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# Final Report

on

# Damage Assessment in High Temperature Materials
# (DURIP99 Grant # F49620-99-1-0134)

to

## Air Force Office of Scientific Research

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13. ABSTRACT *(Maximum 200 words)*

An Echotherm thermal wave imaging system was acquired from Thermal Wave Imaging, Inc. of West Bloomfields, Michigan and implemented as a nondestructive evaluation in our laboratory at Wayne State University. The DURIP grant was matched by Wayne State University. The equipment implementation was completed by end of January, 2000. The thermal wave imaging equipment was checked for its capability in assessment of damage in various materials systems which included thermal barrier coatings, adhesively bonded composites and SiC/SiC woven ceramic composites. The results show great promise in damage assessment for these material systems currently under investigation in our laboratory. The equipment gives us an exceptional capability in interrogating material damage in advanced material systems and can be used in important programs from US Air Force and other agencies and industry.

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## Abstract

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## Introduction

Thermal-wave imaging is a Non-Destructive Evaluation (NDE) tool. One can obtain surface and sub-surface information of a sample specimen from this image. The sample is irradiated with a flash of light momentarily. A thermal wave imaging setup is shown in Figure 1. After the flash, the surface radiates energy much like reflection of light. The irradiated surface also conducts heat into the sub-surface. With time, we first get the IR image of the surface and subsequently the images of the sample at deeper thickness as the heat is conducted. The correspondence between NDE and measurement of thermal properties is based on assumptions that internal defects can be described by local or averaged (over the whole specimen) variation of k (thermal conductivity) and $\alpha$ (thermal diffusivity). The variations of k and $\alpha$ are found at defects like flaws, delaminations, combs, voids, cracks, disbonds, abnormal porosity, contaminations, variations in thermal or electrical conductivity, structure with non-uniformities or variations in the size or shape of a specimen. Among the number of images taken from the non-moving sample with one flash of light, each image informs of a plane of the sample at a particular thickness and the greater the time-delay (observation time) the deeper the defects in the resulting image. An infrared camera is used to take this image. Infrared wave has wavelength range of 0.8 to 300μm and frequency up to $10^{13}$. This technique has been very successful in material damage assessment (1-6).

**Illumination head**

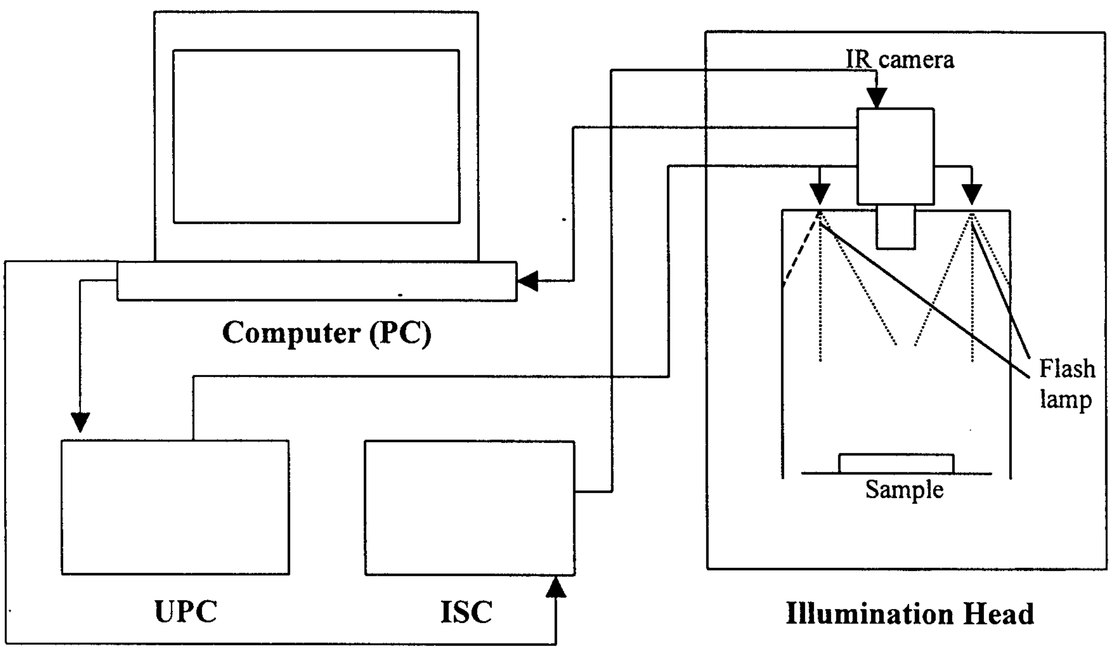


Figure 1:Thermal Wave Imaging setup. UPC and ISC refers to Universal Power Controller and Intelligent Systems Controller.

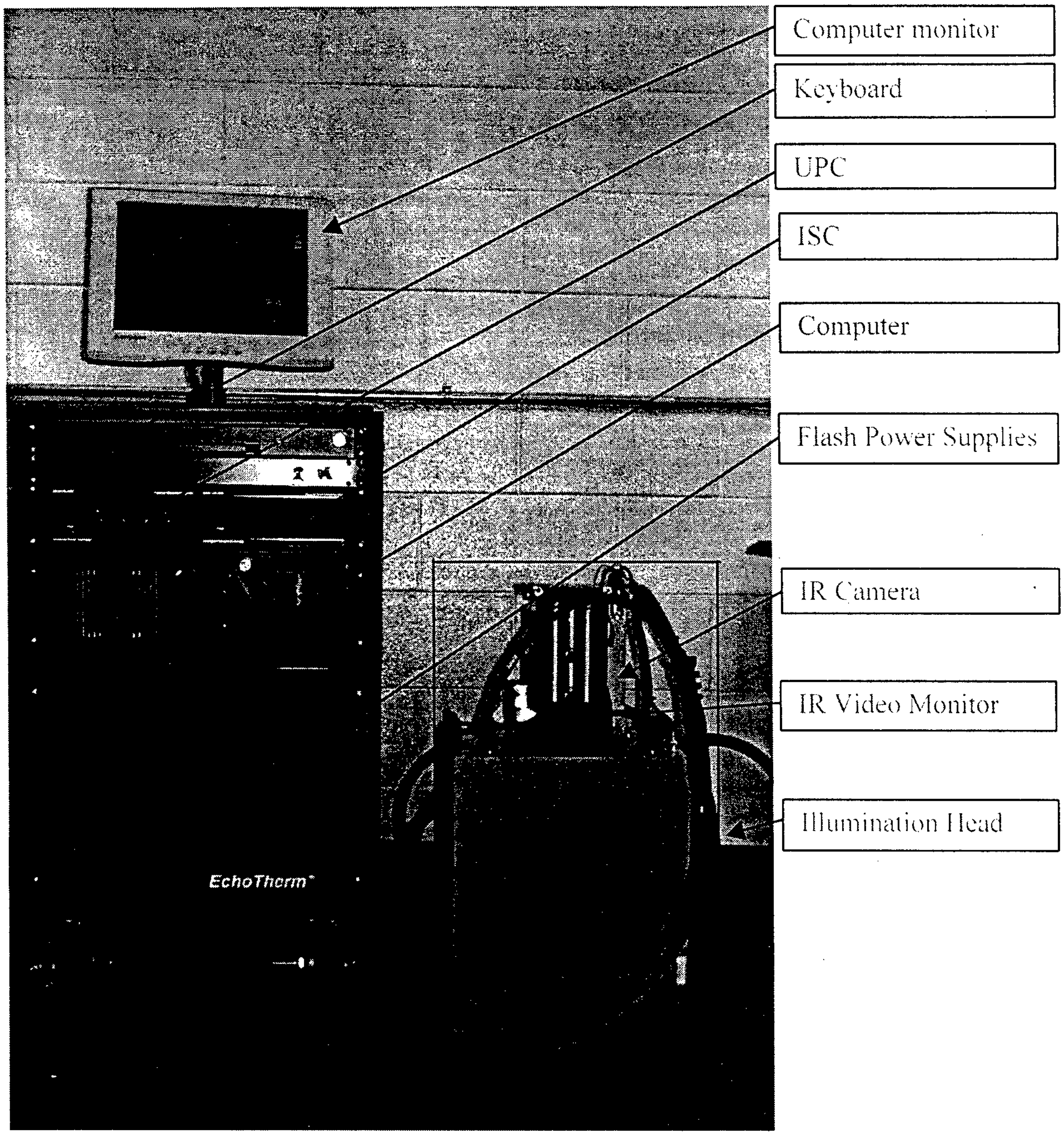


Figure 2: Typical Echotherm® 32 system hardware.

**Illumination Head**

The Illumination Head is Echotherm's interface with the part under inspection. It includes two flashlamps, flash reflectors, the IR camera, LCD video monitor and remote trigger buttons. The umbilical from the electronics rack conveys information and power to and from the illumination head. The illumination head unit can be used for in the field applications in a handheld mode, mounted on a tripod, or integrated into a tabletop. For evaluation of large areas, the opening of the unit is typically placed near, or in contact with the target surface. A rubber bumper at the front opening is provided to prevent damage to the sample surface. Evaluation of smaller samples requires that the sample is securely placed at the illumination head opening with appropriate clamps or fixtures.

**ISC (Intelligent System Controller)**

The intelligent system controller (ISC) communicates with the PC and the IR camera and facilitates coordination of image acquisition and flash heating through a Universal Power Controller (UPC). The ISC also controls image acquisition at variable frame rate through the IR camera.

**UPC (Universal Power Controller)**

The Universal Power Controller (UPC) has dual functionality-it synchronizes triggering of multiple flashlamps and coordinates charging of the flashlamp power supplies so that several power supplies can be charged from a single 110/220 VAC outlet with a 20A capacity (suggested).

### Computer (PC)

The computer (PC) and software control the system components, record the high speed digital IR images, and provide the user with the powerful visualization and analysis tools. The computer's serial ports are used to communicate and control the ISC and camera. A high-speed digital video acquisition card is installed in the computer to bring in the 12-bit IR digital data.

### Evaluation

The software gives us excellent visualization and analysis tool. One can evaluate several material systems to check the utility of the Echotherm unit. We took image of Thermal Barrier Coating (TBC) samples, adhesive bond between composites and ceramics parts. We get images of specimens, response along x and y lines in the image, response of the whole cross-sectional area under scrutiny, response-time plot, histogram, distance between point of interests in the image and so on. Following are the images and plot generated principally from TWI software.

### Thermal Barrier Coating

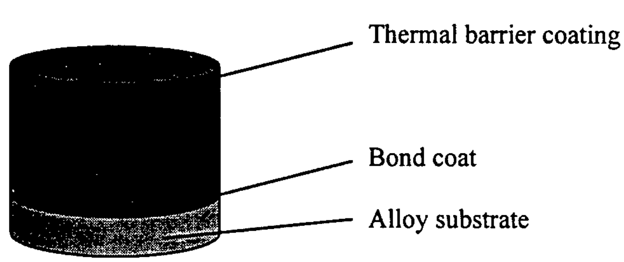


Figure 3: A button specimen of thermal barrier coating without thermal loading.

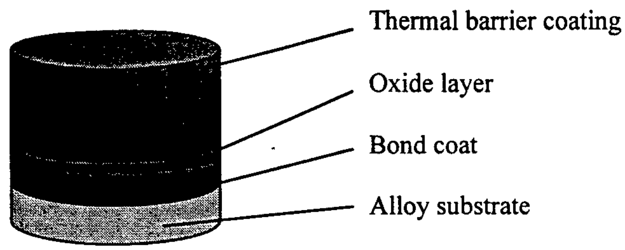


Figure 4: A thermally loaded TBC specimen (Oxide layer forms due to thermal load).

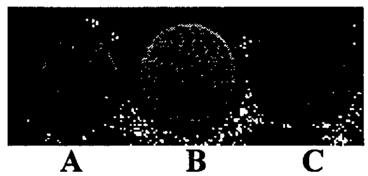


Figure 5: This is an image of three Thermal Barrier Coating (TBC) specimen viewed under IR camera. A is a sample after 125 thermal cycles, B after 50 cycles, C after 0 cycle. A and B are thermally loaded with maximum temperature of 1177C and minimum temperature of 200C. The ramping time is 9 minutes from 200C to 1177C, holding at maximum temperature is 45 minutes and cool down is 15 minutes from 1177C to 200C .

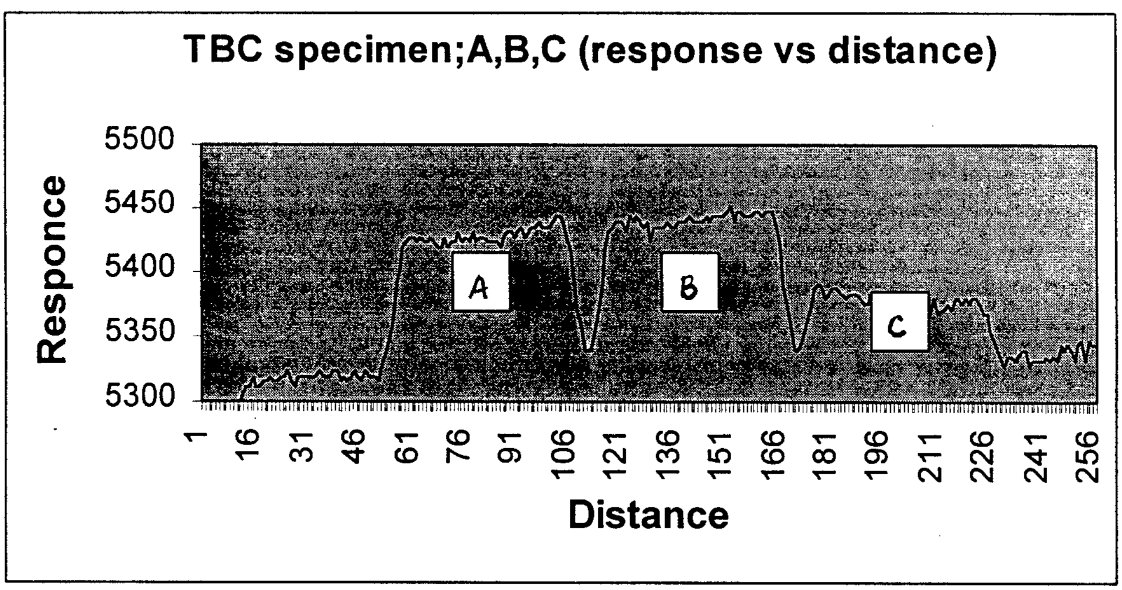


Figure 6: Plot of response on through diameter horizontal line against distance.

## Adhesive joint between composite frames

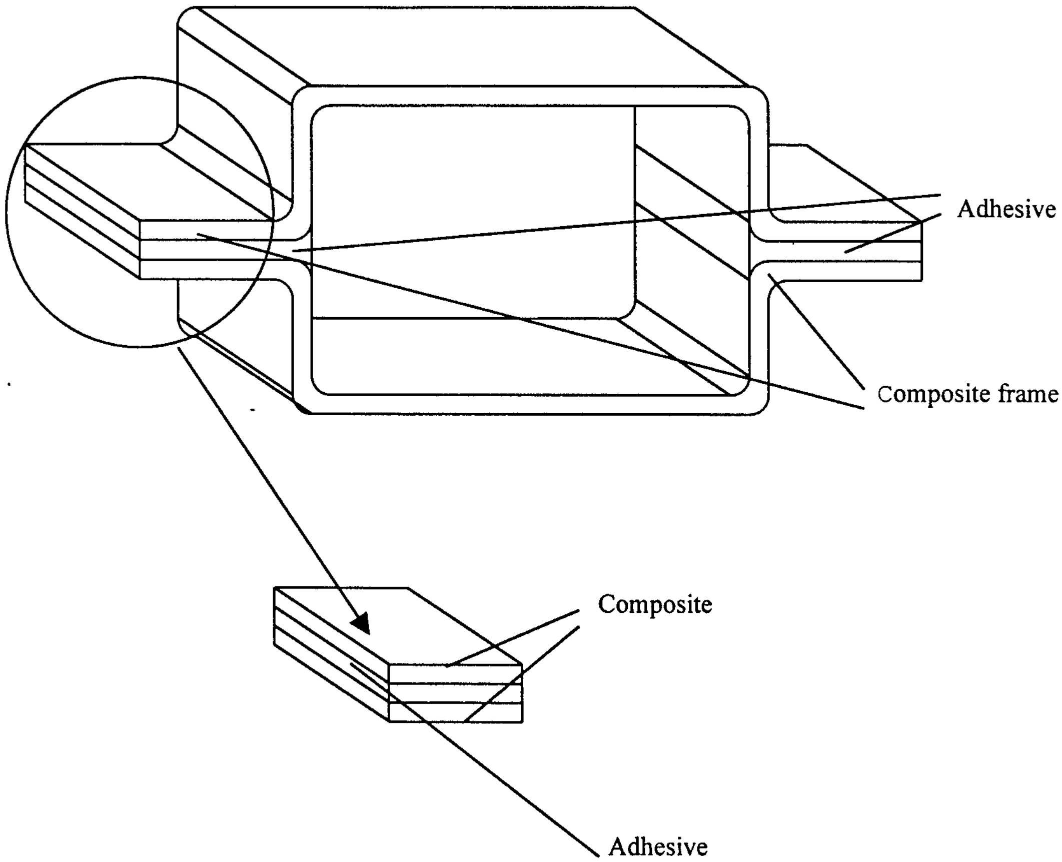


Figure 7: Adhesive joint between composite frames–the cut-away piece is used for thermal wave imaging.

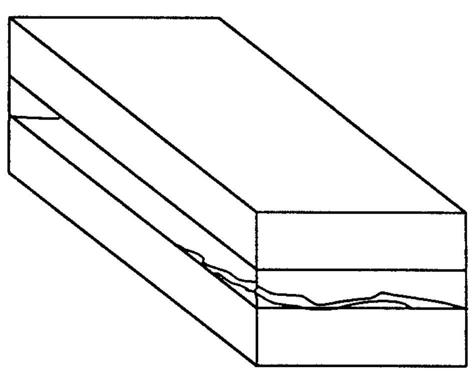

Figure 8: Schematic diagram of partially cracked adhesive joint.

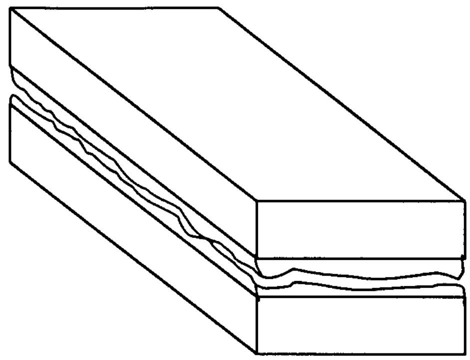

Figure 9: Schematic diagram of complete fracture through adhesive.

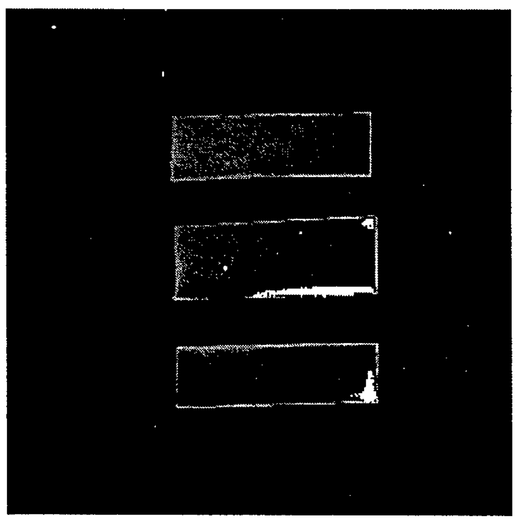

Figure 10: Thermal wave image of adhesive joint (A-untested specimen, B-tested with mechanical load-partially cracked, C-tested with mechanical load-completely fractured)

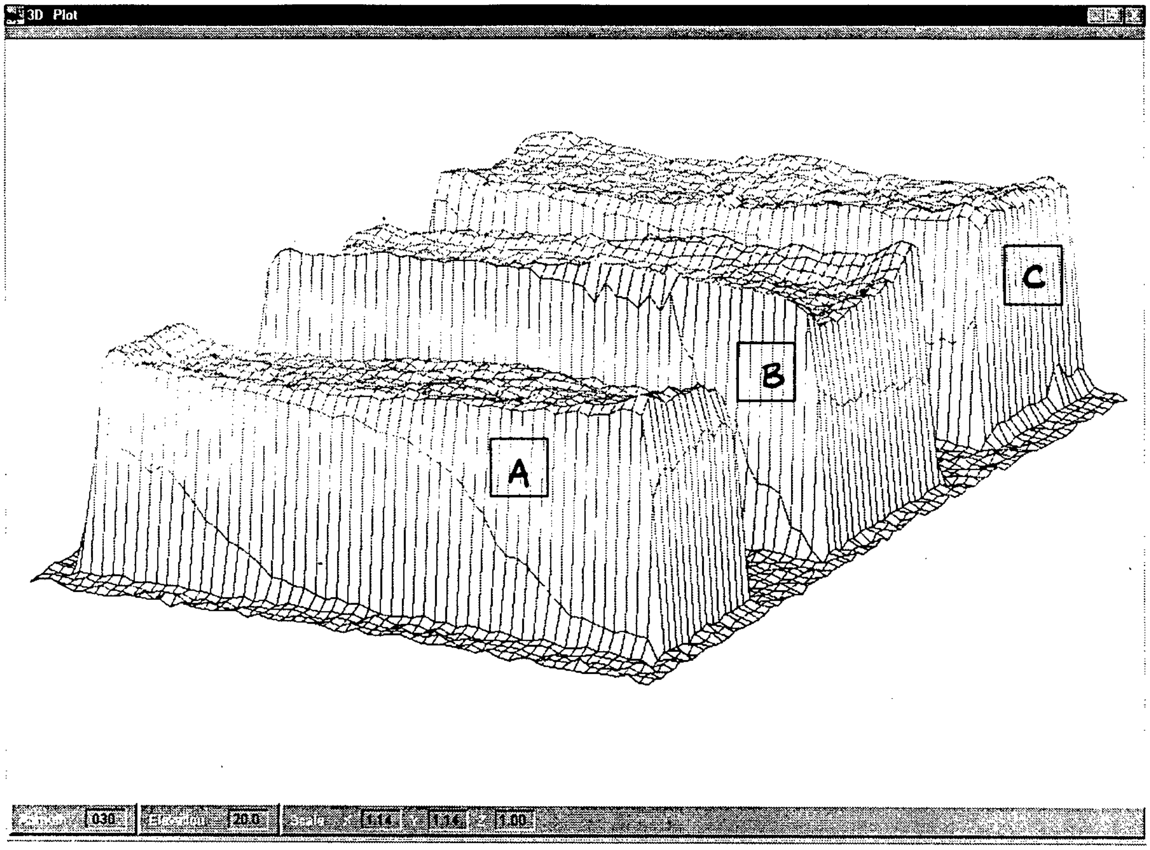


Figure 11: 3D plot option of Echotherm® 32 (software installed in the thermal wave imaging system)-the response of the specimens over the finite area make the 3D plot.

**Ceramic composite**

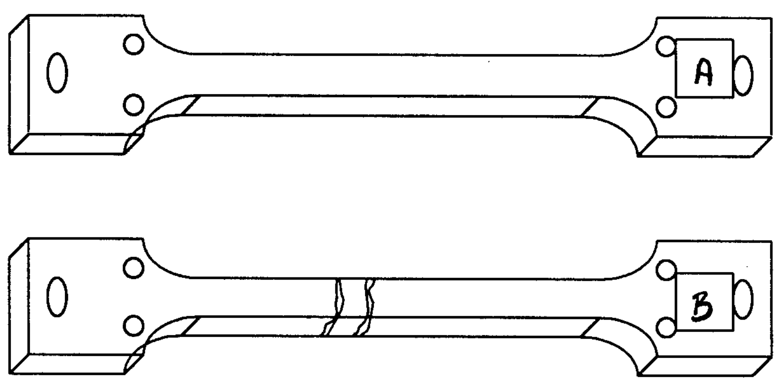


Figure 12: Ceramic composite; A-untested specimen, B-fatigue tested specimen

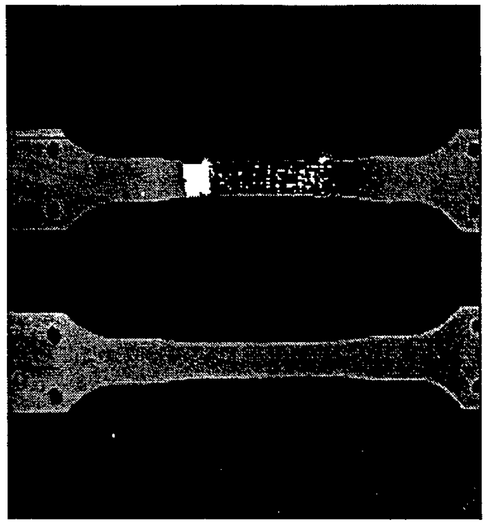

Figure 13: Thermal wave image of tested (B) and untested (A) ceramic composite.

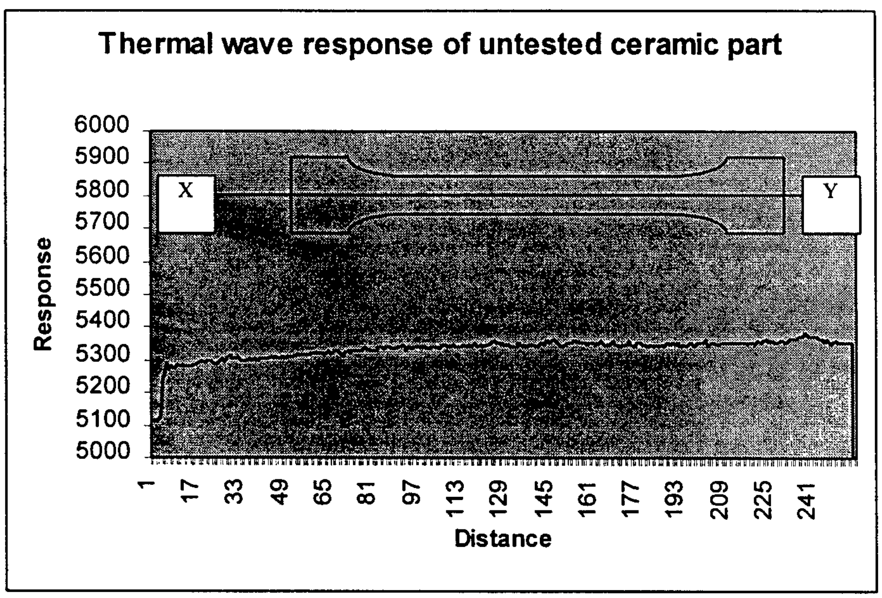


Figure 14: Response of untested ceramic composite on XY line.

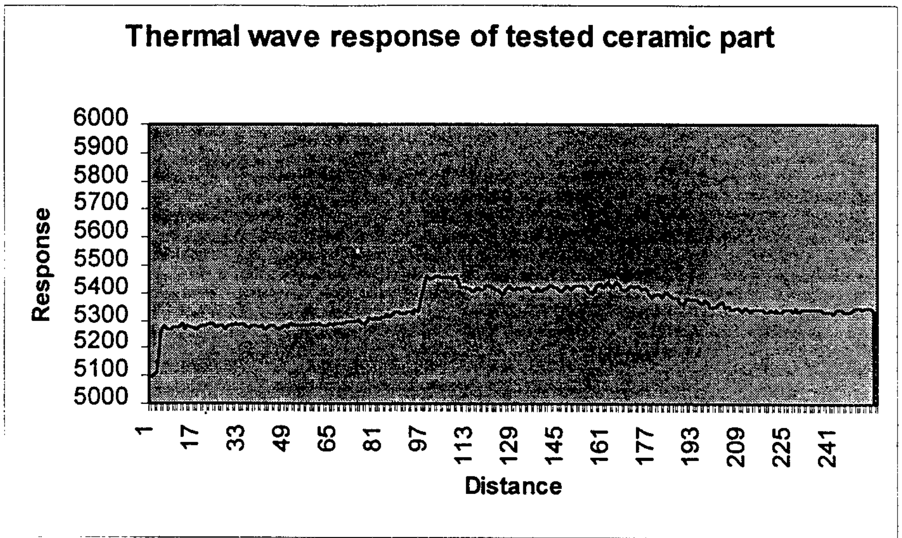


Figure 15: Response of fatigue tested ceramic composite-the peaks and undulations are near fracture area.

## Summary

Thermal wave imaging is a recent, powerful NDE tool. Results from a number of material evaluation efforts indicate that the technique has great promise. Its full potential in evaluation of microcracks is progressing. Meaningful representation of the response with some reference numbers the surface under evaluation can be quantitatively described. With better control over the prediction of depth at which the images provides us much information, this equipment is an excellent addition to our laboratory and can be utilized extensively in future programs from the US Air Force and other agencies.

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