermovision System-680. No differences between the thermograms of dry and water containing specimens were detected for defect-free specimens. However, the presence of trapped water in defective specimens modified the thermographic contrast significantly. It has been concluded that: (1) IR thermography can be used to detect moisture in defective composites and (2) because of the possibility of moisture camouflaging defects, IR thermography for subsurface defect detection should be supplemented by other techniques - such as acoustical imaging and X-radiography.

INTRODUCTION

Advanced graphite fiber-reinforced resin matrix composites have emerged as strong candidates for aerospace applications. However, structural integrity and full life cycle of these materials under normal service environmental conditions must be demonstrated before they can

---

*Vought Corporation, Hampton, VA

come in widespread use. It has been reported[1-6] that absorbed moisture degrades the mechanical properties of these materials. This degradation is generally attributed to the plasticizing effect of the moisture on the matrix. Cyclic swelling and shrinkage caused by successive absorption and desorption of water may also lead to substantial internal stress resulting in mechanical deterioration. Thus the ability to detect the presence of water in composites is important in determining their suitability for continued service.

Infrared thermography has been successfully used[7-9] in detecting subsurface defects in metals and composites. Subsurface defects in materials cause differences in thermal conductance across them and these differences are reflected in the thermograms of the test surfaces. Introduction of water in composites may modify the thermal gradients on the test surface since water is a better heat conductor in comparison with the voids, delaminations and the matric resin itself. It is thus possible that the thermogram of a specimen in wet state would be different from its thermogram in the dry state. The presence of water may even camouflage the defects visible in the dry specimen. If the differences between the dry and wet thermograms are significant, it will be necessary to supplement IR imaging technique of defect detection by other techniques which are not influenced by the presence of moisture in the test specimen. On the other hand, infrared thermography can be used for detecting moisture in composite specimens if their wet and dry state thermograms are significantly different. The present study was undertaken to investigate this latter possibility.

A number of multi-ply Hercules HTS graphite fiber-reinforced polyimide composite specimens (PMR-15) were selected for this study. Graphite-

polyimide composites were selected because NASA has been studying them since 1976 for high temperature (600 K) airframe applications. They are also prime candidates for use in the Shuttle program. The results are discussed in the following sections.

Experimental Procedure

The specimens were first ultrasonically scanned to locate any defects - such as delaminations, fiber cracks, and debonds, etc. - that they may have. They were then examined by the IR thermographic technique,[10] using the AGA Thermovision System-680, in the spectral range of 3.0-5.6 μm. The AGA system is capable of detecting temperature differences of the order of 0.2 K at 293 K object temperature. The thermographic measurements were made on "dry" and "wet" conditions of the specimens. The specimens' linear dimensions were 13 cm x 13 cm x 0.1 cm.

(a) Specimen Heating Procedure: A 13 cm x 13 cm heater pad was attached to one face of the specimen with the help of clamps along the edges, as shown in figure 1. Thermocouples were attached to the rear side of the heater pad. Current was applied to the heating pad to bring the sample through a temperature range of 300 to 350 K and the opposite face scanned for IR emission. The same heating procedure was used for dry and wet specimens.

(b) Procedure for Introducing Water in the Specimen: The diffusion coefficient of water through the polymeric matrix is low at ambient temperatures. Consequently, the specimen had to be placed in a pressurized cooker at 400 K to facilitate moisture difussion in it. The specimen was first weighed and then inserted in a pressure cooker charged with water at 400 K (water boiling point at 1400 Pa) and left there for 4 hours. Care was

taken to insure that the specimen was in the steam atmosphere - not immersed in water. The specimen was then taken out of the cooker and weighed again to determine the weight of water that had diffused into it. The table below shows relevant weights for a selected specimen. The weight of water intake corresponds to about 0.08 percent of the weight of the dry specimen. This weight should be compared with the moisture content of about 0.3 percent calculated for a 24-ply T300/5208 specimen after exposure of 5 weeks in the environment similar to that at Langley Air Force Base.[11]

Specimen Weight Before Introduction into Cooker	Specimen Weight after Immersion in Steam for 4 Hours	Weight of Water Intake
0.0594282 kgm	0.0594742 kgm	4.60×10^{-5} kgm

Results

Figure 2 shows a comparison between an IR thermogram and an ultrasonic C-scan of a typical specimen. Figure 2a shows an ultrasonic transmission C-scan. The dark regions represent defective areas while the clear (white) regions represent defect-free areas. Figure 2b shows the "dry" IR thermogram of the same specimen. In this figure, dark areas represent regions of poorer thermal conductance (and thus cooler), while the white areas are the regions of normal thermal conductivity. Notice that in figure 2b there are other thermal patterns which show across the specimen face, in addition to those seen in figure 2a. These are indicative of spatial differences in thermal conductance or perhaps surface emittance effects. The spatial thermal conductance differences could arise from excess/deficit resin concentration without any mechanical defects therein. The conventional techniques (ultrasonic scan, X-radiography, etc.) cannot detect such differences. It thus appears that IR scanning may

provide additional information about the matrix thickness uniformity, which cannot be easily obtained by other techniques. Figure 3 shows an ultrasonic transmission C-scan of a typical test sample. It shows a defect area on the right. The defect is prominent in the lower portion and decreases in severity towards the upper portion. Figure 4a is a thermogram of the same specimen, taken from the front face in the dry state. Figure 4b represents the wet thermogram under the same conditions. One can see that there is a definite correlation between figures 3 and 4a. The defect area is quite prominent in figure 4a. However, the prominence of the defect area is considerably reduced in the wet thermogram seen in figure 4b. It thus appears that changes in thermal contrast between the dry and moisture bearing state of the sample can signal the presence of moisture in the specimen. Figures 5a and 5b represent the "dry" and "wet" thermograms of the same specimen, at the same temperature but from the rear face. The sharpness of the thermal contrast seen in figure 4a is missing from figure 5a. Furthermore, the thermograms in figures 5a and 5b are not very different from each other. These differences between figures 4 and 5 are discussed in the following section.

DISCUSSION

The effect of an internal defect on heat distribution on the specimen surface is illustrated in figure 6. When the specimen is dry, the defect D acts as a heat barrier shadowing the region a-b on the opposite face. The location of the defect D within the specimen determines its effectiveness as a heat shield. Thus a thermogram of a dry specimen should indicate if a known defect is near face 1 or face 2. Now when the specimen is saturated

with water, the defect D will trap some water in it and will no longer act as an effective heat shield. Consequently, the presence of water should be signaled by the disappearance of (or reduction in the intensity of) the cold spot present in the thermogram of a defective dry specimen. The change in thermal contrast between the dry and wet state will be more marked when the defect is near the surface studied. This explains the differences between figures 4 and 5. A reflection ultrasonic C-scan (shown in figure 7) confirmed that the defect was nearer the front face than the rear face.

When the specimen has no defects, the water is taken up uniformly by the polymer, rendering it plastic. The water thus absorbed in the specimen should affect general heat conduction through it without causing any localized effects. The dry and wet thermograms from defect-free specimen should thus be similar.

CONCLUDING REMARKS

Present study indicates that the presence of moisture in composites modifies the surface temperature distribution associated with regions of anomalous thermal conductance in the specimen - such as cracks, voids, and delaminations. Thus a comparison between the thermogram of a defective test specimen, as received, and its thermogram in the "dry" state can indicate if the test specimen had any moisture in it. The technique cannot however provide a quantitative measure of moisture content in the test specimen. Nor can it be used to provide information about the water content of a defect-free specimen. In general, however, specimens that have seen some service usually develop enough small defects to render this technique usable in most practical cases. In view of the fact that the moisture associated

with the defects tends to camouflage them, it is suggested that infrared imaging technique for subsurface defect detection be supplemented by other techniques (such as acoustical imaging and X-radiography) not influenced by the presence of water in the test specimen.

REFERENCES

1. C. E. Browning and J. T. Hartness: Proceedings of Third Conference on Composite Materials Testing and Design, pp. 284-302 (Williamsburg, VA, March 21-22, 1973).

2. C. E. Browning: Proceedings of 28th Conference of Society of Plastic Industry held at Washington, DC (Feb. 1973).

3. J. Hertz: Final Contract Report No. NASA 8-27435 (June 1973).

4. C. D. Shirrel; J. D. Halpin; and C. E. Browning: Workshop on the Environmental Durability of Resin Matrix Composites held at Battelle's Columbus Laboratories (Sept. 30-Oct. 2, 1975).

5. ASTM Special Publication No. 602 (Proceedings of a Symposium on Environmental Effects on Advanced Composite Materials held at Montreal, Canada, June 22-27, 1975).

6. H. W. Bergman and C. W. Dill: National SAMPE Tech. Conf. Series; Vol. 8, p. 244, 1976.

7. R. D. Dixon, G. D. Lassahn, and A. Digiallonardo: Materials Evaluation, Vol. 30, 73-77, 1972.

8. G. J. Trezek and S. Balk: Materials Evaluation, Vol. 34, 172-176, 1976.

9. R. S. Williams and K. L. Reifsnider: Materials Evaluation, Vol. 35, 50-54, 1977.

10. AGA Thermovision 680 Operating Manual, Publ. 556.053 AGA Infrared Systems AB, c. 1973.

11. J. Unnam and D. R. Tenney: AIAA Paper No. 77-400 (presented at the AIAA-ASME 18th Structures, Structural Dynamics, and Materials Conference, held at San Diego, CA, Mar. 21-23, 1977).

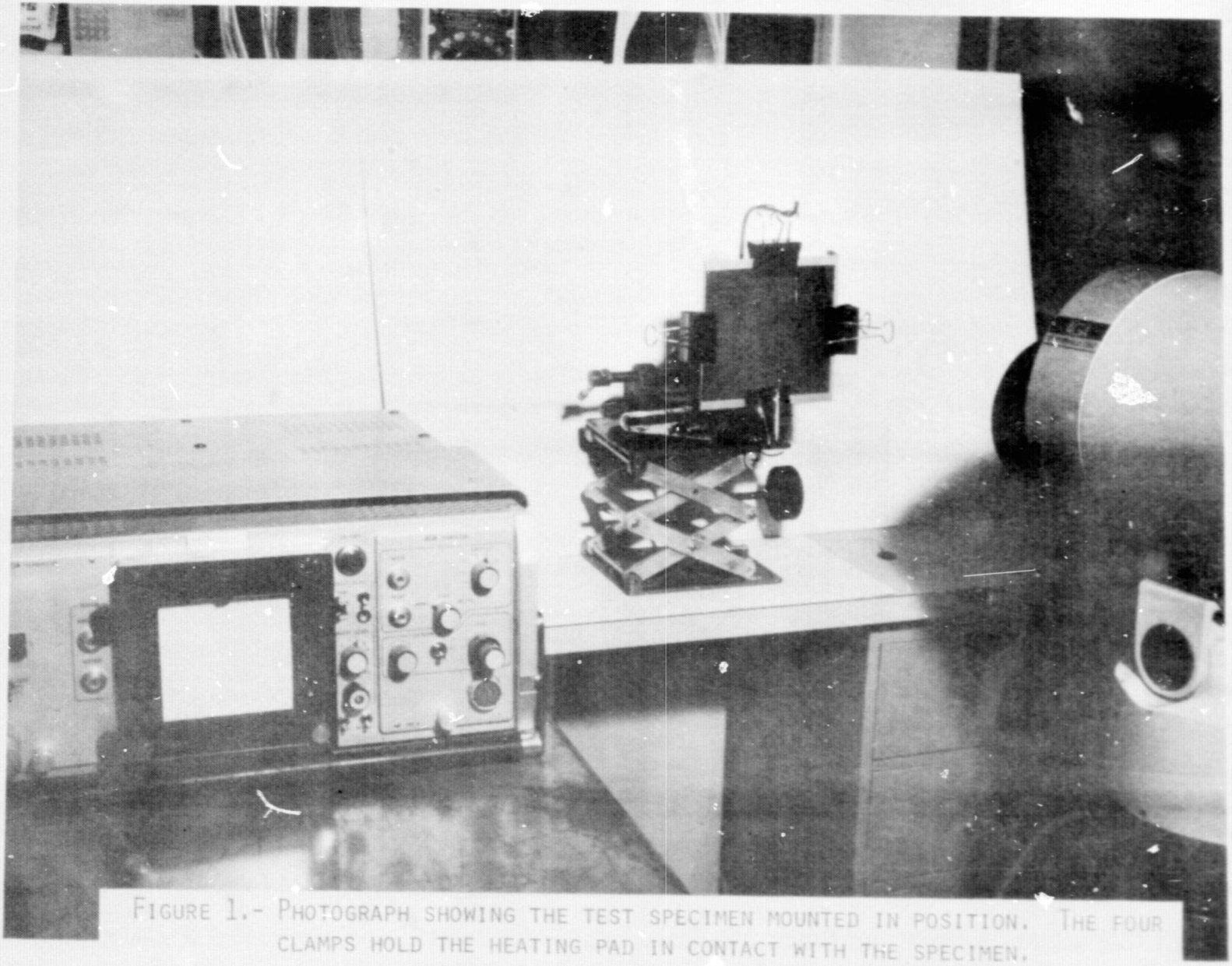


FIGURE 1.- PHOTOGRAPH SHOWING THE TEST SPECIMEN MOUNTED IN POSITION. THE FOUR CLAMPS HOLD THE HEATING PAD IN CONTACT WITH THE SPECIMEN.

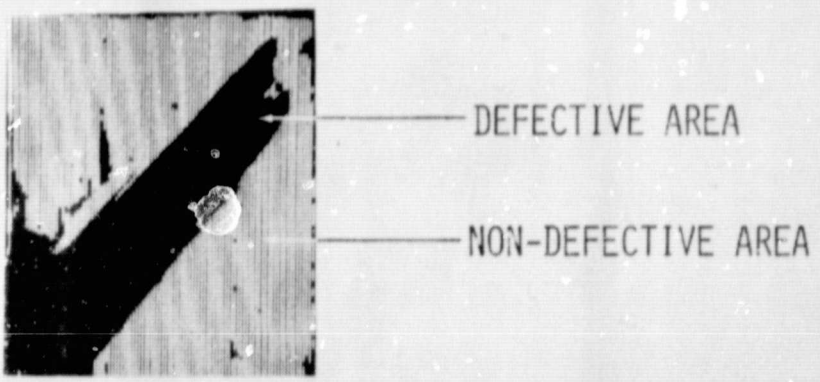


FIGURE 2A.- ULTRASONIC SCAN OF A TYPICAL SPECIMEN CONTAINING DEFECTS.

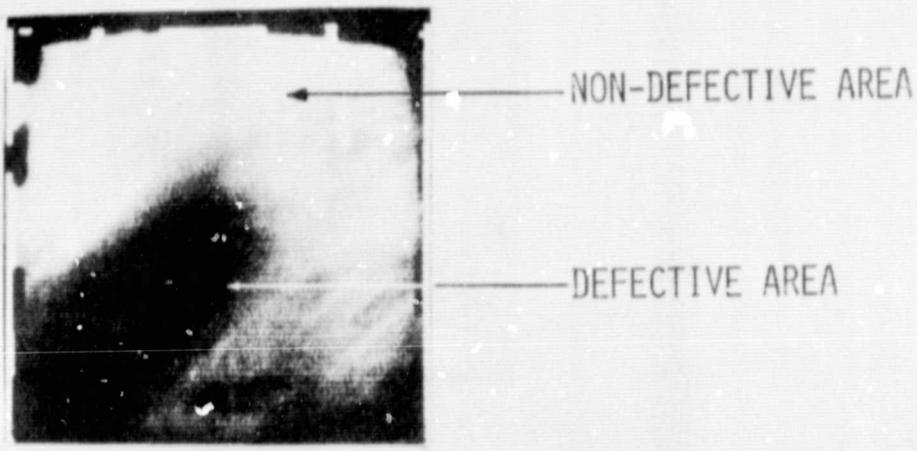
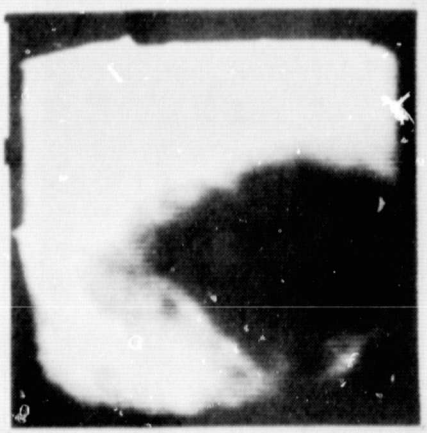
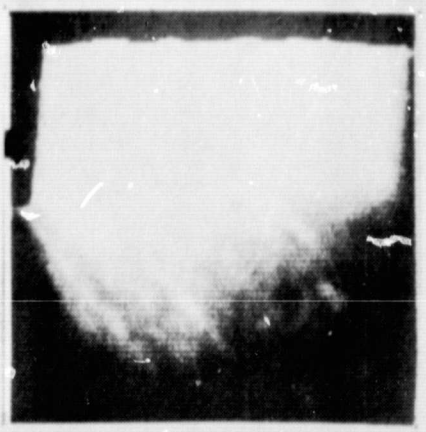


FIGURE 2B.- THERMOGRAM OF SAME SPECIMEN SHOWING DEFECTIVE AND NONDEFECTIVE AREAS.

FIGURE 3.- ULTRASONIC SCAN OF THE TEST SPECIMEN. (THIS SPECIMEN HAS BEEN USED IN FIGURES 3, 4, 5, AND 7.)

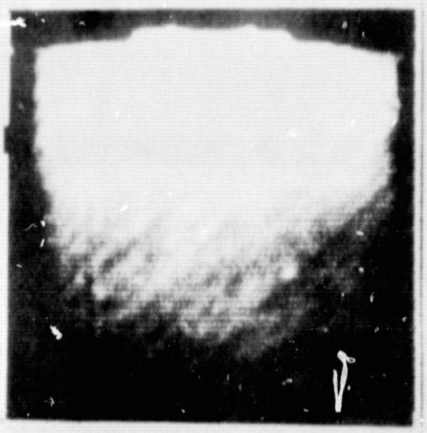


4(A) DRY

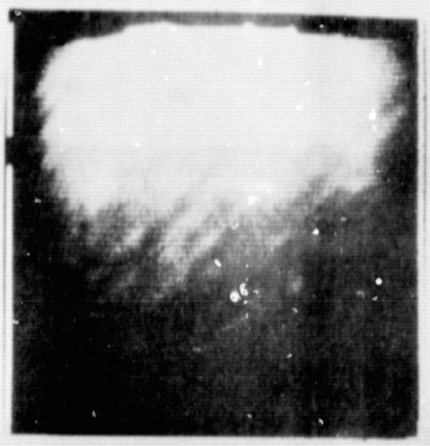


4(B) WET

FIGURE 4.- THERMOGRAM OF DRY AND WET TEST SAMPLE - FRONT FACE.



5(A) DRY



5(B) WET

FIGURE 5.- THERMOGRAPH OF DRY AND WET TEST SAMPLE - REAR FACE.

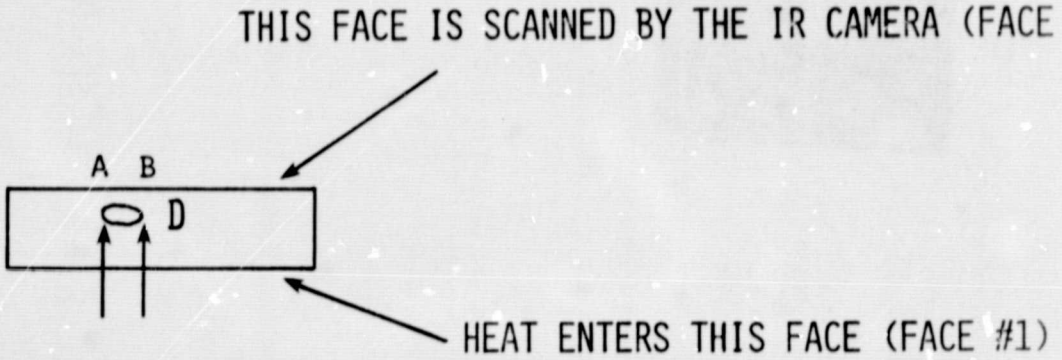
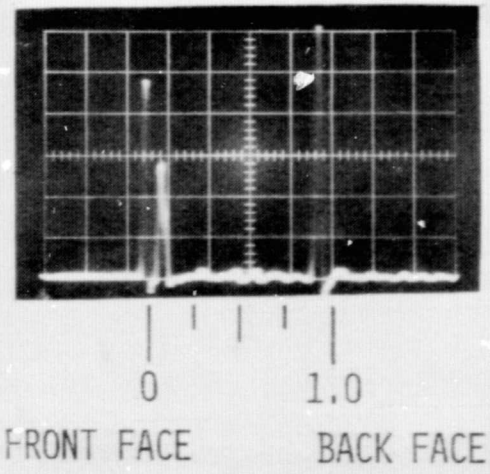
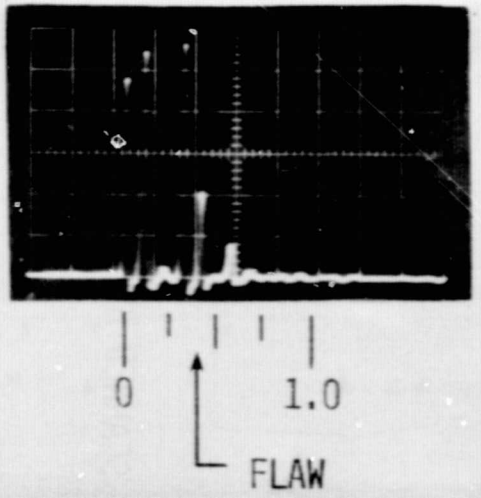


FIGURE 6.- EFFECT OF DEFECT ON HEAT PROPAGATION THROUGH A COMPOSITE SPECIMEN.



7(A)



7(B)

FIGURE 7.- ULTRASONIC INTENSITY SCAN OF THE TEST SPECIMEN SHOWING THE LOCATION OF THE FLAW.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM 78649		

4. Title and Subtitle	5. Report Date
Effects of Moisture in Infrared Thermography of Resin Matrix Composites	January 1978
	6. Performing Organization Code 1200

7. Author(s)	8. Performing Organization Report No.
Jag J. Singh, Andronicos G. Kantsios, Edwin A. McErlean, Robert A. Babcock, Richard D. Buckingham	

9. Performing Organization Name and Address	10. Work Unit No.
NASA Langley Research Hampton, VA 23665	505-02-33-04
	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Infrared Thermography can be used to detect moisture in composites having voids/defects.

16. Abstract

Several multi-ply graphite polyimide composite specimens were examined by real-time infrared thermography in order to study the effects of moisture on their thermograms. Heat was injected from one side and IR emission detected on the opposite side using AGA Thermovision System-680. No differences between the thermograms of dry and water containing specimens were detected for defect-free specimens. However, the presence of trapped water in defective specimens modified the thermographic contrast significantly. It has been concluded that: (1) IR thermography can be used to detect moisture in defective composites and (2) because of the possibility of moisture camouflaging defects, IR thermography for subsurface defect detection should be supplemented by other techniques - such as acoustical imaging and X-radiography.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Composites, Moisture, defects, Infrared Thermography, Nondestructive Evaluation.	Unclassified - Unlimited Star Category - 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	16	$4.00

* For sale by the National Technical Information Service, Springfield, Virginia 22161