Measuring the Plastic Strain Ratio of Sheet Metals

by
Richard Gedney
ADMET, Inc.
Norwood, MA 02062
Tel: 781-769-0850
www.ADMET.com

Introduction - Sheet metal forming operations consist of simple bending, to stretching to deep drawing of complex parts. The mechanical properties of the sheet material greatly influences its formability. Formability is a measure of the amount of deformation a material can withstand prior to fracture or excessive thinning. Determining the extent to which a material can deform is necessary for designing a reproducible forming operation. Testing the incoming sheet material is also essential because material properties may vary from coil to coil and effect part quality and scrap rate.

The Plastic Strain Ratio, r is considered a direct measure of sheetmetal drawability and is useful for evaluating materials intended for forming shapes by a deep-drawing process. The r value is calculated from width and longitudinal strain as a test specimen is pulled in tension. Its determination is governed by ASTM E517 Standard Test Method for Plastic Strain Ratio r for Sheet Metal. The Plastic Strain Ratio r, is given by

$$r = \varepsilon_w / \varepsilon_t \qquad \text{Eq. 1}$$

where true width strain $\varepsilon_w = \ln(w_f/w_0)$,
true longitudinal strain $\varepsilon_t = \ln(t_f/t_0)$,
w_f = final width,
w_0 = original width,
t_f = final thickness,
t_0 = original thickness.

Equation 1 tells us that the r value is dependent on the ratio of width and thickness changes as the sample is pulled in tension. The word "plastic" in the Plastic Strain Ratio name implies that the specimen is pulled beyond its elastic limit and that only the strain that induces plastic flow is considered in the calculation. Because it is very difficult to accurately measure changes in thickness, we assume the volume of the specimen remains constant and express the longitudinal strain as $\varepsilon_t = \ln(L_o w_o / L_f w_f)$. After substituting ε_t into Equation 1 and inverting to eliminate negative values , the Plastic Strain Ratio, r, is given by

$$r = \frac{\ln(w_0/w_f)}{\ln(L_f w_f / L_0 w_0)} \qquad \text{Eq. 2}$$

where, L_f = final length,
L_0 = original length.

Figure 1 - A sample of parts/systems that are manufactured through forming (Evans Findings Company, ITW Drawform, General Motors).

Equation 2 enables the Plastic Strain Ratio, r, to be calculated either manually or automatically with the use of two extensometers, one to measure the change in axial gage length and the other to measure the change in width. If the manual approach is employed, prior to testing the specimen width and distance between gage marks is measured with calipers. The specimen is then pulled to a strain less than at maximum force (dP=0) and then unloaded. The final width and gage length are then measured to determine r value. If the automatic method is employed, the specimen can be tested to fracture. Enabling Ultimate Strength, Yield Strength and Elongation to be calculated on the same pull which saves time and money.

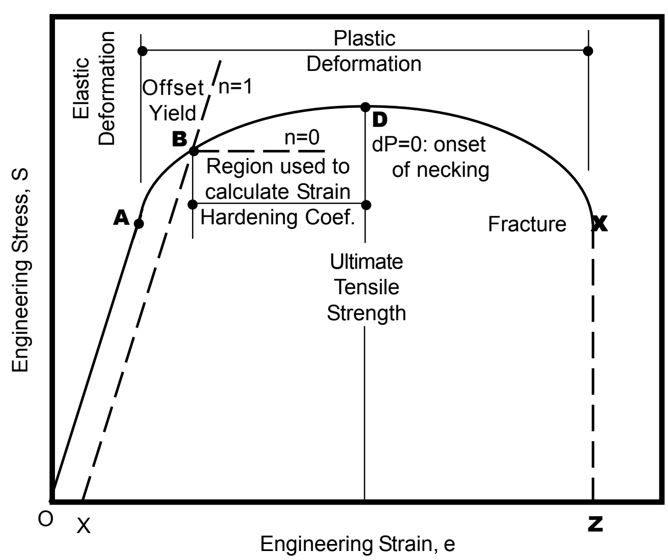

Figure 2 - Stress-Strain Curve.

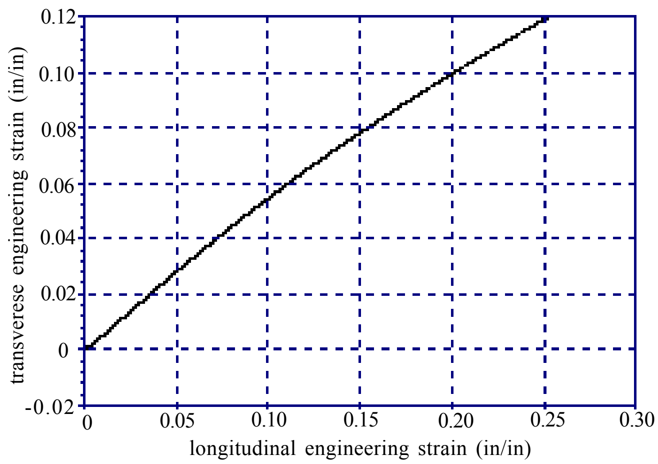

Figure 3 - Longitudinal-Transverse Strain Curve.

Sources of Error in R Value

If we were to perform an error analysis on Equation 2, one would find that r value is much more sensitive to errors in width measurement. The author has seen reported r values that are more than 40% in error. Furthermore, the reported values are always greater than the true value. The two primary source of errors in width strain are: a) the edges of the specimen curl along the length of the specimen as it is being pulled; and b) sharp knife edges on the extensometer used for width strain measurements create high concentrated stresses that result in increased localized straining at the point of measurement.

Both sources of error result in greater width strains and higher r values. After each test, the specimen should be inspected to determine if it remains flat. Errors in the r value will persist unless one compensates for the curling. Errors associated with sharp knife edges are more easily eliminated by installing knife edges with rounded or flat surfaces at the point of contact (see Figure 4).

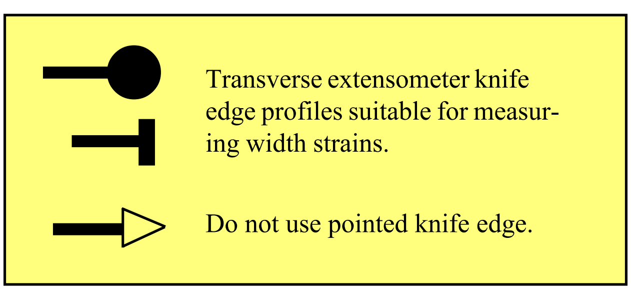

Figure 4 - Knife Edge Profiles

Other Points To Consider

For many materials the r value remains constant over the range of plastic strains up to the maximum force applied to the specimen. For some sheet materials, however, the r value varies with the applied axial strain and as such should be reported with the as tested strain level.

Because rolled sheet metals develop planar anisotropy, sample orientation can be significant to the measurement of Plastic Strain Ratio r. Therefore, test specimens are cut at 0°, 45° and 90°, respectively to the roll direction and the direction must be reported with each result.

Conclusion

Plastic Strain Ratio r is one of the more difficult formability parameters to measure because of the additional width strain measurement. R value errors as large as 40-50% can occur due to errors associated with measuring width strain. Careful inspection of the specimen after each test to check for curling and the use of proper knife edges are paramount to obtain true r values.

Test Methods and Specifications

Material properties that have a direct or indirect influence on formability and product quality are, Ultimate Tensile Strength, Yield Strength, Young's Modulus, Ductility, Strain Hardening Exponent and the Plastic Strain Ratio. All of these parameters can be determined by cutting a test specimen from the blank and performing a tensile test. Below is a list of ASTM test specifications that governs the determination of these parameters.

ASTM E8/E8M Standard Test Methods for Tension Testing of Metallic Materials governs the determination of Ultimate Tensile Strength, Yield Strength plus Elongation and Reduction of Area which are measures of ductility.

ASTM E111 Standard Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus is used for determining Young's Modulus.

ASTM E646 Standard Test Method for Tensile Strain-Hardening Exponents (n-values) of Metallic Sheet Materials is used for determining the Strain Hardening Exponent.

ASTM E517 Standard Test Method for Plastic Strain Ratio r for Sheet Metal governs the determination of r. Of all the mechanical properties determined by a tensile test, ASTM E517 is the most difficult and requires a close attention to detail.

Copies of the ASTM test methods mentioned in this article may be obtained from ASTM, the American Society for Testing and Materials. The test methods are available from the ASTM Web site (www.astm.org) or through Customer Service (610/832-9585; e-mail: service@astm.org). 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959 Phone: (610) 832-9585 Fax: (610) 832-9555.

Transverse Extensometers for Measuring Width Strains

For ´r´ value determination an axial extensometer for length strain measurement is also required (see Figure 7).

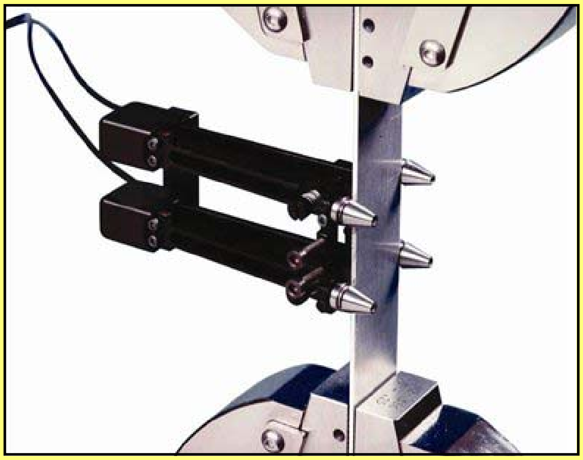

Figure 5 - Instron Corporation transverse averaging extensometer with single channel output and large radius contact points.

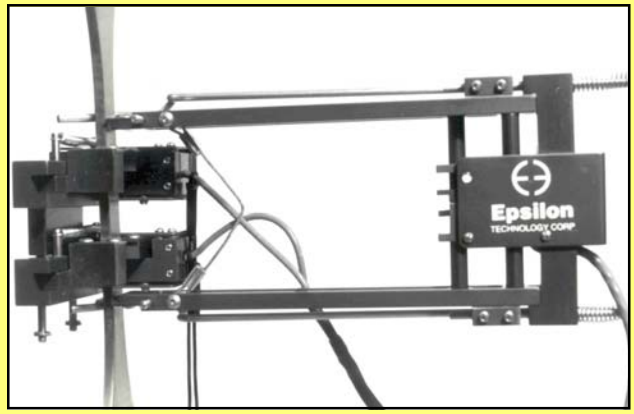

Figure 7 - Typical arrangement of axial and averaging transverse extensometers used for the determination of Plastic Strain Ratio r (Epsilon Technology, Inc.).

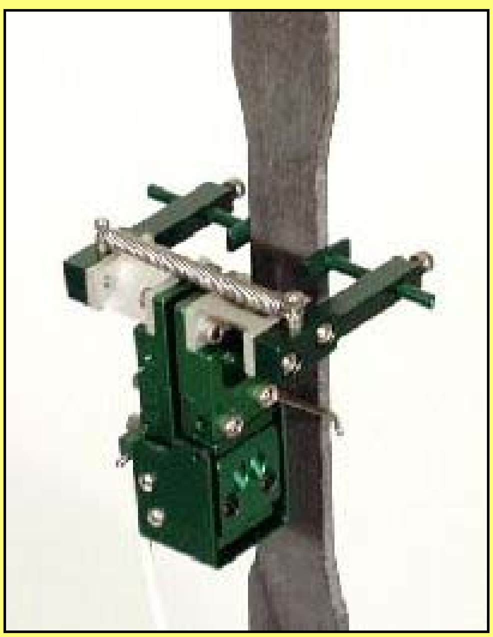

Figure 6 - Epsilon Technology, Inc. transverse non-averaging extensometer with flat contact points.

Figure 8 - Tensile specimen pulled to fracture. Depicts region where necking occurred.