Designation: E 837 – 08

Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method[1]

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INTRODUCTION

The hole-drilling strain-gage method determines residual stresses near the surface of an isotropic linear-elastic material. It involves attaching a strain rosette to the surface, drilling a hole at the geometric center of the rosette, and measuring the resulting relieved strains. The residual stresses within the removed material are then determined from the measured strains using a series of equations.

1. Scope

1.1 *Residual Stress Determination*:

1.1.1 This test method specifies a hole-drilling procedure for determining residual stress profiles near the surface of an isotropic linearly elastic material. The test method is applicable to residual stress profile determinations where in-plane stress gradients are small. The stresses may remain approximately constant with depth ("uniform" stresses) or they may vary significantly with depth ("non-uniform" stresses). The measured workpiece may be "thin" with thickness much less than the diameter of the drilled hole or "thick" with thickness much greater than the diameter of the drilled hole. Only uniform stress measurements are specified for thin workpieces, while both uniform and non-uniform stress measurements are specified for thick workpieces.

1.2 *Stress Measurement Range*:

1.2.1 The hole-drilling method can identify in-plane residual stresses near the measured surface of the workpiece material. The method gives localized measurements that indicate the residual stresses within the boundaries of the drilled hole.

1.2.2 This test method applies in cases where material behavior is linear-elastic. In theory, it is possible for local yielding to occur due to the stress concentration around the drilled hole, for isotropic (equi-biaxial) residual stresses exceeding 50 % of the yield stress, or for shear stresses in any direction exceeding 25 % of the yield stress. However, in practice it is found that satisfactory results can be achieved providing the residual stresses do not exceed about 60 % of the material yield stress.

1.3 *Workpiece Damage*:

1.3.1 The hole-drilling method is often described as "semi-destructive" because the damage that it causes is localized and often does not significantly affect the usefulness of the workpiece. In contrast, most other mechanical methods for measuring residual stresses substantially destroy the workpiece. Since hole drilling does cause some damage, this test method should be applied only in those cases either where the workpiece is expendable, or where the introduction of a small shallow hole will not significantly affect the usefulness of the workpiece.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

E 251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages

3. Terminology

3.1 *Symbols*:

$\bar{a}$	=	calibration constant for isotropic stresses
$\bar{b}$	=	calibration constant for shear stresses
$\bar{a}_{jk}$	=	calibration matrix for isotropic stresses
$\bar{b}_{jk}$	=	calibration matrix for shear stresses
D	=	diameter of the gage circle, see Table 1.

[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.13 on Residual Stress Measurement.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D_0 = diameter of the drilled hole
E = Young's modulus
j = number of hole depth steps so far
k = sequence number for hole depth steps
P = uniform isotropic (equi-biaxial) stress
P_k = isotropic stress within hole depth step k
p = uniform isotropic (equi-biaxial) strain
p_k = isotropic strain after hole depth step k
Q = uniform 45° shear stress
Q_k = 45° shear stress within hole depth step k
q = uniform 45° shear strain
q_k = 45° shear strain after hole depth step k
T = uniform x-y shear stress
T_k = x-y shear stress within hole depth step k
t = x-y shear strain
t_k = x-y shear strain after hole depth step k
T = (superscript) matrix transpose
α_P = regularization factor for **P** stresses
α_Q = regularization factor for **Q** stresses
α_T = regularization factor for **T** stresses
β = clockwise angle from the x-axis (gage 1) to the maximum principal stress direction
ε = relieved strain for "uniform" stress case
ε_j = relieved strain measured after j hole depth steps have been drilled
ν = Poisson's ratio
θ = angle of strain gage from the x-axis
σ_{max} = maximum (more tensile) principal stress
α_{min} = minimum (more compressive) principal stress
σ_x = uniform normal x-stress
$(\sigma_x)_k$ = normal x-stress within hole depth step k
σ_y = uniform normal y-stress
$(\sigma_y)_k$ = normal y-stress within hole depth step k
τ_{xy} = uniform shear xy-stress
$(\tau_{xy})_k$ = shear xy-stress within hole depth step k

4. Summary of Test Method

4.1 *Workpiece*:

4.1.1 A flat uniform surface area away from edges and other irregularities is chosen as the test location within the workpiece of interest. Fig. 1 schematically shows the residual stresses acting at the test location at which a hole is to be drilled. These stresses are assumed to be uniform within the in-plane directions x and y.

NOTE 1—For reasons of pictorial clarity in Fig. 1, the residual stresses are shown as uniformly acting over the entire in-plane region around the test location. In actuality, it is not necessary for the residual stresses to be uniform over such a large region. The surface strains that will be relieved by drilling a hole depend only on the stresses that originally existed at the boundaries of the hole. The stresses beyond the hole boundary do not affect the relieved strains, even though the strains are measured beyond the hole boundary. Because of this, the hole-drilling method provides a very localized measurement of residual stresses.

4.1.2 Fig. 1*(a)* shows the case where the residual stresses in the workpiece are uniform in the depth direction. The in-plane stresses are σ_x, σ_y and τ_{xy} throughout the thickness. Uniform residual stress measurements can be made using this test method with "thin" workpieces whose material thickness is small compared with the hole and strain gage circle diameters, and with "thick" workpieces whose material thickness is large compared with the hole and strain gage circle diameters.

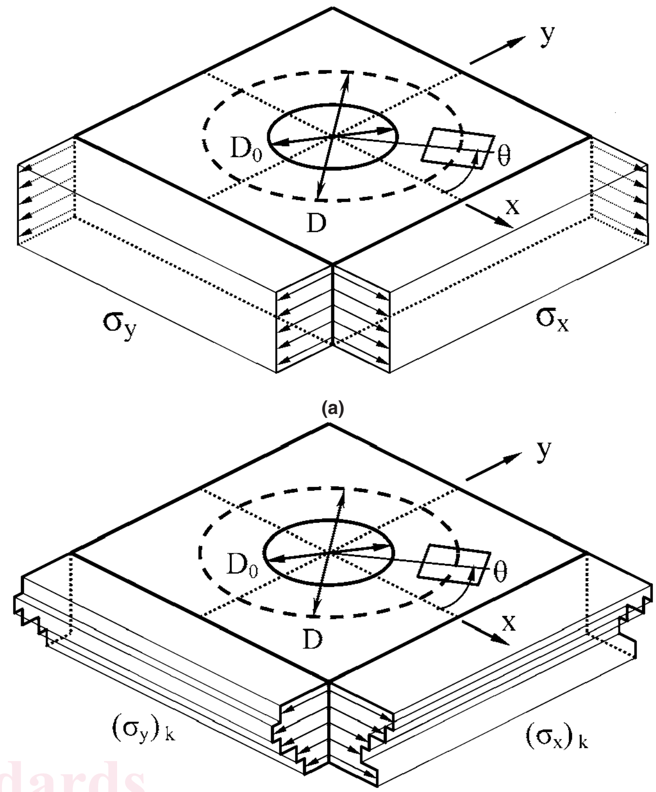

FIG. 1 Hole Geometry and Residual Stresses, (a) Uniform Stresses, (b) Non-uniform Stresses

4.1.3 Fig. 1*(b)* shows the case where the residual stresses in the workpiece vary in the depth direction. The calculation method described in this test method represents the stress profile as a staircase shape, where the depth steps correspond to the depth increments used during the hole-drilling measurements. Within depth step k, the in-plane stresses are $(\sigma_x)_k$, $(\sigma_y)_k$ and $(\tau_{xy})_k$. Non-uniform residual stress measurements can be made using this test method only with "thick" workpieces whose material thickness is large compared with the hole and strain gage circle diameters.

4.2 *Strain Gage Rosette:*:

4.2.1 A strain gage rosette with three or more elements of the general type schematically illustrated in Fig. 2 is attached to the workpiece at the location under consideration.

4.3 *Hole-Drilling*:

4.3.1 A hole is drilled in a series of steps at the geometric center of the strain gage rosette.

4.3.2 The residual stresses in the material surrounding the drilled hole are partially relieved as the hole is drilled. The associated relieved strains are measured at a specified sequence of steps of hole depth using a suitable strain-recording instrument.

4.4 *Residual Stress Calculation Method*:

4.4.1 The residual stresses originally existing at the hole location are evaluated from the strains relieved by hole-drilling using mathematical relations based on linear elasticity theory