

Determination of Residual Stresses by Local Annealing to Laser Speckle Pattern Interferometry

CONF-970763--1

by

M. Pechersky

Westinghouse Savannah River Company

Savannah River Site

Aiken, South Carolina 29808

C. S. Vikram

University of Alabama

AL USA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

A document prepared for 1997 SEM SPRING CONFERENCE ON EXPERIMENTAL AND APPLIED MECHANICS at Bellingham, WA, USA from 7/2/97 - 7/4/97.

HH
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DOE Contract No. DE-AC09-96SR18500

This paper was prepared in connection with work done under the above contract number with the U. S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U. S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or part of the copyrighted paper.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Determination of Residual Stresses by Local Annealing and Laser Speckle Pattern Interferometry

Martin J. Pecherksy, Advisory Engineer, Westinghouse, Savannah River Technology Center, Aiken, SC, 29808,
Chandra S. Vikram, Research Professor, Center for Applied Optics, The University of Alabama in Huntsville, 35899

One of the most common methods of experimentally determining residual stresses is Blind Hole Drilling [1], BHD. A new method which is a thermo-optical analog to BHD is being developed. This method uses local heating to anneal a tiny spot and uses laser speckle interferometry to measure the strain that results. This strain is used to determine the state of stress prior to heating. The peak temperatures are on the order of 200 Celsius so that for most metals, there will be no changes in phase or other material properties except for a slight reduction in yield stress. Preliminary experiments with type 304 stainless steel were performed using resistance heating. The experimental results were in excellent agreement with finite element model predictions of the process [2]. Subsequently, the resistance heating was replaced with laser heating [3]. The heat input (22.5 Watt peak) from a small sealed radio frequency (RF) excited Carbon Dioxide laser was used. In order to both control the heating temperature and efficiently couple the infrared photons from the laser into the test specimen, a substance known as Liquid Temperature Indicating Paint was used. Without this substance the laser power would be so large as to make this approach impractical. Furthermore the measurement and control for the heat input would be very complicated. This laser heating approach was successful in obtaining similar results to those obtained in reference 2.

Since this laser based technique is a thermo-optical analog to blind hole drilling, a simple stress model is required to interpret the measured results. This simple stress model is presented below. As in BHD, the simple model must be modified by empirical coefficients to be useful. These empirical coefficients must be determined by experimentation and/or numerical analysis.

The approach for this laser method is similar to that used in BHD. There are major important differences however. The BHD model is based on the solution of linearly elastic, plane stress field equations for the stress and strain in the vicinity of a through hole in a flat plate. The stress model presented here is based on a lumped parameter model in which elastic-perfectly plastic deformation is assumed to occur as a result of heating. Consider the lumped parameter model of a general solid as shown in Figure 1. This figure represents an elastic body in plane stress as being composed of four springs. The bulk of the

body has a stiffness, k . The region where this stress is being measured is comprised of a series/parallel combination of springs which itself is attached in parallel to k . The heat is applied to the spring designated as k_i which can take on values of k_C or k_H depending on whether the spring is cold or has been heated, respectively. In principle one could characterize the spring constants of the solid by finite element analysis but we are seeking a simple model which can be modified empirically. To simplify the analysis we assume that the residual stress or force, F remains constant. This leads to the lumped parameter model as shown in Figure 2. The system is shown at its initial position with a total displacement X_1 , with a corresponding force F . F and hence X_1 are unknown. In Fig. 2B, k_i is heated and deforms due to: thermal expansion (x_{th}), and elastic (x_y) and plastic (x_p) deformation. When the system is allowed to cool, some permanent deformation has occurred due to plastic flow. Spring k_i has a permanent deformation and the total deformation is $(X_3 - X_1)$. The object of the analysis based on this simple model is to express the unknown force, F in terms of the measurable displacement $(X_3 - X_1)$. The results of this analysis yield the following equation:

$$F = \hat{k} \cdot \left[1 + \frac{\hat{k}}{\tilde{k}_C} \right] \cdot (X_3 - X_1) + \left[1 + \frac{\hat{k}}{\tilde{k}_H} \right] \cdot F_y + \hat{k} \cdot \alpha \cdot \Delta T$$

$$\text{where : } \frac{1}{\tilde{k}_H} = \frac{1}{k_H} + \frac{1}{\tilde{k}} \quad \text{and} \quad \frac{1}{\tilde{k}_C} = \frac{1}{k_C} + \frac{1}{\tilde{k}}$$

and:

- α = thermal expansion coefficient
- L = length of heated region
- ΔT = Temperature rise due to heating
- F_Y = The yield strength at the elevated temperature
- F = the unknown residual force
- $(X_3 - X_1)$ = the measured displacement.

This equation can be transformed into an equation for a

continuous solid by considering square of dimension L with the heated spot being a smaller square of dimension d at the center of the larger square. The heated spot is heated to temperature, T_H from the ambient temperature, T_L . Shearing forces between the heated region and the surrounding region are neglected. The results of this transformation is:

$$\sigma = \left[\frac{L-d}{d} \right] E \cdot \varepsilon + \left[1 - \left(1 - \frac{L}{d} \right) \left(\frac{d}{L} \right)^2 \left(\frac{E}{E_H} - 1 \right) \right] \cdot \sigma_{YH} + \left[\frac{L-d}{L} \right] \left(\frac{d}{L} \right) E \cdot \alpha \cdot \Delta T$$

where:

E_H = Young's Modulus at T_H .

E = Young's Modulus at T_L .

σ_{YH} = Yield Stress at T_H

ε = strain relief near heated spot

For $d/L \ll 1$, the above equation reduces to:

$$\frac{\sigma - \sigma_{YH}}{E} = A \cdot \left(\frac{L}{d} \right) \varepsilon + B \cdot \left(\frac{d}{L} \right) \alpha \Delta T$$

where **A** and **B** are included as dimensionless empirical constants. The results of the calculations presented in reference 2 are plotted in **Figure 3**. A linear regression fit yields a correlation of 0.92 and the **A** and **B** are computed to be 0.00652 and 0.363 respectively. With these constants the above equation can now be used to measure residual stresses for other materials. Naturally there is much work left to verify this result and apply it to general residual stress situations.

References

(1) "Determining residual stress by the hole-drilling strain-gauge method," ASTM Standard E837-92, American Society for Testing and Materials, Philadelphia (1992).

(2) Pechersky, M.J., R.F. Miller and Chandra S. Vikram, "Residual Stress Measurements With Laser Speckle Correlation Interferometry and Local Heat Treating," **OPTICAL ENGINEERING**, Vol. 34, No. 10 pp. 2964-71.

(3) Vikram, C.S., M.J. Pechersky, C. Feng and D. Englehaupt, "Residual Stress Analysis by Local Laser Heating and Speckle-Correlation Interferometry," **Experimental Techniques**, Vol. 20, No. 6, pp. 27-30.

Acknowledgment

This work was sponsored in part by the US Department of Energy under contract number DE-AC09-96SR18500

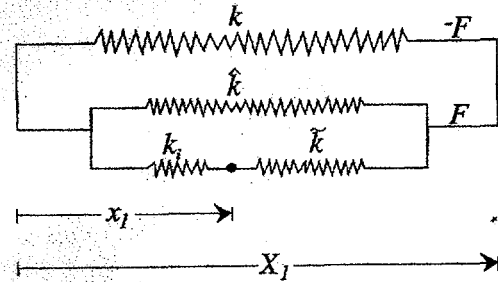


Figure 1 - Generalized Spring Model

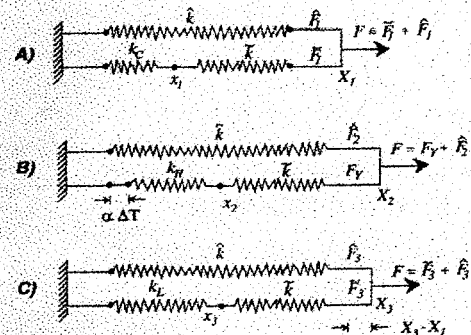


Figure 2 - Constant Force Model

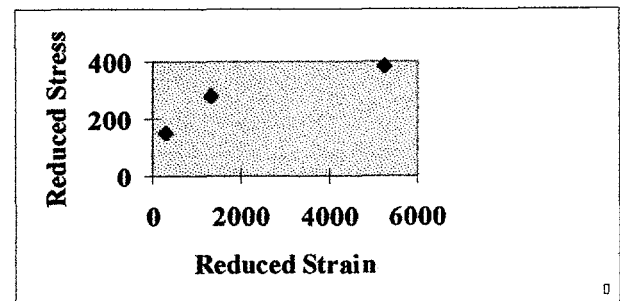


Figure 3 - Reduced Stress versus Observed Strain where:

$$\text{Reduced Strain} = 1000(\sigma - \sigma_{YH})/E$$

$$\text{Reduced Strain} = 1000(L/d)\varepsilon$$