JUDGEMENT OF RESIDUAL STRESS FIELD UNIFORMITY
WHEN USING THE HOLE-DRILLING METHOD

GARY S. SCHAJER
Senior Research Engineer
Weyerhaeuser Technology Center
Tacoma, WA 98477, USA.

ABSTRACT

This paper examines the residual stress field depth uniformity test specified in the ASTM Standard E837-85 for measuring residual stresses using the hole-drilling method. It shows that the specified test does not give reliable results because the test does not properly account for the differences in the strain response caused by different types of residual stress fields, and also because the procedure uses a non-optimal data normalization method. A modified procedure is described which overcomes these difficulties and gives consistent results. Because of the relative insensitivity of the hole drilling method to sub-surface stresses, the new procedure has only modest capabilities. The main use of the modified procedure is as an indicator of substantial stress field non-uniformity and of strain measurement error.

INTRODUCTION

The hole-drilling method is one of the most popular and widely used techniques for residual stress measurement. Over the past forty years, the procedure has been extensively studied and developed [e.g. 1,2,3,4,5,6]. Much of this substantial research and practical experience has been incorporated into the ASTM Standard Test Method E837-85 [7], first published in 1981. The ASTM standard provides a well-planned routine procedure for making reliable residual stress measurements in a wide range of different materials.

Most often the hole-drilling method is used under the assumption that the residual stress field does not vary significantly with depth below the surface. In such cases, the calibration data provided in E837-85 can be used to calculate the original residual stresses from the measured strain relaxation data. The standard also specifies checking the measured strain relaxation data to confirm that the residual stresses are in fact sufficiently uniform. This involves comparing the shapes of the measured relaxed strain vs. hole depth curves with standard curves.

This paper examines the E837-85 test for residual stress field uniformity. Theoretical strain relaxation data from recent studies [8,9] are used to evaluate the effectiveness of the specified test and also of a proposed modified procedure.
Residual stress measurements by the hole drilling method use a specialized 45°
three-element strain gauge rosette [7]. A hole drilled at the center of the rosette
pattern partially relieves the residual strains in the material adjacent to the hole.
These strain changes are measured by the three gauges of the rosette, from which the
original residual stresses at the hole location can be calculated using the equations
and calibration coefficients provided in E837-85.

To check residual stress field uniformity with depth, E837-85 specifies making strain
readings after at least ten approximately equal hole depth increments, up to a max­
imum depth of 1.2 x hole diameter. The measured strain data are then non-dimension­
alized by expressing them as percentages of the strains measured at the maximum
hole depth. The curves in Figure 1 show the allowed ranges for the numerically
minimum and maximum strains for hole diameters in the range D/D₀ = 2.5 to 3.3, where
D₀ = hole diameter, and D = mean diameter of strain gauge rosette. An experimental
residual stress field is accepted as uniform if its measured percent strain
relaxation curves lie substantially within the limits shown in Figure 1.

![Figure 1. Standard percentage strain relaxation curves for uniform residual stress
fields. Adapted from ASTM Standard Test Method E837-85 [7].](image)

**THEORETICAL BACKGROUND**

For a linear elastic isotropic material, the following general formula relates the
strain relaxation measured at any of the strain gauges in the standard strain
gauge rosette to the principal residual stresses and the angle relative to the
maximum principal stress direction

\[
\varepsilon_r = A (\sigma_x + \sigma_y) + B (\sigma_x - \sigma_y) \cos 2\alpha
\]

where
\[
\begin{align*}
\varepsilon_r & = \text{measured strain relaxation} \\
A,B & = \text{calibration constants} \\
\sigma_x & = \text{maximum principal stress} \\
\sigma_y & = \text{minimum principal stress} \\
\alpha & = \text{angle measured counter-clockwise from the maximum principal stress direction to the strain gauge axis}
\end{align*}
\]