Determining material properties and batch-to-batch variations with bulge testing

BY EREN BILLUR AND TAYLAN ALTAN

Finite element analysis (FEA) is used widely for process and die design in metal forming applications. The accuracy of the input data (material properties, friction coefficient, die geometry) affects analysis results.

One of the most important input data is the flow stress curve (or true strain/true stress diagram), which can be determined in a number of ways.

Tensile Test

The tensile test is a very well-established, standard test method for obtaining material properties. Most engineering designs are based on parameters determined by tensile tests, such as yield strength, ultimate tensile strength, and elastic modulus.

However, metal forming involves very high plastic strains, so flow stress (true stress) at high strains is required for accurate analysis. The tensile test typically gives flow stress of only about 0.15 to 0.30 true strain, depending on the material, because of local necking in one-directional (uniaxial) deformation.

Bulge Test

In a bulge test, the sheet blank is clamped at its edges and stretched against a circular die using a viscous pressure medium. The sheet metal bulges into a hemispherical dome; eventually it bursts (see **Figure 1**). The deformation is two-directional (biaxial), which is more similar to most metal forming applications than the one-directional deformation of the tensile test. In addition, flow stress can be determined up to 0.5 to 0.7 true strain before necking and fracture of the sample occur.

The dome height of the bulged blank and the pressure in the viscous medium are measured and used to calculate flow stress. The Center for Precision Forming (CPF) has developed analysis methods and prepared easy-to-use computer programs for flow stress calculations.

For an advanced high-strength

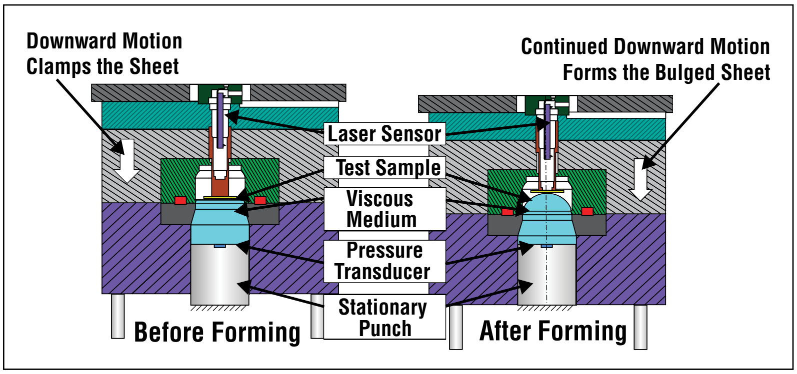

Figure 1

The bulge test can be done using a single-action hydraulic press with a cushion. The upper die moves down and clamps the blank with the cushion. The press then continues its movement and compresses the viscous medium, deforming the blank into a hemispherical shape.

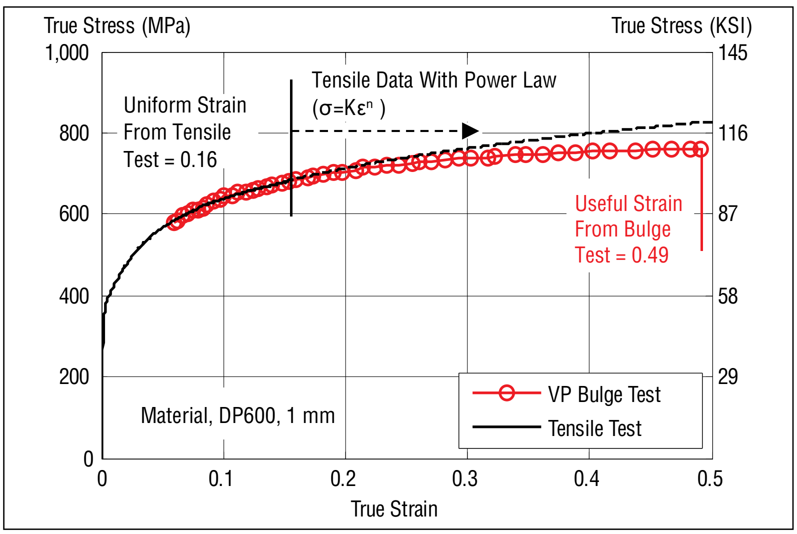

Figure 2

Useful strain from the tensile test on AHSS (extrapolated with $\sigma = K\varepsilon^n$) is limited to 0.16. With the bulge test, flow stress data can be obtained until 0.49 true strain.

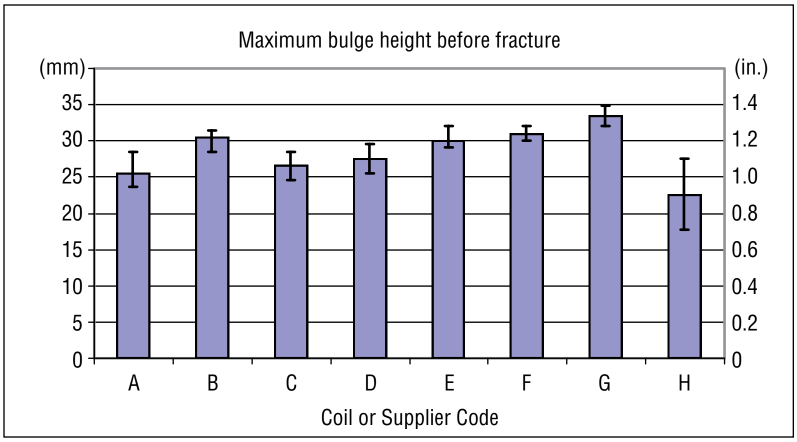

Figure 3

Maximum bulge height before fracture can estimate the material variation and scrap rate from batch to batch.

steel (AHSS) (dual-phase 600 MPa [87,000 PSI], DP600), useful strain from the tensile test is limited to 0.16 (see **Figure 2**). For forming analysis, a power law equation ($\sigma = K\varepsilon^n$) is fit, and data is extended over larger strains using extrapolation. When the same material is tested using a bulge test, flow stress data can be obtained until 0.49 true strain. This either reduces errors caused by curve fit or eliminates the need for it.

At about 0.5 true strain, flow (true) stress obtained from the bulge test is about 10 percent lower than the extrapolated data. This affects press force calculations as well as predicted thinning and possible fractures, as the strain hardening is not realistically modeled with tensile test data.

Other Uses of Bulge Testing

Variations in incoming AHSS material are very common. Because these steels are so-called performance grades, different suppliers have different chemistries and heat treatments to achieve the same nominal grade. A steel sold as DP600 can be any dual-phase steel with tensile strength of more than 600 MPa (87,000 PSI). Elongation (maximum strain) and strain-hardening characteristics may differ from batch to batch or even coil to coil.

Bulge testing can be an easy and quick method for evaluating batch-to-batch variations in strength and elongation properties. Earlier studies at CPF showed that scrap rate can be estimated simply by checking the maximum bulge height at fracture in every coil (see **Figure 3**). This is similar to the limiting dome height (LDH) test, but with the bulge test, the blank does not slide over a punch. Therefore, the effect of friction in the LDH test is not observed in the bulge test.

Figure 3 shows how 304 stainless steels from eight different coils fracture at different levels of deformation, as indicated by the maximum bulge height. The highest scrap rate was observed in coil H, which had the lowest average bulge height. SJ

Eren Billur is a postdoctoral researcher and Taylan Altan is professor and director of the Center for Precision Forming (CPF) at The Ohio State University, 339 Baker Systems, 1971 Neil Ave., Columbus, OH 43210, 614-292-5063, www.cpforming.org and www.ercnsm.org .