~~Designation:E837–01~~ Designation: E 837 – 08$^{\varepsilon 1}$

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

This standard is issued under the fixed designation E 837; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ($\varepsilon$) indicates an editorial change since the last revision or reapproval.

$\varepsilon^1$ NOTE~~— Equations 17 and 18, Sections 9.2.2, 9.2.3, 11.2.5 , 11.2.6 and Table 2 were editorially upated in January 2002.~~
—Equation 27 was editorially corrected in July 2009.

## INTRODUCTION

~~The hole-drilling strain-gage method measures residual stresses near the surface of a material. The method involves attaching strain gages to the surface, drilling a hole in the vicinity of the gages, and measuring the relieved strains. The measured strains are then related to relieved principal stresses through a series of equations.~~

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



~~1.1This test method covers the procedure for determining residual stresses near the surface of isotropic linearly-elastic materials. Although the concept is quite general, the test method described here is applicable in those cases where the stresses do not vary significantly with depth and do not exceed one half of the yield strength. The test method is often described as "semi-destructive" because the damage that it causes is very localized and in many cases does not significantly affect the usefulness of the specimen. In contrast, most other mechanical methods for measuring residual stress substantially destroy the specimen. Since the test method described here does cause some damage, it should be applied only in those cases either where the specimen is expendable or where the introduction of a small shallow hole will not significantly affect the usefulness of the specimen.~~

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

[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.

~~Current edition approved Oct. 10, 2001. Published November 2001. Originally published as E837–81. Last previous edition E837–99.~~
Current edition approved Feb. 1, 2008. Published April 2008. Originally approved in 1981. Last previous edition approved in 2001 as E 837 – 01 $^{\varepsilon 1}$ .

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. Summary of Test Method

3.1A strain gage rosette with three or more elements of the general type schematically illustrated in Fig. 1 is placed in the area under consideration. The numbering scheme for the strain gages follows a clockwise (CW) convention **(1)** .

NOTE1—The gage numbering convention used for the rosette illustrated in Fig. 1 differs from the counter-clockwise (CCW) convention used for some designs of general-purpose strain gage rosettes and for some other types of residual stress rosette. If a strain gage rosette with CCW gage numbering is used, the residual stress calculation methods described in this test method still apply. The only change is a reversal in the assignment of the direction of the most tensile principal stress. This change is described in Note 7. All other aspects of the residual stress calculation are unaffected.

3.2A hole is drilled at the geometric center of the strain gage rosette to a depth of about 0.4 of the mean diameter of the strain gage circle, D.

3.2.1The residual stresses in the area surrounding the drilled hole relax. The relieved strains are measured with a suitable strain-recording instrument. Within the close vicinity of the hole, the relief is nearly complete when the depth of the drilled hole approaches 0.4 of the mean diameter of the strain gage circle, D.

3.3Fig. 2 shows a schematic representation of the residual stress and a typical surface strain relieved when a hole is drilled into a material specimen. The surface strain relief is related to the relieved principal stresses by the following relationship:

$$\varepsilon_r = (\bar{A} + \bar{B}\cos 2\beta)\sigma_{max} + (\bar{A} - \bar{B}\cos 2\beta)\sigma_{min} \quad (1)$$

Terminology

3.1 *Symbols*:



[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* , Vol 03.01.volume information, refer to the standard's Document Summary page on the ASTM website.

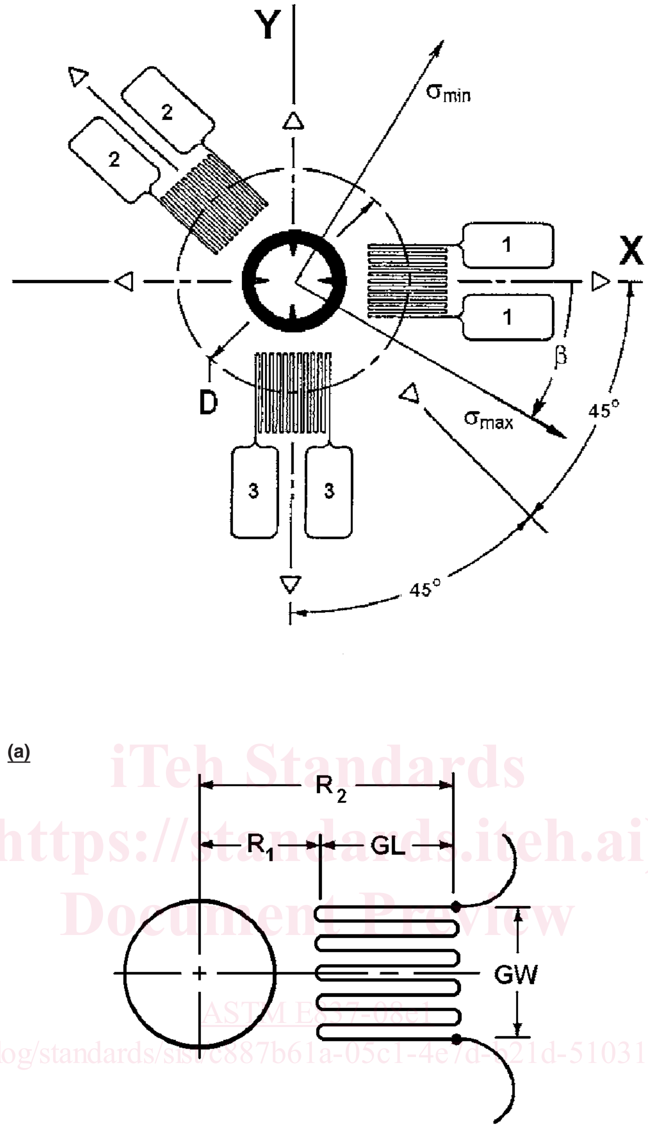





**FIG. 1 2 Schematic Diagram Showing the Geometry of a Typical Three-Element Clockwise (CW) St Hole-Draillin Gage Rosette f, (a) Rorsethte H Layole-ut, (b) Dretaill of a Strain Gag Method**

**(b)**

D0

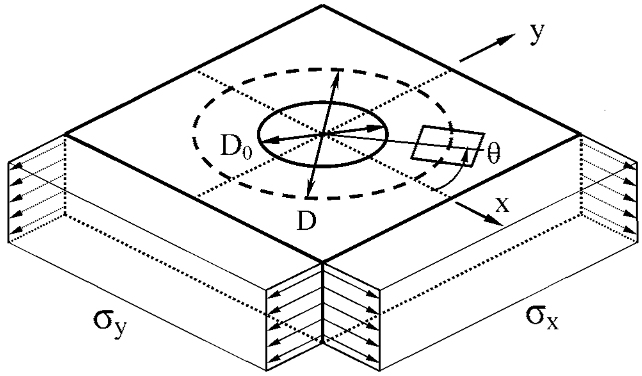
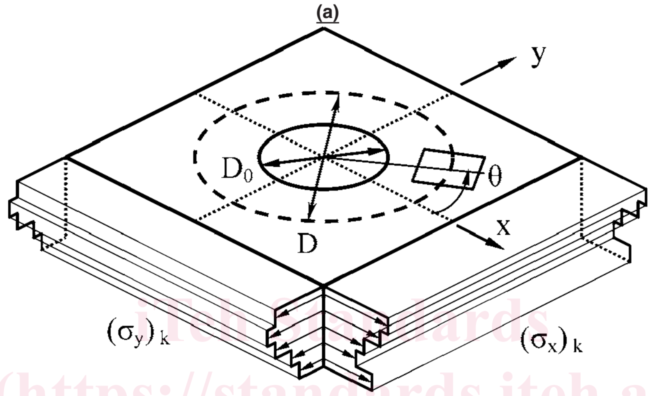



FIG. 2 1 DHolefi Geometry and Residual Stresses, (a) Unifonrm Stresses, (b) Non-unif Symbolrm Stresses

(a)




(b)



~~where:~~

$\bar{a}$ = 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
~~$\varepsilon_r$~~ $D$ = ~~relieved strain measured by a radially aligned strain gage centered at P,~~ diameter of the gage circle, see Table 1.
~~$A, B$~~ $D_0$ = ~~calibration constants,~~ diameter of the drilled hole
~~$\sigma_{max}$~~ $E$ = ~~maximum (most tensile) and~~ Young's modulus
~~$\sigma_{min}$~~ $j$ = ~~minimum (most compressive) principal stresses present at the hole location before drilling,~~ 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
$\alpha_P$ = regularization factor for **P** stresses
$\alpha_Q$ = regularization factor for **Q** stresses
$\alpha_T$ = regularization factor for **T** stresses

$\beta$ = angle measured clockwise from the direction of gage 1 to the direction of $\sigma$ clockwise angle from the x-axis (gage 1) to the maximum principal stress direction

$\varepsilon$ = relieved strain for "uniform" stress case

$\varepsilon_j$ = relieved strain measured after $j$ hole depth steps have been drilled

$\nu$ = Poisson's ratio

$\theta$ = angle of strain gage from the x-axis

$\sigma_{max}$ = maximum (more tensile) principal stress

$D$ $\sigma_{min}$ = diameter of the gage circle, minimum (more compressive) principal stress

$D_0$ $\sigma_x$ = diameter of the drilled hole.

3.3.1 The following equations may be used to evaluate the constants $\bar{A}$ and $\bar{B}$ for a material with given elastic properties:

$$\bar{A} = -\bar{a}\,(1+\nu)\,/\,(2E) \quad (2)$$

$$\bar{B} = -\,\bar{b}\,/\,(2E) \quad (3)$$

where: uniform normal x-stress

$E$ $(\sigma_x)_k$ = Young's modulus, normal x-stress within hole depth step $k$

$\nu$ $\sigma_y$ = Poisson's ratio, and uniform normal y-stress

$(\sigma_y)_k$ = normal y-stress within hole depth step $k$

$\tau_{xy}$ = uniform shear xy-stress

$(\tau_{xy})_k$ = shear xy-stress within hole depth step $k$

$\bar{a}$ and $\bar{b}$ are dimensionless, almost material-independent constants (see Note 2). Slightly different values of these constants apply for a through-thickness hole made in a thin specimen and for a blind hole made in a thick specimen. The numerical values of these constants are provided in this test method.

## 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 2—The dimensionless coefficients $\bar{a}$ and $\bar{b}$ vary with hole depth, as indicated in Table 1. They are both nearly material-independent. They do not depend on Young's modulus, $E$, and they vary by less than 1% for Poisson's ratios in the range 0.28 to 0.33. For a through-hole in a thin plate, $\bar{a}$ is independent of Poisson's ratio.



3.3.2 The relieved strains $\varepsilon_1$, $\varepsilon_2$, and $\varepsilon_3$ are measured by three correspondingly numbered strain gages as shown in 1—For reasons of pictorial clarity in Fig. 1. For specialized applications, a rosette with three pairs of strain gages arranged in directions 1 - 2 - 3 may be used (see 5.2.3, 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 $\sigma_x$, $\sigma_y$ and $\tau_{xy}$ 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.

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 **(1-5)**).Measurement of these three relieved strains provides sufficient information to calculate the principal stresses σ[3] The relieved strains depend on the residual stresses that existed in the material originally within the hole.

4.4.2 For the uniform stress case shown in Fig. 1 *(a)*, the surface strain relief measured after hole-drilling is:

$$\varepsilon = \frac{1+\nu}{E}\,\bar{a}\,\frac{\sigma_x+\sigma_y}{2} + \frac{1}{E}\bar{b}\,\frac{\sigma_x-\sigma_y}{2}\cos 2\theta + \frac{1}{E}\bar{b}\,\tau_{xy}\sin 2\theta \quad (1)$$

4.4.3 The calibration constants $\bar{a}$ and $\bar{b}$ indicate the relieved strains due to unit stresses within the hole depth. They are dimensionless, almost material-independent constants. Slightly different values of these constants apply for a through-thickness hole made in a thin workpiece and for a blind hole made in a thick workpiece. Numerical values of these calibration constants have been determined from finite element calculations **(4)** for standard rosette patterns, and are tabulated in this test method.

4.4.4 For the non-uniform stress case shown in Fig. 1*(b)*, the surface strain relief measured after completing hole depth step $j$ depends on the residual stresses that existed in the material originally contained in all the hole depth steps $1 \le k \le j$:

$$\varepsilon_j = \frac{1+\nu}{E}\sum_{k=1}^{j}\bar{a}_{jk}\,((\sigma_x+\sigma_y)/2)_k + \frac{1}{E}\sum_{k=1}^{j}\bar{b}_{jk}\,((\sigma_x-\sigma_y)/2)_k\cos 2\theta + \frac{1}{E}\sum_{k=1}^{j}\bar{b}_{jk}\,(\tau_{xy})_k\sin 2\theta \quad (2)$$

4.4.5 The calibration constants $\bar{a}_{jk}$ and $\bar{b}_{jk}$ indicate the relieved strains in a hole $j$ steps deep, due to unit stresses within hole step $k$ . Fig. 3 shows cross-sections of drilled holes for an example sequence where a hole is drilled in four depth steps. Within this sequence, calibration constant represents an intermediate stage where the hole has reached 3 steps deep, and has a unit stress acting within depth step 2. Numerical values of the calibration constants have been determined by finite element calculations **(4)** for standard rosette patterns, and are tabulated in this test method.

4.4.6 Measurement of the relieved strains after a series of hole depth steps provides sufficient information to calculate the stresses $\sigma_x$, $\sigma_y$ and $\tau_{xy}$ within each step. From these stresses, the corresponding principal stresses $\sigma_{max}$ and $\sigma_{min}$ and their orientation β.

3.3.3For reasons of pictorial clarity in Fig. 2, the principal residual stresses $\sigma_{max}$ and $\sigma_{min}$ are shown as uniformly acting over the entire region around the hole location. In actuality, it is not necessary for the residual stresses to be uniform over such a large



[3] The boldface numbers in parentheses refer to the list of references at the end of this test method.standard.

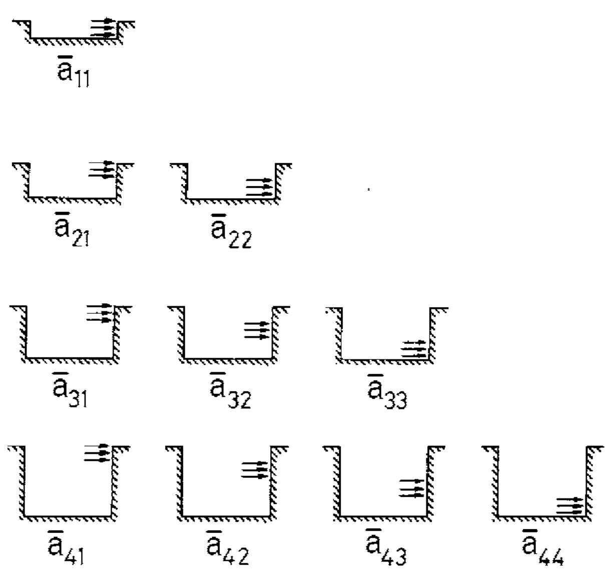



**FIG. 3 Physical Interpretation of Coefficients $\bar{a}_{jk}$**

region. The relieved surface strains depend only on the principal stresses that originally existed at the boundaries of the hole (2**and their orientation β can be found.**

4.4.7 The relieved strains are mostly influenced by the near-surface residual stresses. Interior stresses have influences that diminish with their depth from the surface. Thus, hole-drilling measurements can evaluate only near-surface stresses. Deep interior stresses cannot be identified reliably, see Note 7.

4.4.8 In theory, it is possible for local yielding to occur due to the stress concentration around the drilled hole. Such yielding can occur with isotropic residual stresses exceeding 50 % of the yield stress, and for shear stresses 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 (**6**). The stresses beyond the hole boundaries do not affect the relieved strains. Because of this, the hole-drilling method provides a very localized measurement of residual stresses.

3.3.4It is assumed that the variations of the original stresses within the boundaries of the hole are small and that the variation with depth is negligible. It is not necessary for the original stresses outside of the hole location to be uniform.

**4.Significance and Use**

4.1Residual stresses are present in almost all structures. They may be present as a result of manufacturing processes or they may occur during the life of the structure. In many cases residual stresses are a major factor in the failure of a structure, particularly one subjected to alternating service loads or corrosive environments. Residual stress may also be beneficial as, for example, compressive stresses produced by shot peening. The hole-drilling strain-gage technique is a practical method for determining residual stresses. See Table 1.

## 5. Strain Gages

5.1A rosette comprising three single or pairs of strain gage grids shall be used. Significance and Use

5.1 *Summary*:

5.1.1 Residual stresses are present in almost all materials. They may be created during the manufacture or during the life of the material. If not recognized and accounted for in the design process, residual stresses can be a major factor in the failure of a material, particularly one subjected to alternating service loads or corrosive environments. Residual stress may also be beneficial, for example, the compressive stresses produced by shot peening. The hole-drilling strain-gage technique is a practical method for determining residual stresses.



## 6. Workpiece Preparation

6.1 *Requirements*:

6.1.1 For a "thin" workpiece, where a through-hole is to be used, the workpiece thickness should not exceed 0.4D for a type A or B rosette, or 0.48D for a type C rosette (see Fig. 4).

6.1.2 For a "thick" workpiece, where a hole depth less than the workpiece thickness is to be used, the workpiece thickness should be at least 1.2D for a type A or B rosette, or 1.44D for a type C rosette (see Fig. 4).

6.1.3 A smooth surface is usually necessary for strain gage application. However, abrading or grinding that could appreciably alter the surface stresses must be avoided. Chemical etching could be used, thus avoiding the need for mechanical abrasion.

6.1.4 The surface preparation prior to bonding the strain gages shall conform to the recommendations of the manufacturer of the adhesive used to attach the strain gages. A thorough cleaning and degreasing is required. In general, surface preparation should be restricted to those methods that have been demonstrated to induce no significant residual surface stresses. This is particularly important for workpieces that contain sharp near-surface stress gradients.

## 7. Strain Gages and Instrumentation

7.1 *Rosette Geometry*:

7.1.1 A rosette comprising three single or pairs of strain gage grids shall be used. The numbering scheme for the strain gages follows a clockwise (CW) convention (**7**).

NOTE 2—The gage numbering scheme used for the rosette illustrated in Fig. 2 differs from the counter-clockwise (CCW) convention often used for general-purpose strain gage rosettes and for some other types of residual stress rosette. If a strain gage rosette with CCW gage numbering is used, the residual stress calculation procedure described in this test method still applies. The only changes are that the numbering of gages 1 and 3 are interchanged and that the angle β defining the direction of the most tensile principal stress $\sigma_{max}$ is reversed and is measured counter-clockwise from the new gage 1.

NOTE 3—It is recommended that the gages be calibrated in accordance with Test Methods E 251.

5.1.1The7.1.2 The gages shall be arranged in a circular pattern, equidistant from the center of the rosette.

5.1.2The principal 7.1.3 The gage axes shall be oriented in each of three directions, *(1)* a reference direction, *(2)* 45° or 135° to the reference direction, and *(3)* perpendicular to the reference direction. Direction *(2)* bisects directions *(1)* and *(3)*, (see as shown in Fig. 2.

7.1.4 The measurement direction of gage 1 in Fig. 1 ).

5.2Several different standardized rosettes are available to meet a wide range of residual stress measurement needs. Fig. 3 shows three different rosette types.

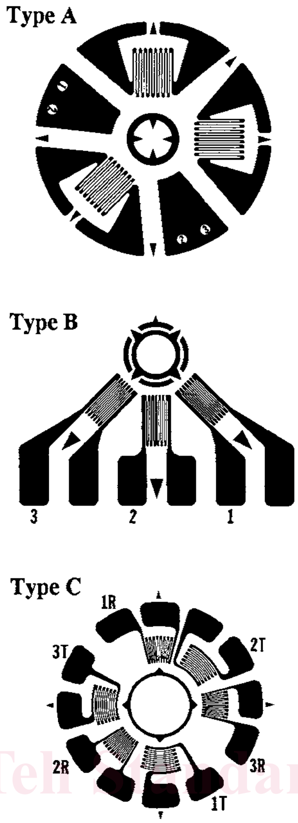



FIG. 4 Hole-Drilling Rosettes



5.2.1Fig. 3 (a) shows the type A rosette, first introduced by Rendleer and Vigness (3**is identified as the x-axis. The y-axis is 90° counterclockwise of the x-axis.**

7.1.5 The center of the gage circle shall be clearly identifiable.



7.2 *Standardized Rosettes*:

7.2.1 Several different standardized rosettes are available to meet a wide range of residual stress measurement needs. The use of standardized rosette designs greatly simplifies the calculation of the residual stresses. Fig. 4 shows three different rosette types and Table 1 lists their dimensions.

7.2.2 The type A rosette shown in Fig. 4 was first introduced by Rendler and Vigness (**5**) . This pattern is available in several different sizes, and is recommended for general-purpose use.

5.2.2Fig. 3 (b) shows thr type B rosette. This pattern has all strain gage grids located on one side. It is useful where measurements need to be made near an obstacle.

5.2.3Fig. 3 (c) shows the type C rosette. This special-purpose pattern has three pairs of opposite strain gage grids that are to be connected as three half-bridges. It is useful where large strain sensitivity and high thermal stability are required (**19**).

NOTE4—Standardized hole-drilling rosette patterns were first proposed by Rendler and Vigness (3 **4—Choice of rosette size is a primary decision. Larger rosettes tend to give more stable strain measurements because of their greater capacity to dissipate heat. They are also able to identify residual stresses to greater depths. Conversely, smaller rosettes can fit smaller workpieces, require smaller drilled holes, and give more localized measurements.**

7.2.3 The type B rosette shown in Fig. 4 has all strain gage grids located on one side. It is useful where measurements need to be made near an obstacle.

7.2.4 The type C rosette shown in Fig. 4 is a special-purpose pattern with three pairs of opposite strain gage grids that are to be connected as three half-bridges. It is useful where large strain sensitivity and high thermal stability are required (**8**). The use of standardized rosette designs greatly simplifies the calculation of the residual stresses.

5.3The center of the gage circle shall be clearly identifiable both before and after the drilling operation.

5.4The application of the strain gage (cementing, wiring, protective coating) shall closely follow the manufacturer's recommendations, and shall ensure the protection of the strain gage grid during the drilling operation.

5.5The strain gages shall remain permanently connected and the stability of the installation shall be verified. A resistance to ground of at least 20000 MΩ is preferable.

TABLE 2 1 Rosette Dimensions and Recommended Hole Diameters[A]

| Rosette Type | D | GL[B] | D | GL | GW[B] | R1[B] | R2 | Min D0 Max D0 [CB] |
|---|---|---|---|---|---|---|---|---|
| | | Type A Rosette | | | | | | |
| Conceptual | D | 0.309D | 0.309D | 0.3455D | 0.6545D 0.6 Max $D_0$ | Max $D_0$ | | |
| Conceptual | D | 0.309D | 0.309D | 0.3455D | 0.6545D 0.6 Max $D_0$ | Max $D_0$ | | |
| 1⁄32 in. nominal | 0.101 | 0.031 | 0.031 | 0.035 | 0.066 0.024 | 0.040 | | |
| 1⁄32 in. nominal | 0.101 | 0.031 | 0.031 | 0.035 | 0.066 0.024 | 0.040 | | |
| | (2.57) | (0.79) | (0.79) | (0.89) | (1.68) | (0.61) | (1.01) | |
| 1⁄16 in. nominal | 0.202 | 0.062 | 0.062 | 0.070 | 0.132 0.060 | 0.100 | | |
| 1⁄16 in. nominal | 0.202 | 0.062 | 0.062 | 0.070 | 0.132 0.060 | 0.100 | | |
| | (5.13) | (1.59) | (1.59) | (1.77) | (3.36) | | | |
| | (1.52) | (2.54) | | | | | | |
| | | (2.54) | | | | | | |
| 1⁄8 in. nominal | 0.404 | 0.125 | 0.125 | 0.140 | 0.264 | | | |
| 1⁄8 in. nominal | 0.404 | 0.125 | 0.125 | 0.140 | 0.264 | | | |
| 0.132 | 0.220 | | | | | | | |
| | 0.220 | | | | | | | |
| | (10.26) | (3.18) | (3.18) | (3.54) | (6.72) | | | |
| | | | (3.35) | | | (5.59) | | |
| | | | (3.35) | | | (5.59) Type B | | |
| Conceptual | | | | | | | | |
| Type B Rosette | | | | | | | | |
| Conceptual | D | 0.309D | 0.223D | 0.3455D | 0.6545D 0.6 Max $D_0$ | Max $D_0$ | | |
| 1⁄16 in. nominal | 0.202 | 0.062 | 0.045 | 0.070 | 0.132 0.060 | 0.100 | | |
| 1⁄16 in. nominal | 0.202 | 0.062 | 0.045 | 0.070 | 0.132 0.060 | 0.100 | | |
| | (5.13) | (1.59) | (1.14) | (1.77) | (3.36) | | | |
| | | | (1.52) | | | (2.54) | | |
| | | | (1.52) | | | (2.54) Type C | | |
| Conceptual | | | | | | | | |
| Type C Rosette | | | | | | | | |
| Conceptual | D | 0.176D | 30° sector | 0.412D | 0.588D 0.6 Max $D_0$ | Max $D_0$ | | |
| 1⁄16 in. nominal | 0.170 | 0.030 | 30° | 0.070 | 0.100 | 0.060 | 0.100 | |
| 1⁄16 in. nominal | 0.170 | 0.030 | 30° | 0.070 | 0.100 | 0.060 | 0.100 | |
| | (4.32) | (0.76) | (30°) | (1.78) | (2.54) | (1.52) | (2.54) | |

[A] Dimensions are in inches. Di (mensions in parentheses are inmm).
[B] Rosette dimensions are defined in Fig. 1.
[C] From 8.1.1 2.

## 6. Instrumentation

6.1 The instrumentation for recording of strains shall have a strain resolution of $\pm 2\times10^{-6}$, and stability and repeatability of the measurement shall be at least $\pm 2\times10^{-6}$.

7.3 *Installation and Use*:

7.3.1 The strain gage rosette should be attached to the workpiece surface such that its center is at least 1.5D from the nearest edge, or the boundary of another material should the workpiece be comprised of more than one material.

7.3.2 When using a type B rosette adjacent to an obstacle, the center of the rosette should be at least 0.5D from the obstacle, with the set of strain gages diametrically opposite to the obstacle.

7.3.3 The application of the strain gage (bonding, wiring, protective coating) should closely follow the manufacturer's recommendations, and shall ensure the protection of the strain gage grid during the drilling operation.

7.3.4 The strain gages should remain permanently connected and the stability of the installation shall be verified. A resistance to ground of at least 20 000 MΩ is preferable.

7.3.5 Checks should be made to validate the integrity of the gage installation. If possible, a small mechanical load should be applied to the workpiece to induce some modest strains. The observed strains should return to zero when the load is removed. In addition, a visual inspection of the rosette installation should be made to check for possible areas that are not well bonded. If incomplete bonding is observed, the rosette must be removed and replaced.

7.4 *Instrumentation*:

7.4.1 The instrumentation for recording of strains shall have a strain resolution of $\pm 1 \times 10^{-6}$, and stability and repeatability of the measurement shall be at least $\pm 1 \times 10^{-6}$. The lead wires from each gage should be as short as practicable and a three-wire temperature-compensating circuit (4(9) should be used with rosette types A and B. Half-bridge circuits should be used with rosette type C, the resulting outputs of which are designated $\varepsilon_1$, $\varepsilon_2$, and $\varepsilon_3$.