

# NIST Center for Metal Forming

## Objective

Our objective is to develop the measurement methodology, standards and analysis necessary for the US auto industry and base metal suppliers to transition from a strain-based to a stress-based design system for auto body components, and successfully transfer this technology to our customers in industry. With this knowledge, the US automotive industry will be able to transition to new advanced and lightweight materials more easily, as more accurate data and material models will lead to more accurate die designs, reducing die tryouts and new model development costs.



## Impact and Customers

- Reduction of sheet metal forming die tryouts (redesigns) through improved material data and models will save the US auto industry a large portion of the \$600M wasted per year in these efforts.
- We have spearheaded the adoption this year by ASTM of the springback cup test (below) favored by industry, and developed the data on its robustness, allowing industry to move forward in using this test to characterize the springback characteristics of new materials.
- The multiaxial testing technique developed in our lab is being installed in the GM research lab and at several academic sites.
- Our customers include GM, Ford, United States Steel, ALCOA, USCAR, Volvo, ALCAN, and LSTC.



## Approach

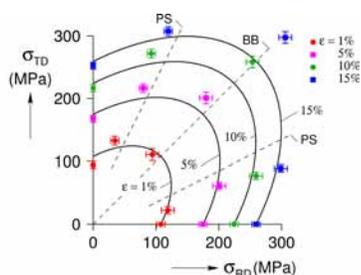
The US auto industry spends \$600M per year fixing and tweaking forming dies that do not make correct parts. The primary reason that the dies are inaccurate is that the computer models of the dies use material models that are inaccurate. Upon surveying our industrial partners, we determined that a key NIST role in addressing this problem lies in developing new mechanical testing methods and metrology, and also developing a fundamental understanding of the interplay between multiaxial strain behavior and sheet microstructure.



We have developed a technique where, for the first time, the sheet's stress-strain response can be measured along non-linear multiaxial paths. This provides unique data on how the multiaxial flow surface changes with plastic strain, and this can be used to modify materials models used by industry. Concurrent with this, we also measure the evolving crystallographic texture of the sheet and the surface roughness, to develop a microstructural understanding of the materials' deformation response.

## Accomplishments

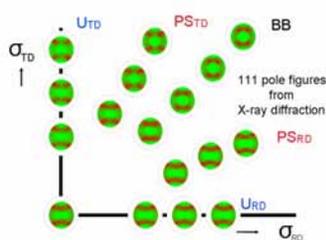
The tensile multiaxial yield surface of 5754 aluminum alloy sheet was measured from initial yield up to failure for the first time. The initial shape of the surface closely approximates an ellipse, as predicted by most plasticity models of forming. However, as the strain levels increase to levels typical of forming (5 % to 20 % plastic strain), the locus evolves asymmetrically, and an apex forms in the direction of balanced biaxial (BB) straining. At the highest strain levels, the error between the predicted and the measured flow stresses exceeds 25 %.



Yield locus evolution

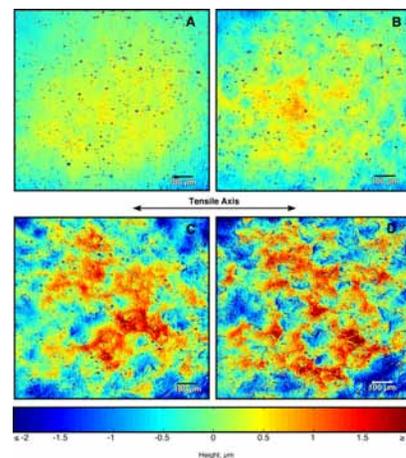
On the same samples, the crystallographic texture evolves from a rolling texture to one of the predominant FCC deformation textures, as expected. Unexpectedly, the deformation texture that develops when the sheet is deformed in the rolling direction (RD) differs from that which develops during deformation in the transverse direction (TD).

The two deformation textures are 90 degree rotations with respect to one another, but the twofold symmetries of the textures leads to an asymmetry in the stress needed to form the textures, which coincides with the measured asymmetry in the yield surface. These results are being modeled using a Taylor-type description of the flow behavior of polycrystalline aggregates undergoing evolving textures, which is the basis of many common plasticity models, to see if this formulation adequately captures the behavior.



Texture evolution with strain

Surface roughness, and how it changes with plastic strain and contributes to forming friction, is another highly important issue. Conventionally, roughness is measured with a profilometer. However, we have found that these measures may be misleading—as both measurement uncertainties and statistical errors are compounded when the 2-D lines are extrapolated to the



Surface roughness evolution with strain

entire surface.

Our new approach uses data from a scanning laser confocal microscope, an instrument that builds a point-by-point image of a surface in 3-D. The data from a single image—representing an area of about  $1000 \mu\text{m} \times 800 \mu\text{m} \times 20 \mu\text{m}$  in depth—are analyzed using mathematical techniques that treat every point in the image simultaneously to produce a roughness measure that considers the entire 3-D surface rather than a collection of 2-D stripes. This technique will reduce uncertainties in the measured surface roughness and allow more accurate characterization of the evolution of roughness with strain.

## Learn More

**Mark Iadicola**  
**Steve Banovic**  
**Mark Stoudt**  
**Thomas Gnaeupel-Herold (NCNR)**  
**Adam Creuzige**

**Tim Foecke**  
**(Metallurgy Division)**  
**(301) 975-6592**  
**timothy.foecke@nist.gov**  
**www.nist.gov/metallurgy**

## Publications

Iadicola MA, Foecke T and Banovic SW *Experimental Observations of Evolving Yield Loci in Biaxially Strained AA5754-O* International Journal of Plasticity, 24: 2084 (2008)

Banovic SW, Iadicola MA and Foecke T *Textural Development of AA 5754 Sheet Deformed under In-Plane Biaxial Tension* Metallurgical and Materials Transactions A, 39A: 2246 (2008)

Foecke T, Iadicola MA, Lin A and Banovic SW *A Method for Direct Measurement of Multiaxial Stress-Strain Curves in Sheet Metal* Metallurgical and Materials Transactions A, 38A: 306 (2007)

Foecke T and Gnaeupel-Herold T *Robustness of the Sheet Metal Springback Cup Test* Metallurgical and Materials Transactions A, 37A: 3503 (2006)