Designation: E2860 – 12

Standard Test Method for Residual Stress Measurement by X-Ray Diffraction for Bearing Steels[1]

This standard is issued under the fixed designation E2860; 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

The measurement of residual stress using X-ray diffraction (XRD) techniques has gained much popularity in the materials testing field over the past half century and has become a mandatory test for many production and prototype bearing components. However, measurement practices have evolved over this time period. With each evolutionary step, it was discovered that previous assumptions were sometimes erroneous, and as such, results obtained were less reliable than those obtained using state-of-the-art XRD techniques. Equipment and procedures used today often reflect different periods in this evolution; for example, systems that still use the single- and double-exposure techniques as well as others that use more advanced multiple exposure techniques can all currently be found in widespread use. Moreover, many assumptions made, such as negligible shear components and non-oscillatory $\sin^2\psi$ distributions, cannot safely be made for bearing materials in which the demand for measurement accuracy is high. The use of the most current techniques is, therefore, mandatory to achieve not only the most reliable measurement results but also to enable identification and evaluation of potential measurement errors, thus paving the way for future developments.

1. Scope

1.1 This test method covers a procedure for experimentally determining macroscopic residual stress tensor components of quasi-isotropic bearing steel materials by X-ray diffraction (XRD).

1.2 This test method provides a guide for experimentally determining stress values, which play a significant role in bearing life.

1.3 Examples of how tensor values are used are:

1.3.1 Detection of grinding type and abusive grinding;

1.3.2 Determination of tool wear in turning operations;

1.3.3 Monitoring of carburizing and nitriding residual stress effects;

1.3.4 Monitoring effects of surface treatments such as sand blasting, shot peening, and honing;

1.3.5 Tracking of component life and rolling contact fatigue effects;

1.3.6 Failure analysis;

1.3.7 Relaxation of residual stress; and

1.3.8 Other residual-stress-related issues that potentially affect bearings.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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]

E6 Terminology Relating to Methods of Mechanical Testing
E7 Terminology Relating to Metallography
E915 Test Method for Verifying the Alignment of X-Ray Diffraction Instrumentation for Residual Stress Measurement
E1426 Test Method for Determining the Effective Elastic Parameter for X-Ray Diffraction Measurements of Residual Stress

[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.

2.2 *ANSI Standards:*[3]
N43.2 Radiation Safety for X-ray Diffraction and Fluorescence Analysis Equipment
N43.3 For General Radiation Safety—Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies Up to 10 MeV

3. Terminology

3.1 *Definitions*—Many of the terms used in this test method are defined in Terminologies E6 and E7.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *interplanar spacing, n*—perpendicular distance between adjacent parallel atomic planes.

3.2.2 *macrostress, n*—average stress acting over a region of the test specimen containing many gains/crystals/coherent domains.

3.3 *Abbreviations:*

3.3.1 *ALARA*—As low as reasonably achievable

3.3.2 *FWHM*—Full width half maximum

3.3.3 *LPA*—Lorentz-polarization-absorption

3.3.4 *MSDS*—Material safety data sheet

3.3.5 *XEC*—X-ray elastic constant

3.3.6 *XRD*—X-ray diffraction

3.4 *Symbols:*

$\frac{1}{2} S_2^{\{hkl\}}$ = X-ray elastic constant of quasi-isotropic material equal to $\frac{1+\nu}{E_{eff}^{\{hkl\}}}$

α_L = Linear thermal expansion coefficient

β = Angle between the incident beam and σ_{33} or surface normal on the $\sigma_{33}\ \sigma_{11}$ plane

χ = Angle between the $\sigma_{\varphi+90°}$ direction and the normal to the diffracting plane

χ_m = Fixed χ offset used in modified-chi mode

d = Interplanar spacing between crystallographic planes; also called *d*-spacing

d_o = Interplanar spacing for unstressed material

$d_\perp$ = Perpendicular spacing

Δd = Change in interplanar spacing caused by stress

ε_{ij} = Strain component *i*, *j*

E = Modulus of elasticity (Young's modulus)

$E_{eff}^{\{hkl\}}$ = Effective elastic modulus for X-ray measurements

μ = Attenuation coefficient

η = Rotation of the sample around the measuring direction given by φ and ψ or χ and β

ω or Ω = Angle between the specimen surface and incident beam when $\chi = 0°$

φ = Angle between the σ_{11} direction and measurement direction azimuth, see Fig. 1

"*hkl*" = Miller indices

σ_{ij} = Normal stress component *i*, *j*

$s_1^{\{hkl\}}$ = X-ray elastic constant of quasi-isotropic material equal to $\frac{-\nu}{E_{eff}^{\{hkl\}}}$

τ_{ij} = Shear stress component *i*, *j*

θ = Bragg angle

ν = Poisson's ratio

x^{Mode} = Mode dependent depth of penetration

ψ = Angle between the specimen surface normal and the scattering vector, that is, normal to the diffracting plane, see Fig. 1

4. Summary of Test Method

4.1 A test specimen is placed in a XRD goniometer aligned as per Test Method E915.

4.2 The diffraction profile is collected over three or more angles within the required angular range for a given {hkl} plane, although at least seven or more are recommended.

4.3 The XRD profile data are then corrected for LPA, background, and instrument-specific corrections.

4.4 The peak position/Bragg angle is determined for each XRD peak profile.

4.5 The *d*-spacings are calculated from the peak positions via Bragg's law.

4.6 The *d*-spacing values are plotted versus their $\sin^2\psi$ or $\sin^2\beta$ values, and the residual stress is calculated using Eq 4 or Eq 8, respectively.

4.7 The error in measurement is evaluated as per Section 14.

4.8 The following additional corrections may be applied. The use of these corrections shall be clearly indicated with the reported results.

4.8.1 Depth of penetration correction (see 12.12) and

4.8.2 Relaxation as a result of material removal correction (see 12.14).

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

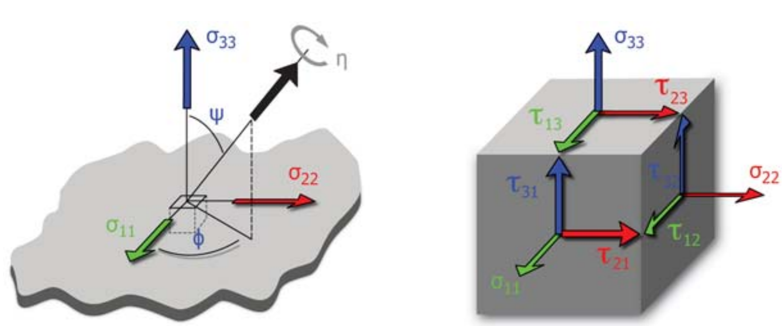

FIG. 1 Stress Tensor Components