Using the frictionless dome test to determine flow stress data

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In sheet metal forming, simulation plays an important role in predicting metal flow, optimizing geometry, and selecting process variables. The accuracy of the simulation results is highly dependent on the accuracy of the input parameters and the boundary conditions used in the finite element (FE) model. In FE simulation of the sheet metal forming process, the tensile data and flow stress data are the most important required parameters, along with the selection of the coefficient of friction.

Tensile Test

Data such as Young's modulus, anisotropy value (r-value), yield stress, and ultimate tensile strength usually is obtained through a tensile test. Flow stress data also can be obtained from tensile test data by converting the plastic region of the engineering stress/strain curve to a true stress/strain curve. With this method, for most materials, the flow stress curve can be obtained only up to the point of maximum load, where diffused necking initiates.

However, strains in sheet forming operations usually are greater than the uniform strain obtained in the tensile test. Therefore, during the simulation, the flow stress obtained from tensile data is extrapolated up to a higher strain value such as 0.5. Studies have shown that for some materials, especially some advanced high-strength steels, extrapolation of the flow stress obtained from tensile data does not accurately represent the actual flow stress of that material. Morever, in the tensile test, materials are elongated in uniaxial stress conditions, whereas most sheet metal forming processes exhibit biaxial deformation. Therefore, the simulation results may not be accurate enough when using flow stress obtained from a tensile test.

Bulge Test

The hydraulic bulge test and the viscous pressure bulge (VPB) test provide the flow stress data in higher strain values while the material undergoes biaxial stress conditions.

In the bulge test (see **Figure 1a**), stress and strain can be determined up to failure of the specimen, which is greater than the strain values that can be obtained from a tensile test. The bulge test has been used for many years as a standard test to determine the true stress/strain curves in biaxial tension. A low-viscosity hydraulic fluid such as oil is used to form the sheet. The most important advantage of this test is the absence of contact between the sheet and tools.

In the VPB test, a semisolid product made of viscous material such as polyurethane or silicone is used as a pressure medium instead of a hydraulic fluid.

Simulation results obtained when using the flow stress data from the hydraulic bulge or VPB tests are more accurate than those obtained using tensile data. However, bulge tests need special tooling that is not available in most forming companies.

Frictionless Dome Test

At The Ohio State University, Center for Precision Forming (CPF), in

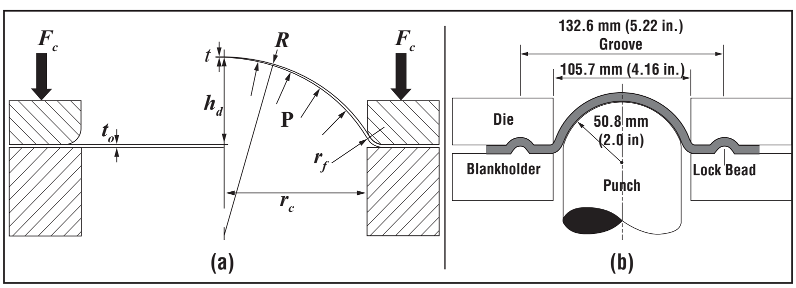

Figure 1

Biaxial testing methods include bulge testing (a) and frictionless dome testing (b).

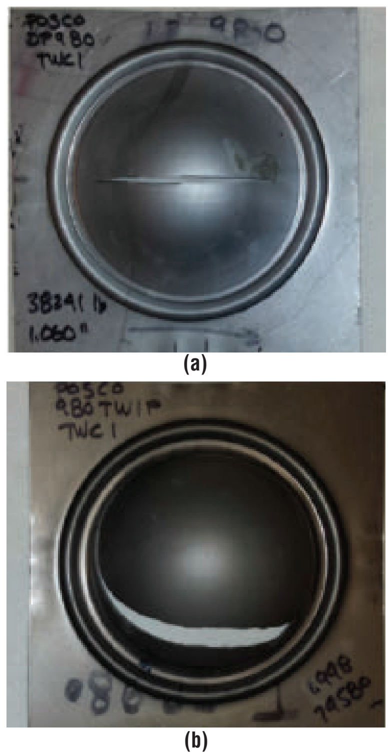

Figure 2

Appropriate lubrication for nearly frictionless deformation (a) causes fracture to occur at the apex with DP 980 (t =1.4 mm) with lubrication (Teflon®/clay/WD-40). Poor lubrication (b) causes fracture to occur far from the apex for TWIP 980 (t = 1.3 mm).

cooperation with Honda R&D, researchers have developed a new testing method that can provide the flow stress data up to ~0.5 strain value, similar to what is obtained from a bulge test but using simpler tooling. The test is called a frictionless dome test (FDT).

In the FDT (see **Figure 1b**), a spherical punch forms the sheet material into a cylindrical die. Unlike the bulge test, the punch and sheet contact each other, and the friction between the contact surfaces must be reduced to create the frictionless condition and equibiaxial deformation. So using an appropriate lubricant is the key parameter in the FDT to provide a frictionless forming condition and obtain a crack at the apex of the dome (see **Figure 2**).

In the bulge test the flow stress data is determined by measuring the bulge height and the pressure of the hydraulic fluid. The theory of thin membrane is used to calculate the flow stress from the data. In contrast, the only data that FDT provides is punch force versus stroke. Thus, CPF developed a MATLAB code called PRODOME that automatically calculates the flow stress data from the load-stroke curve by comparing the force stroke data with a database obtained from simulation.

Test Results

To evaluate the accuracy of the results obtained from FDT, CPF determined the flow stress curves for several advanced high-strength steels using tensile test, bulge test, and FDT.

As shown in **Figure 3**, for some materials such as CP800 and DP590, extrapolation of tensile data did not provide accurate flow stress data in high strain values. For most tested materials, the flow stress curves at high strain values (from 0.3 to 0.5) obtained from FDT are closer to the bulge test results compared to the curves calculated by extrapolating the tensile test data. Therefore, simulation results will be more accurate when using flow stress obtained from FDT.

In lower strain values, however, the flow stress curves obtained from FDT did not represent the accurate flow stress data, especially for strain lower than 0.1. Further investigation is required to improve the PRODOME code and testing procedures to obtain accurate flow stress data in low strain values using FDT.

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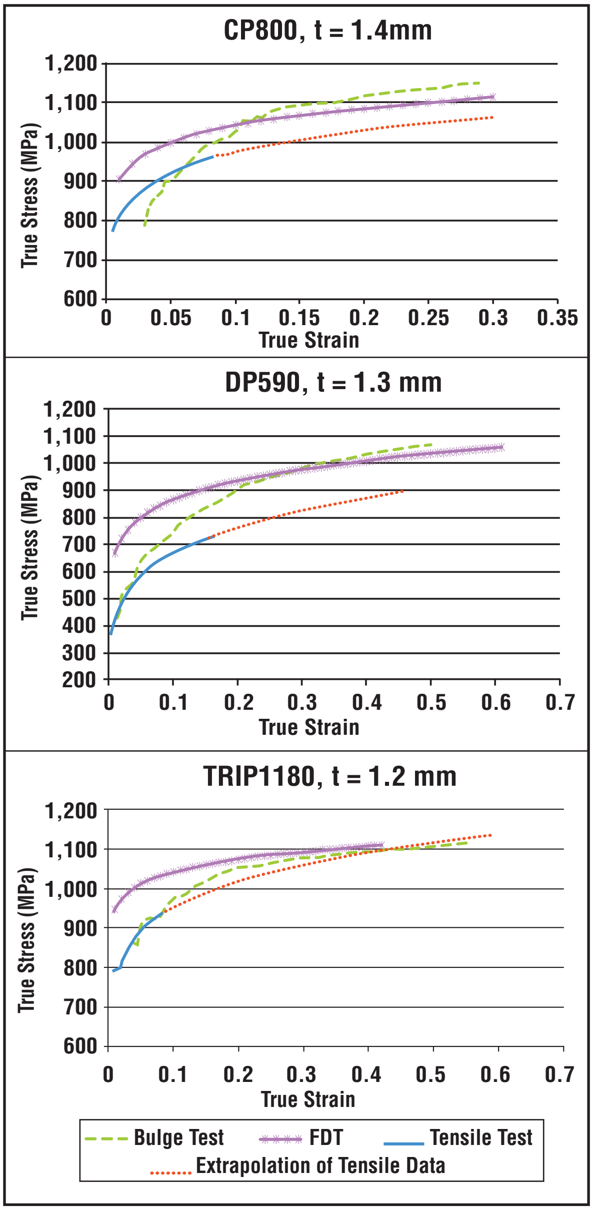

Figure 3

For most tested advanced high-strength steels, in high strain values, the flow stress curves obtained from FDT agreed with the bulge test results. In lower strain values, however, the flow stress curves obtained from FDT did not represent the accurate flow stress data, especially for strain lower than 0.1.

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