Stress Photonics

Thermoelastic Forum

A Newsletter of Thermoelastic Technology

Vol.1, No.5, Oct. 1994

First Words

Much has happened since the last issue of the *Thermoelastic Forum*. Stress Photonics completed a NASA Phase II SBIR contract that involved the development of a high-speed Thermoelastic Stress Analysis (TSA) array camera. This prototype camera was successfully used in a Stress Photonics Air Force Phase I project, which in turn resulted in the award of an Air Force Phase II SBIR.

Under the Phase II contract, Stress Photonics will be using the array camera to study high-temperature fracture mechanics of isotropic and anisotropic materials. (Please refer to the R&D Side column in this issue of the *Thermoelastic Forum* for details of this new research.)

Development of the array camera has lead to another bit of recognition. Each year *R&D* Magazine honors the 100 most technologically significant new products of the year. This year, Stress Photonics, together with NASA Langley, was awarded the ”*coveted R&D 100 Award*” for the *DELTATHERM* array camera.

In this issue of the *Thermoelastic Forum* don't miss (1) new SPATE* and VPI imaging software, *DELTAVISION*, featured in New Products; (2) the application of fracture mechanics equations to Thermoelastic Stress Analysis data in the R&D Side; (3) the University Corner featuring joint research done by the University of Illinois Champaign/Urbana and Stress Photonics.

If you would like to contribute a comment, an article, or share some TSA advice, use the response card provided or write to the *Thermoelastic Forum* at Stress Photonics.

*SPATE is a trademark of Ometron Ltd. London.

New Products

Stress Photonics’ DELTAVISION

DELTAVISION ™ software by Stress Photonics allows SPATE, VPI and *DELTATHERM 1000* users to take advantage of powerful UNIX workstation computers, software and network resources to process and present data quickly and easily.

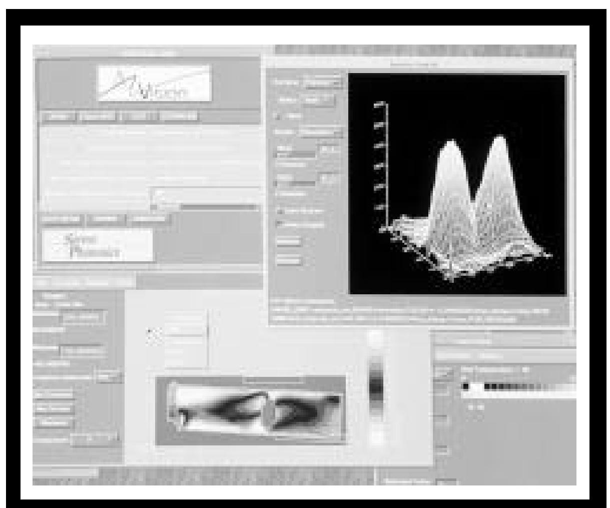
Moving image processing to the UNIX workstation allows the user to take advantage of valuable network resources, such as

- Color laser printers
- Network communications and file transfer
- Remote processing and display of data
- Network-wide access
- Network storage and backup services

DELTAVISION software is written in Visual Numerics' popular PV-WAVE Command Language making it portable between platforms and easily customized and adapted to work with other popular engineering workstation software.

DELTAVISION was written specifically to simplify data visualization. *DELTAVISION* features

- Superior graphics performance
- Various graphical data presentations
- Advanced data manipulation routines
- Quick and easy pull down menus
- Support for TIFF, PostScript, PICT, PCL and more
- UNIX compatibility
- Display of SPATE, VPI and *DELTATHERM 1000* data images
- Data transfer via floppy disk or ethernet



DELTAVISION’S graphical user interface conforms to the Motif and X-Windows standards making it easy to learn and operate. The windowing environment

- Makes comparing data as easy as opening a second window
- Allows viewing of alternate analysis methods
- Makes comparing phase and magnitude, sine and cosine, or AC and DC images easy

The software offers options to output or “save” graphics to several popular file formats including TIFF, PostScript, PICT and PCL. These files can be printed directly or easily transferred to an IBM or Macintosh format for word processing. *DELTAVISION* images have already been used for journal articles, reports and newsletters such as this.

ΔVision ™

For more information on ***DELTAVISION*** *software, contact Stress Photonics or send in the reader response card.*

The R&D Side

Quantitative Fracture Mechanics, Least Squares Method

By Jon Lesniak

In the December '92 issue of the *Thermoelastic Forum,* I described techniques for measuring stress concentrations in an article entitled "Stress Intensity Measurement Through Image Deconvolution." That article did not directly address stress intensity factors by the fracture mechanics definition. This article, however, offers a method for directly measuring stress intensity factors. It was found that, unlike the stress concentration measurements, stress intensity factors can be accurately measured without image deconvolution. In work supported by an Air Force (WPAFB) Phase I SBIR grant, a reliable quantitative method for measuring stress intensity factors from TSA data was developed. Advancements to the works of Peter Stanley and Janice Dulieu-Smith include

- Accommodation of more terms in stress functions
- Full utilization of the data field
- Consideration of thermal conduction
- Consideration of optical limitations

William sought Airy's stress functions under the coordinate system described in Fig. 1 for a crack in a plate.

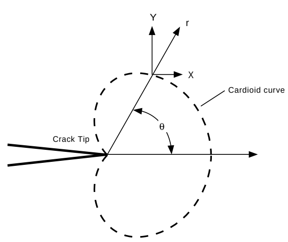


Fig. 1 Stress-function coordinate system.

By taking the appropriate derivatives of the stress functions and combining σ_r and σ_θ the following sum of the principal stress shapes are derived.

$$A_{-1/2}=\frac{2}{\sqrt{2\pi r}}\cos(\theta/2) \qquad \lambda_I=-1/2 \qquad \text{(1a)}$$

$$A_0=1 \qquad \lambda_I=0 \qquad \text{(1b)}$$

$$A_{1/2}=r^{\frac{1}{2}}\cos(\theta/2) \qquad \lambda_I=1/2 \qquad \text{(1c)}$$

$$A_1=\cos(\theta) \qquad \lambda_I=1 \qquad \text{(1d)}$$

Notice, only the λ=-1/2 term of Eq. 1a is of significance at the crack tip where it is singular. For this reason, in classical fracture mechanics, the other terms are ignored. The shape of the λ=-1/2 term is referred to as the cardioid curve. The stress distribution for many higher order terms of Eq. 1b - 1d increases as r increases.

The stress intensity factors are derived from the λ=-1/2 terms as

$$K_I=C_{\lambda I=-1/2} \qquad (2)$$

However, it is difficult to measure data solely near the crack tip where Eq. 1a is dominant because of

- Inelastic material behavior
- Heat conduction
- Optical limitations

Away from the crack tip, fundamental stress patterns resembling shapes other than the cardioid curve will be present. Therefore, it is important for the stress measurement technique to account for all possible fundamental stress terms.

For the reasons mentioned above, a new technique of determining stress intensity factors from thermoelastic data was derived. Putting the terms of Eq. 1 in matrix algebra form, the total stress field can be written as a combination of the fundamental stress shapes,

$$\{S\}_n=[\{A_{-1/2}\}_n\ \{A_0\}_n\ \{A_{1/2}\}_n\ \{A_1\}_n]\begin{Bmatrix} C_{-1/2} \\ C_0 \\ C_{1/2} \\ C_1 \end{Bmatrix} \qquad (3)$$

This can be written more simply as

$$\{S\}=[Q]\{C\} \qquad (4)$$

The least squares algorithm applied to Eq. 4 yields

$$[Q]^T\{S\}=[Q]^T[Q]\{C\} \qquad (5)$$

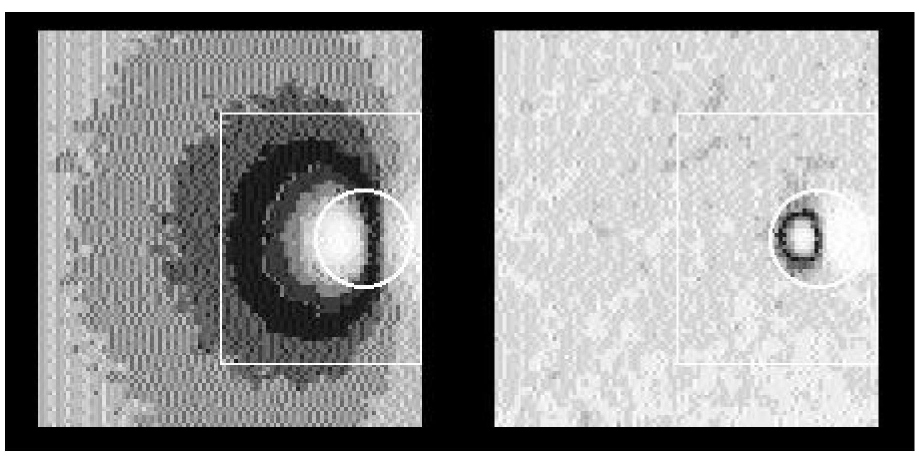
To simplify the least square algorithm, the basis is orthogonalized and normalized over the fit window allowing for rapid application and re-application of the fit. From the solution of Eq. 5, the values of {C} can be determined and K_I is determined from Eq. 2.

The SPATE 9000 camera was used in the stress intensity quantification study. Simple pin-connected 1018 steel specimens were used in the stress intensity verification study. Three specimen geometries were used with EDM notches of a/w ratios of 0.1, 0.3, 0.5. The specimens have a thickness of 1.6 mm and are considered to be in a plane-stress state.

Figure 2a, showing the fit window, is the close-up TSA image for a/w = 0.1. Figure 2b shows the out of phase image and the effects of the anomalies.

The data around the crack tip is not used in the fit for reasons previously described. The fit area is about 10 mm square. In-phase refers to the fact that the oscillating thermal signal is synchronized with the applied oscillating load. Out-of-phase signal occurs when inelastic events or heat transfer is present. From the out-of-phase image the minimum acceptable radius of the fit window can be determined.

See "Fracture Mechanics" next page



(a) fit window with TSA data (b) effects of anomalies

Fig. 2 Close-up TSA image and fit window.

Stress Photonics

Tech Tips

Point Scanning to Select the Proper "Scan Parameters"

By Brad Boyce

Have you ever started a scan and then found out half way through that you had selected the wrong scan parameters, resulting in an inadequate scan? If so, here is a suggestion that just might help.

First, do a Point Scan with the same sampling time, time constant, and acquisition parameters that you intend to use for your frame scan.

A Point Scan provides a line plot of the stress at a point over time. The Point Scan will quickly and graphically display the signal to noise ratio for the sampling parameters you have chosen.

For the Point Scan, select a point of nominal stress. (We like to use the point we used to phase in the lock-in.) Then test that spot with a 100 sample Point Scan. The resulting plot should have a magnitude of about 500 data acquisition units (+2048 is positive full scale). If your acquisition parameters are set too conservatively, your plot will be a nearly perfect straight horizontal line. If your acquisition parameters are not conservative enough, the Point Scan data will plot as a widely varying line with a constant offset from zero.

Soon you will be able to recognize the proper setting of the acquisition parameters in the familiar 100 sample Point Scan. We recommend that you always set the 2D-Plot parameters to cover the full data acquisition range from -2048 to +2048. With these parameters, the plot will always look the same and you will more quickly get a feel for how the plot should look.

Want more scanning tips? Call, send, FAX or e-mail in your ideas or questions to Stress Photonics in care of the *Thermoelastic Forum.*

Improve Your SPATE

Hot Detectors

from Stress Photonics

With Hot Detectors from Stress Photonics you can now dramatically improve the scanning performance of your SPATE. Stress Photonics has just upgraded Pratt & Whitney East Hartford's SPATE 9000 head with the latest in high performance infrared detectors. With the new detector installed, the infrared signal is 12 times stronger! This new improvement assures 4 times better or 12 times faster scans. For detailed information please refer to the insert in this edition of the *Thermoelastic Forum.*

If this improvement might help your productivity, simply contact Stress Photonics or Ometron, or send in the reader response card, and we'll tell you more about Hot Detectors.

from "Fracture Mechanics" page 2

Figure 3 shows the ability of TSA to quantify stress intensity factors. The quantified values of Y, as defined in Fig. 3 for the three geometries, are plotted vs. a/w for the four-term and one-term fit estimations and the theoretical solution.

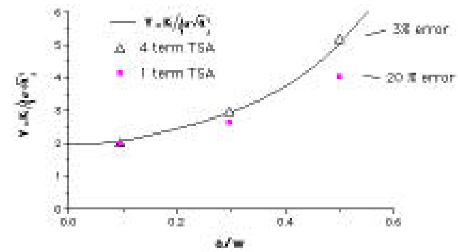


Fig.3 Y vs. a/w, 1-term and 4-term fit compared to theoretical data.

The 4-term fit, and a more appropriate use of crack tip data, affords significant improvement in stress intensity measurements. Simulations indicate an equal accuracy in determining mixed-mode stress intensity factors.

TSA directly measures the stress intensity factor. It does require knowledge of the thermoelastic response of the material (i.e., the thermal properties), but these can be easily determined for each material from a simple uniaxial bar experiment, the results of which are valid for all applications of that material.

For more information contact Jon Lesniak or select "Quantitative Fracture Mechanics" on the reader response card.

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University Corner

Evaluation of Stress Redistribution after Impact in Laminated Composites

By Dr. T.J. Mackin *Department of Mechanical and Industrial Engineering, The University of Illinois, Urbana, IL*

Composite aircraft wing-skins are manufactured to a prescribed thickness using a lamination process, wherein fabrics of fiber reinforced material are stacked atop each other, followed by matrix infiltration. The interface between layers is matrix rich and especially susceptible to delamination damage. This is a particularly vexing problem in the aerospace industry, since sub-surface delaminations are not easily detected.

Modern aircraft are designed to carry substantial loads in the wing-skins: tension on the lower side, compression on the upper side. Impact events generate stress waves that, in effect, probe the interface region of a laminated structure. Thus, impact, such as tools dropped on the wing during routine service, can generate insidious, sub-surface interface delaminations. Delamination damage greatly reduces the compressive strength of a laminate and must be avoided or contained in order for the wing to carry its design load. Modern composite materials employ stitching to improve interface toughness. The stitching holds the layers together such that a delamination is halted at the stitching line.

A controlled study of impact damage was conducted to evaluate the retained compressive strength of carbon fiber reinforced epoxy laminates. Plates of composite wing-skin were subjected to a range of impact conditions, spanning changes in impact velocity, energy, and radius of the striking tip. Certain impact conditions resulted in sub-surface delaminations with

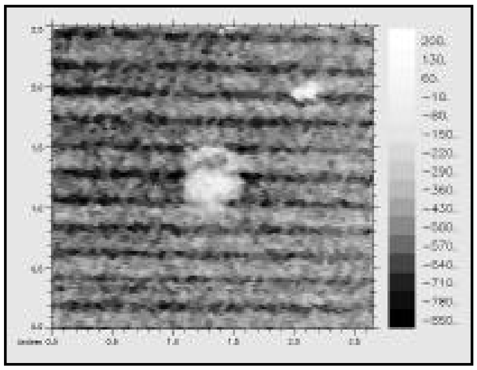

Fig. 1 TSA Scan of Stitched Composite

little or no trace of damage at the impact location. After impact, thermoelastic stress analysis was used to evaluate the damage. The specimens were loaded under cyclic compression, at a maximum load equal to 10% of their compressive strength. Thermoelastic images revealed a region of damage coincident with the location of impact, Figure 1, where the extent of damage was related to the striker geometry and impact energy. Notice the visible stitch lines appearing horizontally across the image.

Thermoelastic analysis was also used to evaluate stress redistribution across the specimen. Using this information it is possible to quantify the damage and relate post-impact compression strength to the extent of the damaged zone. It is postulated that, during post-impact compression testing, the damaged zone suffers from an early onset of compressive buckling, which cascades into the remainder of the specimen.

For more information contact Dr. Mackin at the University of Illinois.

TSA image collected at the University of Wisconsin-Madison by Jon Lesniak of Stress Photonics.

Events

SEM

Spring Conference Highlights

The Spring SEM Conference was held this past June in Baltimore, Maryland. On the trade-show floor Stress Photonics displayed an array-based TSA camera.

Two papers were presented at the conference that dealt with thermoelasticity.

"A High-Speed Differential Thermographic Camera" by Lesniak and Boyce

This paper describes the development of an array-based TSA camera with short image acquisition times (10 to 15 seconds). The signal to noise ratio of staring-arrays and scanning-detectors was compared with excellent results.

"The Thermoelastic Response of a Thin-Walled Orthotropic Cylinder Loaded in Torsion" by Dulieu-Smith and Stanley

In this paper, TSA was performed on a thin-walled wound aramid-epoxy cylinder.

Upcoming Fall Conference

The next SEM conference, *"Integration of FEA and Structural Testing with Rapid Prototyping,"* is to be held November 7-8 with an optional tour November 9th, 1994 at the Hyatt Regency in Dearborn, Michigan.

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