Stress Photonics

Thermoelastic Forum

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First Words

In this issue of the *Thermoelastic Forum* the temperature rises in the "R&D Side" as Jon Lesniak describes simple measures to keep the *DeltaTherm™1000* working at peak performance while applying TSA at temperatures as high as 1000˚C! The "University Corner" highlights TSA experimentation on a new class of CMCs by T.J. Mackin and M.C. Roberts of the University of Illinois at Urbana-Champaign. Mike Zickel "puts Krylon to the test" as he rates the emissivity of six different types of flat spray paint coatings in the "Tech Tips" section. The "Events" column lists four conferences that are sure to interest TSA users. You can see a live *DeltaTherm™* demonstration *and* try out the latest version of *DeltaVision™* software for control, acquisition and post processing of TSA data at two of the four conferences. Get a "bit" of information about SP's latest SBIR and STTR contracts in the "Tid Bits" section of this newsletter.

If you're still hungry for TSA information after reading this issue of the *Thermoelastic Forum* (or if you just want to see cool TSA data images), join the thousands who have already visited the Stress Photonics WWW site at **http://www.StressPhotonics.com**. The Stress Photonics home page is continuously updated so, even if you have already paid us a visit, be sure to stop by again for the latest in example applications, accessories, products and new Thermoelastic Stress Analysis developments.

The R&D Side

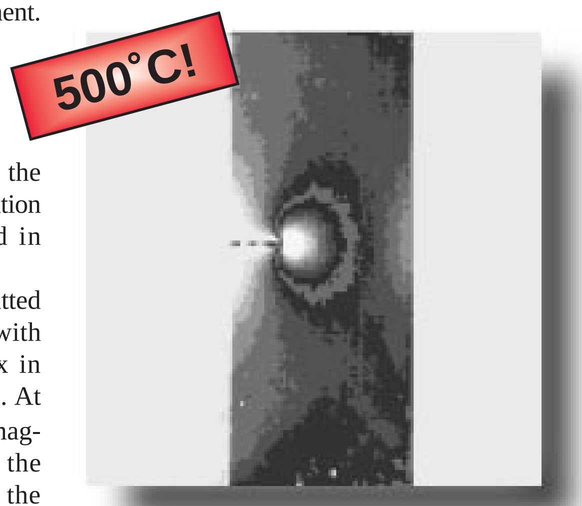
Elevated Temperature Camera Operation

by Jon Lesniak

As a result of high-temperature testing under the current Air Force SBIR contract, Stress Photonics has had the opportunity to gain more experience applying TSA at temperatures as high as 1000˚C. Not every engineer needs to test under these extreme conditions, but most engineers do run into situations, such as a transmission case, that require testing a heated component. In this article, I will describe the simple measures that will keep the *DeltaTherm™1000* operating at peak performance at any temperature without saturating the camera. (There are other calibration issues that will be discussed in future articles.)

The number of photons emitted from a warm body increases with temperature. At 50˚C the flux in the 3-5 μm band nearly doubles. At 100˚C it is nearly an order of magnitude higher. To understand the effects that this may have on the camera we need to understand the basic design of the IR camera head. The camera collects electrons generated from each photon strike and stores them in a capacitor known as the quantum well. The depth of this well is about 40 million photons. When the capacity of this well is saturated it is not possible to measure a differential thermal signal and all is lost. The camera empties these wells at the framing rate of 434 Hz. or about every 2 ms. As seen in figure 1, *DeltaTherm™* is set up to handle temperature excursions of up to 50˚C without saturating. At temperatures above 50˚C, an attenuator must be used to deal with the abundance of photons.

There are several options available to avoid camera saturation. Similar to a photographic camera, the amount of light striking the film or detector can be attenuated by changing the aperture stop, using a faster shutter speed, or using a neutral density filter. The impact of apertures and neutral density filters are dictated by a very important difference between visible optics and infrared optics. A physical aperture or filter emits IR radiation by the virtue of its own absolute temperature. The radiation it emits will not carry useful signals but will still contribute to measurement



noise. By decreasing the exposure time or the integration time, one can control the abundance of photons without introducing non-signal photons. With the electronic iris feature the sample integration time can be controlled from 2.3 ms to 36 μs.

As exemplified in figure 1, a 100˚C component temperature would require an aperture attenuating all but 5% of the photon flux. Roughly half the well will be filled

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University Corner

Stress Redistribution and Notch Sensitivity in Ceramic Matrix Composites

by T. J. Mackin and M. C. Roberts of the Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign

A new generation of relatively "ductile" Ceramic Matrix Composites (CMCs) is being developed to meet the demands of increased operating temperatures in energy conversion systems. These new materials rely on inelastic mechanisms such as interface failure, matrix cracking, fiber failure, and fiber pullout to redistribute stress away from locations of stress concentration. Experiments at The University of Illinois at Urbana-Champaign are being carried out to determine the mechanistic underpinnings and the absolute extent of stress redistribution in this new class of CMCs.

A *DeltaTherm™1000* system is being utilized to assess damage initiation and evolution in several cement-based and oxide-based ceramic fiber reinforced composite systems. The cement based systems are aimed at intermediate temperature applications (up to ≈600˚C) while the oxide composites are envisioned for high temperature engine applications (>1000˚C). Tensile specimens are fabricated with edge notches, figure 1, and pulled to various percentages of the sample ultimate strength. Thermoelastic stress maps are made of the specimen at each damage level, and used to qualitatively assess the extent of non-linearity and stress redistribution in the samples. Figure 2 shows a sequence of three damage states in an alumina fiber reinforced alumina matrix composite. This figure reveals shear bands propagating perpendicular to the notch plane, effectively blunting the stress concentration at the notch tip. Line scans between the notches are normalized by the far field TSA signal and used to quantitatively assess the change in stress concentration factor at the notch root, figure 2. These data are useful in determining the operative damage mechanism (in this instance, shear bands) and in measuring the effect of that damage mechanism.

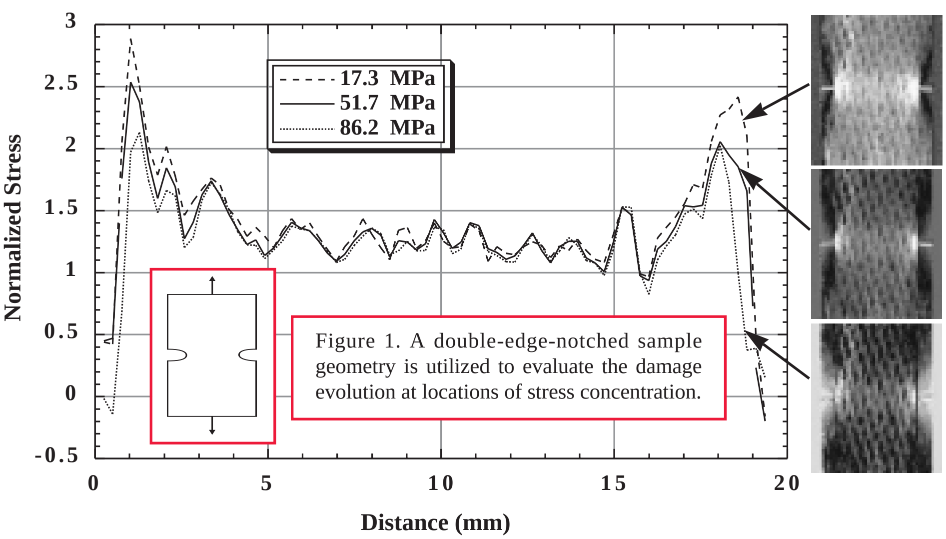

Figure 1. A double-edge-notched sample geometry is utilized to evaluate the damage evolution at locations of stress concentration.

Figure 2. A sequence of three damage images after far field loading to 17, 52 and 86Mpa. As shown in the notch plane line scans, the development and growth of shear bands alters the stress distribution and the notch root stress concentration factor.

For more information, contact Stress Photonics Inc. or contact Dr. Mackin at t-macki@staff.uiuc.edu • ph 217-244-1016 • fx 217-333-1942

New Products

Elevated Temperature Accessories

Stress Photonics is introducing a new line of *DeltaTherm™1000* accessories to assist elevated temperature applications. Depending on your application and temperature range, several products are available including screw in apertures, filters, and an electronic iris or "shutter speed control" (as described in the R&D side article). These products will improve moderately elevated temperature work and facilitate work at temperatures in excess of 1000˚C.*

The screw in filter holder mounts to the back of most standard IR lenses supplied with the *DeltaTherm™* and can be used to hold neutral density filters as well as physical apertures. The holder kit comes with several apertures, with neutral density filters available for an additional cost.

The electronic iris is part of an electronics upgrade package available for the *DeltaTherm™1000*. The electronic iris allows more efficient use of the sensor's photon wells (as discussed in "R&D Side") and has been integrated into the *DeltaVision™* control, acquisition, and post processing software as a simple slide bar setting. The electronic iris will allow TSA measurements up to 300˚C without optically limiting the flux. Example applications include testing of drivetrain components in operation and material testing at elevated temperatures.

With the use of the electronic iris, filters and apertures, the *DeltaTherm™* is capable of taking TSA images at temperatures upwards of 1000˚C (see cover article). For questions or comments about these products please contact Stress Photonics.

**Extreme temperature work may require the use of Stress Photonics' Stealth Furnace.*

Tech Tips

Coatings

by Mike Zickel

Choosing and applying the proper coating for thermographic analysis (TSA or standard thermography) is a simple but important step in acquiring accurate and reliable data. In the last issue of the *Thermoelastic Forum* (Vol. 1, No. 8, Oct. '96), Dan Bazile described general characteristics of good thermographic coatings and provided some tips on applying a coating.

Flat black spray paint has been mentioned as one of the best types of coatings for thermographic analysis because it is highly emissive (non-reflective) and easy to apply. TSA users prefer to use Krylon™ Ultra Flat Black over any other kind of flat black spray, claiming that its "ultra" low reflectivity makes a difference when measuring small temperature changes on an oscillating sample. We decided to put Krylon to the test.

An aluminum bar was prepared with various types of flat spray paints and then uniformly heated to a few degrees above room temperature. A room temperature image was subtracted from the "hot" image and the resulting image (fig. 1) represents a measurement of the relative emissivities of the different paints. Each type of paint is labeled in the image. A thin region of bare aluminum was left between each stripe to set them apart and to provide a highly reflective surface to contrast the low reflectivity paints.

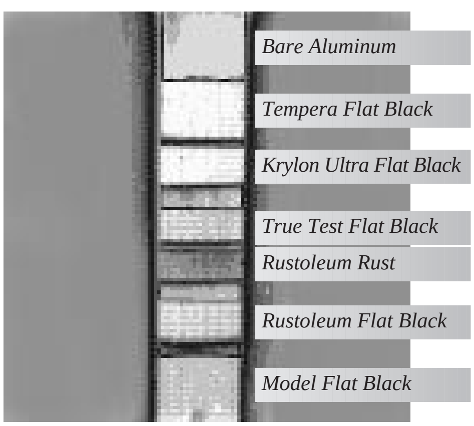

Figure 1. Thermal image of aluminum bar with six stripes of flat paint.

A profile plot along a line drawn vertically down the image produces the graph shown in fig. 2. The plot indicates that all of the paints are relatively close in emissivity, with Krylon and Tempera having the highest response. In a standard thermographic test any of these coatings (excluding the Rust) would probably be sufficient. In a thermoelastic test, where the sample is oscillating, it is very important to use the coating with the lowest reflectivity (i.e. greatest emissivity; where emissivity + reflectivity = 1), because it is more difficult to account for oscillating reflections that might not be apparent in a static test. Estimating the average values for each coating and doing a simple analysis reveals that TrueTest, Rusteolum Black and Model Black are at least 11% more reflective than the Tempera and Krylon. This may not seem significant, but when you consider that temperature changes on the order of 0.001°C are being detected in a typical TSA test, then even the most innocuous seeming reflection can corrupt your results.

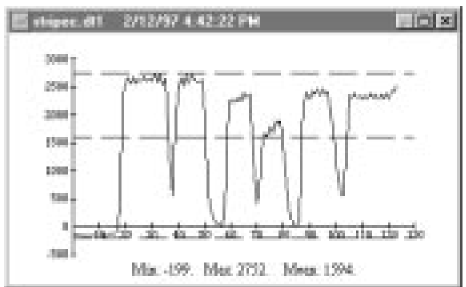

Figure 2. Profile plot showing the relative emissivities of six flat paints.

The relative emissivity of the Tempera paint is a surprise. It has the advantage of being non-toxic, water soluble and easily removable; however, it is more difficult to spray onto a sample. Just the right amount of water needs to be added to make the paint sprayable, but not so much that it is too watery, causing drips.

from "High Temperature" page 1

by the flux emanating from the filter itself, so only half the well capacity is left to be utilized by the component flux. At extreme temperatures, filters and apertures can be applied if the electronic iris is first reduced. This is because the emissions from the aperture are reduced to an insignificant level by the electronic iris.

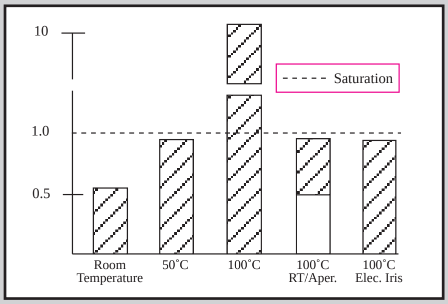

Figure 1. Photon Management

If you would like more information about elevated temperature testing, please contact Stress Photonics Inc.

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T S A

Thermoelastic Stress Analysis (TSA) produces a full-field stress map by imaging temperature changes with a sensitive infrared camera. All materials, whether solid, liquid or gas, change temperature when compressed or expanded. In solids, stresses cause small temperature changes described by the thermoelastic equation

$$\Delta T = \frac{-\alpha T}{\rho C_p}\left(\Delta\sigma\right)$$

To provide accurate measurements, the temperature changes induced by the thermoelastic effect are repeated and time-averaged during a continuous dynamic loading, usually provided by a closed-loop hydraulic load frame.

A special infrared camera, known as a differential thermographic system, correlates the load-induced IR signals with the reference signal from the load system. This allows a thermal resolution of 1.0mK, which translates to the following stress resolutions:

Material	Stress Resolution	
Steel	150psi	1.0MPa
Aluminum	60psi	0.4MPa
Epoxy	8.0psi	55kPa

Stress sensitivity is similar to that of a common strain gage.

Tid Bits

Stress Photonics has been awarded two new research contracts for new product development. The first contract is a Phase II Small Business Innovative Research (SBIR) grant from the Federal Highway Administration (FHWA). The second is a Phase II Small Business Technology Transfer (STTR) grant from NASA Langley. Each contract has a two year duration closing in early 1999.

The Phase II SBIR with the FHWA began in late September of 1996 and is aimed at producing an easy to use bridge inspection system for use on the many aging steel bridges in the US. The research will focus on implementing a thermal method based on Forced Diffusion Thermography to inspect bridges and other large steel structures efficiently. The envisioned single operator unit will be hand held with an easy interface into current bridge inspection reporting systems.

The Phase II STTR is a contract from NASA to SP and The College of William & Mary. The STTR program, introduced by Congress in 1994, differs from the SBIR program in that offerors must be teams of small businesses and research institutions who will conduct joint research. The goal of the program is to transfer technology developed by universities and federal labs into the private marketplace through the entrepreneurship of a small business.

In the spirit of the STTR, Stress Photonics and W&M will jointly carry out the development of new research which will focus on combining TSA with photoelasticity for full field stress imaging. W&M will concentrate on new coatings useful for TSA and photoelasticity.

If you need more information, or if you would like to keep up with these and other new developments, check out the SP WWW site over the coming months at **http://www.StressPhotonics.com.**

Events

AIAA Structures Conference

The 38th AIAA Structures, Structural Dynamics, and Materials Conference and Exhibition will take place in Orlando at the Orlando Hyatt Resort, April 7-10. Visit the SP booth in the exhibition hall to see a live *DELTATHERM*™ demonstration and try out the latest version of *DELTAVISION*™ software for acquisition and post processing of TSA data.

ASCE Structures Congress XV

The American Society of Civil Engineers is sponsoring the 15th Structures Congress to be held in Portland, April 14-16 at the Portland Hilton Hotel. Jon Lesniak has been invited to present a paper describing Stress Photonics' progress in Forced Diffusion Thermography of structures.

Thermosense XIX

Thermosense XIX: An International Conference on Thermal Sensing and Imaging Diagnostic Applications is set within SPIE's Aerosense '97 Symposium, and takes place in Orlando, April 20-25. Stress Photonics will be presenting in the NDE technical session. The conference site is Marriott's Orlando World Center.

SEM Spring Conference

The 1997 Spring Conference and Exhibition will be held in Bellevue, WA, June 2-4 at the Red Lion Hotel. Lesniak with co-authors Bazile and Zickel anticipate presenting papers in the Thermal Methods Technical Division and in Applied Photoelasticity. Brad Boyce will chair the Thermal Methods Round Table Discussion.

The SP booth in the exhibit hall will feature the latest instrumentation and software advancements SP has to offer.

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