Designation: E1561 – 20

Standard Practice for Analysis of Strain Gage Rosette Data[1]

This standard is issued under the fixed designation E1561; 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 (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

There can be considerable confusion in interpreting and reporting the results of calculations involving strain gage rosettes, particularly when data are exchanged between different laboratories. Thus, it is necessary that users adopt a common convention for identifying the positions of the gages and for analyzing the data.

1. Scope*

1.1 The two primary uses of three-element strain gage rosettes are (*a*) to determine the directions and magnitudes of the principal surface strains and (*b*) to determine residual stresses. Residual stresses are treated in a separate ASTM standard, Test Method E837. This practice defines a reference axis for each of the two principal types of rosette configurations used and presents equations for data analysis. This is important for consistency in reporting results and for avoiding ambiguity in data analysis—especially when computers are used. There are several possible sets of equations, but the set presented here is perhaps the most common.

1.2 The equations in 4.2 and 4.3 of this practice are derived from infinitesimal (linear) strain theory. They are very accurate for the low strain levels normally encountered in the stress analysis of typical metal test objects. They become detectably inaccurate for strain levels greater than about 1 %. Rosette data reduction for larger strains is beyond the scope of this practice.

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E6 Terminology Relating to Methods of Mechanical Testing

E837 Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method

3. Terminology

3.1 The terms in Terminology E6 apply. These terms include modulus of elasticity and residual stress.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *reference line*—the axis of the *a* gage.

3.3 *Symbols:*

3.3.1 *a, b, c*—the three-strain gages making up the rosette.

3.3.1.1 *Discussion*—For the 0° – 45° – 90° rosette (Fig. 1) the axis of the *b* gage is located 45° counterclockwise from the *a* (reference line) axis and the *c* gage is located 90° counterclockwise from the *a* axis. For the 0° – 60° – 120° rosette (Fig. 2) the axis of the *b* gage is located 60° counterclockwise from the *a* axis and the *c* axis is located 120° counterclockwise from the *a* axis.

3.3.2 ε_a, ε_b, ε_c—the strains measured by gages *a*, *b*, and *c*, respectively, positive in tension and negative in compression.

3.3.2.1 *Discussion*—After corrections for thermal output and transverse sensitivity have been made, the measured strains represent the surface strains at the site of the rosette. It

[1] This practice is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

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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.

***A Summary of Changes section appears at the end of this standard**

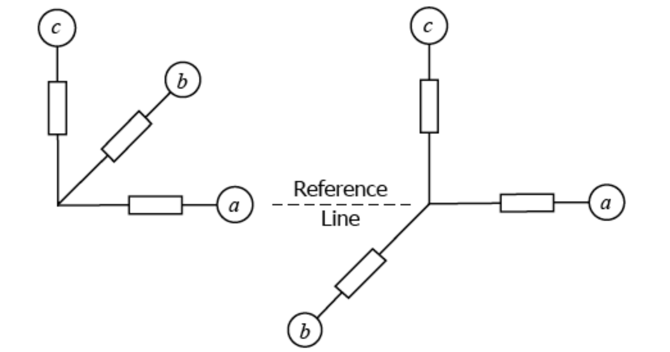

FIG. 1 0° – 45° – 90° Rosette

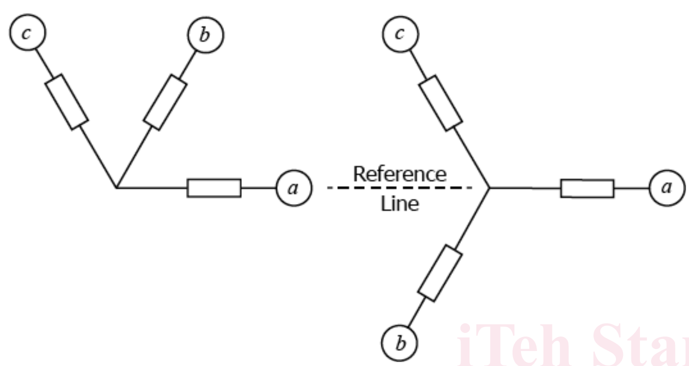

FIG. 2 0° – 60° – 120° Rosette

is assumed here that the modulus of elasticity and thickness of the test specimen are such that mechanical reinforcement by the rosette is negligible. For test objects subjected to unknown combinations of bending and direct (membrane) stresses, use 4.5 to calculate the separate bending and membrane stresses can be obtained as shown in 4.5.3.

3.3.3 ε'_a, ε'_b, ε'_c—reduced membrane strain components (4.5).

3.3.4 ε''_a, ε''_b, ε''_c—reduced bending strain components (4.5).

3.3.5 ε_1—the calculated maximum (more tensile or less compressive) principal strain.

3.3.6 ε_2—the calculated minimum (less tensile or more compressive) principal strain.

3.3.7 γ_M—the calculated maximum shear strain.

3.3.8 θ_1—the angle from the reference line to the direction of ε_1.

3.3.8.1 *Discussion*—This angle is less than or equal to 180° in magnitude.

3.3.9 *C, R*—values used in the calculations. *C* is the location, along the ε-axis, of the center of the Mohr's circle of strain and *R* is the radius of that circle.

4. Procedure

4.1 Construct Mohr's circle of strain in generally the same manner as Mohr's circle of stress. Plot normal strains, ε, as abscissae—positive for elongation and negative for contraction. Plot one-half the shear strains, γ/2, as ordinates. If the shear strains on opposite sides of an element of area appear to form a clockwise couple, then plot γ/2 on the upper half of the axis. Similarly plot shear strains that appear to form a counterclockwise couple on the lower half. With this convention, angular directions on the circle are the same as angular directions on the specimen. See Fig. 3.

4.2 Fig. 3 shows a typical Mohr's circle of strain for a 0° – 45° – 90° rosette. The calculations when ε_a, ε_b, ε_c, are given are:

$$C = \frac{\varepsilon_a + \varepsilon_c}{2} \tag{1}$$

$$R = \sqrt{(\varepsilon_a - C)^2 + (\varepsilon_b - C)^2} \tag{2}$$

$$\gamma_M = 2R \tag{3}$$

$$\varepsilon_1 = C + R$$

$$\varepsilon_2 = C - R$$

$$\tan 2\theta_1 = 2\frac{(\varepsilon_b - C)}{(\varepsilon_a - \varepsilon_c)} \tag{4}$$

4.2.1 If $\varepsilon_b < C$, then the ε_1-axis is clockwise from the reference line.

4.2.2 If $\varepsilon_b > C$, then the ε_1-axis is counterclockwise from the reference line.

4.3 Fig. 4 shows a typical Mohr's circle of strain for a 0° – 60° – 120° rosette. The calculations when ε_a, ε_b, ε_c, are given are:

$$C = \frac{\varepsilon_a + \varepsilon_b + \varepsilon_c}{3} \tag{5}$$

$$R = \sqrt{2/3[(\varepsilon_a - C)^2 + (\varepsilon_b - C)^2 + (\varepsilon_c - C)^2]} \tag{6}$$

$$\gamma_M = 2R \tag{7}$$

$$\varepsilon_1 = C + R$$

$$\varepsilon_2 = C - R$$

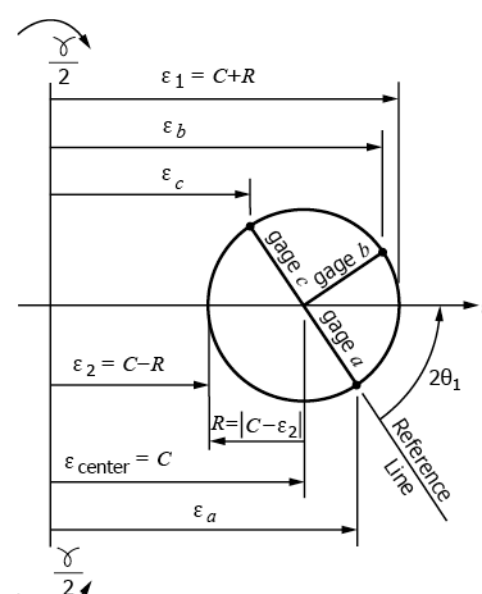

FIG. 3 Typical Mohr's Circle of Strain for a 0° – 45° – 90° Rosette

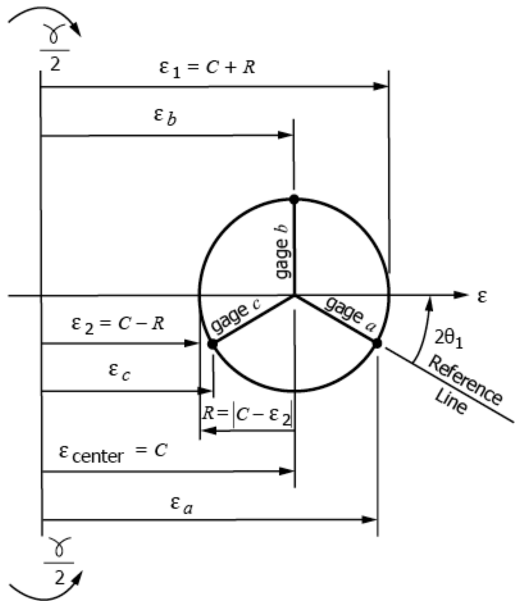

FIG. 4 Typical Mohr's Circle of Strain for a 0° – 60° – 120° Rosette

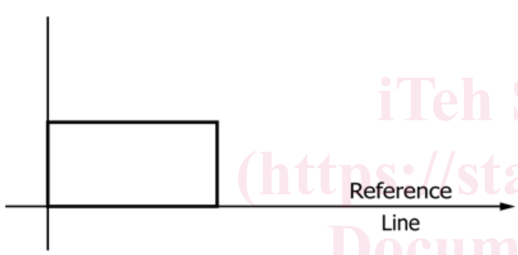

FIG. 5 Differential Element on the Undeformed Surface

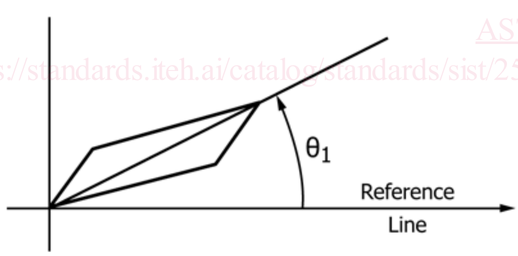

FIG. 6 Deformed Shape of Differential Element

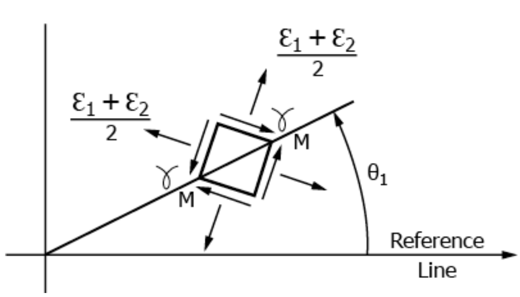

FIG. 7 Planes of Maximum Shear Strain

$$\tan 2\theta_1 = \frac{(\varepsilon_b - \varepsilon_c)}{\sqrt{3}(\varepsilon_a - C)} \quad (8)$$

4.3.1 If $\varepsilon_c - \varepsilon_b < 0$, then the ε_1-axis is counterclockwise from the reference line.

4.3.2 If $\varepsilon_c - \varepsilon_b = 0$, then $\theta_1 = 0°$.

4.3.3 If $\varepsilon_c - \varepsilon_b > 0$, then the ε_1-axis is clockwise from the reference line.

4.4 *Identification of the Maximum Principal Strain Direction:*

4.4.1 Take care when determining the angle θ_1 using (Eq 4) or (Eq 8) so that the calculated angle refers to the direction of the maximum principal strain, ε_1, rather than the minimum principal strain, ε_2. Refer to Fig. 10 to place the double angle $2\theta_1$ in its correct orientation relative to the reference line shown in Fig. 1 and Fig. 2. The terms "numerator" and "denominator" refer to the numerator and denominator of the right-hand sides of (Eq 4) and (Eq 8). When both numerator and denominator are positive, as shown in Fig. 10, the double angle $2\theta_1$ lies within the range $0° \leq 2\theta_1 \leq 90°$ counterclockwise of the reference line. Therefore, in this particular case, the corresponding angle θ_1 lies within the range $0° \leq \theta_1 \leq 45°$ counterclockwise of the reference line.

NOTE 1—Several computer languages have arctangent functions that directly place the angle $2\theta_1$ in its correct orientation in accordance with the scheme illustrated in Fig. 10 for evaluating Eq 4 and Eq 8. In Fortran or C, the two-argument arctangent functions are ATAN2 or atan2.

NOTE 2—*Interpretation of Maximum Shear Strain*— Ordinarily the sense of the maximum shear strain is not significant when analyzing the behavior of isotropic materials. It can, however, be important for anisotropic materials, such as composites. Mohr's circle of strain can be used for interpretation of the sense of the shear strain. Fig. 3 shows a typical circle for a 0°–45°–90° rosette. A differential element along and perpendicular to the reference line is initially as shown in Fig. 5. Its deformed shape, corresponding to the assumed strains, is shown in Fig. 6. The planes of maximum shear strain are at 45° to the θ_1 direction as in Fig. 7 (see 4.1).

4.5 *Back-to-Back Rosettes:*

4.5.1 When the loading of a member or structure introduces bending strains in the surface at the intended site of the rosette,

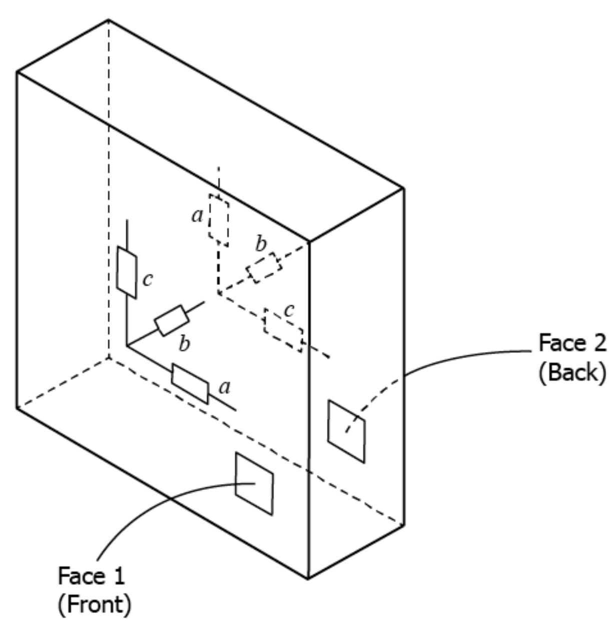

FIG. 8 Gage Labeling for Back-to-Back Rosettes