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Standard Test Method for Determining the Effective Elastic Parameter for X-Ray Diffraction Measurements of Residual Stress[1]

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INTRODUCTION

When a crystalline material is strained the spacings between parallel planes of atoms, ions, or molecules in the lattice change. X-ray diffraction techniques can measure these changes and, therefore, they constitute a powerful means for studying the residual stress state in a body. To calculate macroscopic stresses from lattice strains requires a material constant, E_{eff}, called the effective elastic parameter, that must be empirically determined by X-ray diffraction techniques as described in this test method.

1. Scope

1.1 This test method covers a procedure for experimentally determining the effective elastic parameter, E_{eff}, for the evaluation of residual and applied stresses by X-ray diffraction techniques. The effective elastic parameter relates macroscopic stress to the strain measured in a particular crystallographic direction in polycrystalline samples. E_{eff} should not be confused with E, the modulus of elasticity. Rather, it is nominally equivalent to $E/(1 + \nu)$ for the particular crystallographic direction, where ν is Poisson's ratio. The effective elastic parameter is influenced by elastic anisotropy and preferred orientation of the sample material.

1.2 This test method is applicable to all X-ray diffraction instruments intended for measurements of macroscopic residual stress that use measurements of the positions of the diffraction peaks in the high back-reflection region to determine changes in lattice spacing.

1.3 This test method is applicable to all X-ray diffraction techniques for residual stress measurement, including single, double, and multiple exposure techniques.

1.4 The values stated in inch pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

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:*

E 4 Practices for Force Verification of Testing Machines[2]

E 6 Terminology Relating to Methods of Mechanical Testing[2]

E 7 Terminology Relating to Metallography[2]

E 1237 Guide for Installing Bonded Resistance Strain Gages[2]

3. Terminology

3.1 *Definitions:*

3.1.1 Many of the terms used in this test method are defined in Terminology E 6 and E 7.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *interplanar spacing*—the perpendicular distance between adjacent parallel lattice planes.

3.2.2 *macrostress*—an average stress acting over a region of the test specimen containing many crystals.

3.3 *Symbols:*

3.3.1 a = dummy parameter for Sum(a) and SD(a).

3.3.2 c = ordinate intercept of a graph of Δd versus stress.

3.3.3 d = interplanar spacing between crystallographic planes; also called d-spacing.

3.3.4 d_0 = interplanar spacing for unstressed material.

3.3.5 Δd = change in interplanar spacing caused by stress.

3.3.6 E = modulus of elasticity.

3.3.7 E_{eff} = effective elastic parameter for X-ray measurements.

3.3.8 i = measurement index, $1 \leq i \leq n$.

3.3.9 m = slope of a graph of Δd versus stress.

3.3.10 n = number of measurements used to determine slope m.

[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] *Annual Book of ASTM Standards*, Vol 03.01.

3.3.11 $SD(a)$ = standard deviation of a set of quantities "a".
3.3.12 $Sum(a)$ = sum of a set of quantities "a".
3.3.13 $T_i = X_i$ minus mean of all X_i values.
3.3.14 X_i = i-th value of applied stress.
3.3.15 Y_i = measurement of Δd corresponding to X_i.
3.3.16 ν = Poisson's ratio.
3.3.17 ψ = angle between the specimen surface normal and the normal to the diffracting crystallographic planes.

4. Summary of Test Method

4.1 A test specimen is prepared from a material that is representative of that of the object in which residual stress measurements are to be made.

NOTE 1—If a sample of the same material is available it should be used.

4.2 The test specimen is instrumented with an electrical resistance strain gage, mounted in a location that experiences the same stress as the region that will be subsequently irradiated with X-rays.

4.3 The test specimen is calibrated by loading it in such a manner that the stress, where the strain gage is mounted, is directly calculable, and a calibration curve relating the strain gage reading to the stress is developed.

4.4 The test specimen is mounted in a loading fixture in an X-ray diffraction apparatus, and sequentially loaded to several load levels.

4.4.1 The change in interplanar spacing is measured for each load level and related to the corresponding stress that is determined from the strain gage reading and the calibration curve.

4.5 The effective elastic parameter and its standard deviation are calculated from the test results.

5. Significance and Use

5.1 This test method provides standard procedures for experimentally determining the effective elastic parameter for X-ray diffraction measurement of residual and applied stresses. It also provides a standard means of reporting the precision of the parameter.

5.2 This test method is applicable to any crystalline material which exhibits a linear relationship between stress and strain in the elastic range.

5.3 This test method should be used whenever residual stresses are to be evaluated by an X-ray diffraction technique and the effective elastic parameter of the material is unknown.

6. Apparatus

6.1 Any X-ray diffraction instrument intended for measurements of residual macrostress that employs measurements of the diffraction peaks in the high back-reflection region may be used, including film camera types, diffractometers, and portable systems.

6.2 A loading fixture is required to apply loads to the test specimen while it is being irradiated in the X-ray diffraction instrument.

6.2.1 The fixture shall be designed such that the surface stress applied by the fixture shall be uniform over the irradiated area of the specimen.

6.2.2 The fixture shall maintain the irradiated surface of the specimen at the exact center of rotation of the X-ray diffraction instrument throughout the test with sufficient precision to provide the desired levels of precision and bias in the measurements to be made.

6.2.3 The fixture may be designed to apply tensile or bending loads. A four-point bending technique such as that described by Prevey[3] is most commonly used.

6.3 Electrical resistance strain gages are mounted upon the test specimen to enable it to be accurately stressed to known levels.

7. Test Specimens

7.1 Test specimens should be fabricated from material with microstructure as nearly the same as possible as that in the material in which residual stresses are to be evaluated.

7.2 For use in tensile or four-point bending fixtures, specimens should be rectangular in shape.

7.2.1 The length of tensile specimens, between grips, shall be not less than four times the width, and the width-to-thickness ratio shall not exceed eight.

7.2.2 For use in four-point bending fixtures, specimens should have a length-to-width ratio of at least four. The specimen width should be sufficient to accommodate strain gages (see 7.5) and the width-to-thickness ratio should be greater than one and consistent with the method used to calculate the applied stresses in 8.1.

NOTE 2—Nominal dimensions often used for specimens for four-point bending fixtures are $4.0 \times 0.75 \times 0.06$ in. ($10.2 \times 1.9 \times 0.15$ cm).

7.3 Tapered specimens for use in cantilever bending fixtures, and split-ring samples, are also acceptable.

7.4 Specimen surfaces may be electropolished or as-rolled sheet or plate.

7.5 One or more electrical resistance strain gages is affixed to the test specimen in accordance with Guide E 1237. The gage(s) should be aligned parallel to the longitudinal axis of the specimen, and should be mounted on a region of the specimen that experiences the same strain as the region that is to be irradiated. The gage(s) should be applied to the irradiated surface of the beam either adjacent to, or on either side of, the irradiated area in order to minimize errors due to the absence of a pure tensile or bending load.

NOTE 3—In the case of four-point bending fixtures the gage(s) should be placed well inside the inner span of the specimen in order to minimize the stress concentration effects associated with the inner knife edges.

8. Calibration

8.1 Calibrate the instrumented specimen using loads applied by dead weights or by a testing machine that has been verified according to Practices E 4. The loading configuration is such that the applied stresses, in the region where the strain gages are mounted and where X-ray diffraction measurements will be

[3] Prevey, P. S., "A Method of Determining the Elastic Properties of Alloys in Selected Crystallographic Directions for X-Ray Diffraction Residual Stress Measurement," *Advances in X-Ray Analysis 20*, 1977, pp. 345–354.