Determining the flow stress curve with yield and ultimate tensile strengths, Part II

Using the curve for FE simulation

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Editor's Note: Part I of this article appeared in the May/June 2011 issue.

The tensile test and Equations 1 through 6 in Part I can be used to determine uniaxial stress-strain relationships, both in elastic and plastic regions. The relationships, often called Hooke's law and Hollomon's (Power) law, relate stress and strain or load and deformation for design purposes. In the elastic region, Hooke's law can be used to relate stress to strain with the equation:

$$\sigma = Ee \quad \text{(Eq. 7)}$$

where E is the modulus of elasticity. This is a linear relationship, so the modulus of elasticity can be determined from the slope of the engineering stress-strain curve in the elastic region.[3] In the plastic region, the relationship between stress and strain is nonlinear. In this region, flow stress definitions are used.

Hollomon's (Power) law is a simple and commonly used empirical stress-strain relationship, obtained by fitting an exponential curve to the experimental data points of the flow stress curve:

$$\sigma = K\epsilon^n \quad \text{(Eq. 8)}$$

where:
K = strength coefficient
n = strain-hardening exponent

Either the Power law or the experimental points of a flow stress curve can be used in FE analysis to simulate a sheet metal forming process. However, in practice, sheet material properties obtained from tensile tests often are described by using only three values:

1. Yield strength (Y)
2. Ultimate tensile strength (UTS)
3. Total elongation

FE simulations require the full flow stress curve, so Equation 8 coefficients K and n must be obtained from the values of Y and UTS. In doing so, the assumptions are that the effect of strain rate is neglected and that the strain-hardening exponent, n, does not change with strain.

Y and UTS correspond to two

Steel	Material Property	Values From Tensile Tests	Calculated Values
Prephosphated JAC270D (per mill certificate)	Y	163	—
	UTS	311	—
	n	0.25 (6-12% strain)	0.24
	K	—	557
SAE 1020 (hot rolled)	Y	262	—
	UTS	441	—
	n	0.19	0.205
	K	738	749
RQC-100 (hot rolled)	Y	883	—
	UTS	931	—
	n	0.06	0.049
	K	1,172	1,136
SAE 4340 (Q&T)	Y	1,172	—
	UTS	1,241	—
	n	0.066	0.051
	K	1,579	1,519

Figure 5

The K and n values obtained from the tensile test and developed procedure are compared.

points (P1 and P2) on the engineering stress-strain curve as shown in Figure 2. The x and y coordinates of P2 are UTS and e_u, respectively. The y coordinate of P1 is Y. However, the x coordinate of P1, e_o, changes depending on material and is larger than 0.2 percent engineering strain. For steel, the engineering strain is assumed to be 0.6 percent.

Both P1 and P2 are in the plastic region. Thus, both points should satisfy the Power law as given in Equations 9 and 10. Furthermore, it can be shown that uniform elongation in the flow stress curve, ϵ_u, is equal to the strain-hardening exponent, n.[4] The equivalent value of K from Equation 10 is substituted in Equation 9, and Equation 9 is solved for n using a numerical method. Once n is calculated, Equation 9 or 10 can be used to calculate K.

$$\sigma_{\mathrm{UTS}} = K\epsilon_u^{\,n} = Kn^n \quad \text{(Eq. 9)}$$

$$\sigma_{\mathrm{Y}} = K\epsilon_o^{\,n} \quad \text{(Eq. 10)}$$

The developed procedure was tested for various steels. These examples are given in **Figure 5** and illustrate that the K and n values agree well with values determined by other tensile tests.

In summary, the flow stress curve in the Power law form can be obtained approximately from Y and UTS values. The method will be generalized for other materials in the future. It is also possible to obtain K and n by conducting a series of tensile test simulations by considering different K and n values.[5] Ⓢ

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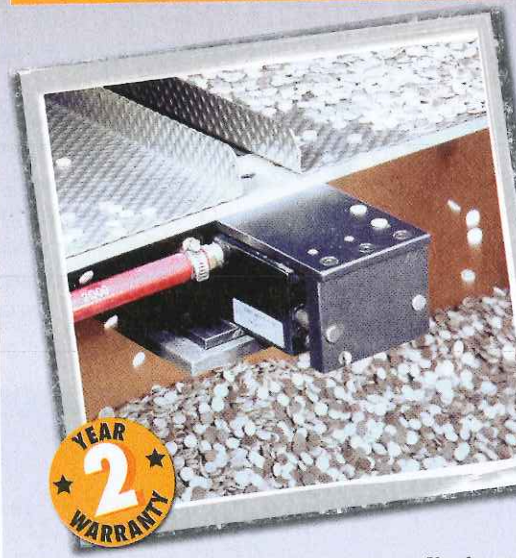
Notes

3. *W.F. Hosford and R.M. Caddell,* Metal Forming: Mechanics and Metallurgy, *3rd ed. (Cambridge, U.K.: Cambridge University Press, 2007).*

4. *T. Altan, S. Oh, and H. Gegel,* Metal Forming: Fundamentals and Applications *(Metals Park, Ohio: ASM Intl., 1983).*

5. *Changhyok Choi, "Prediction of Flow Stress Using Ultimate Tensile Strength and Yield Strength," Presentation at Center for Precision Forming (CPF), Columbus, Ohio, Dec. 10, 2010.*



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