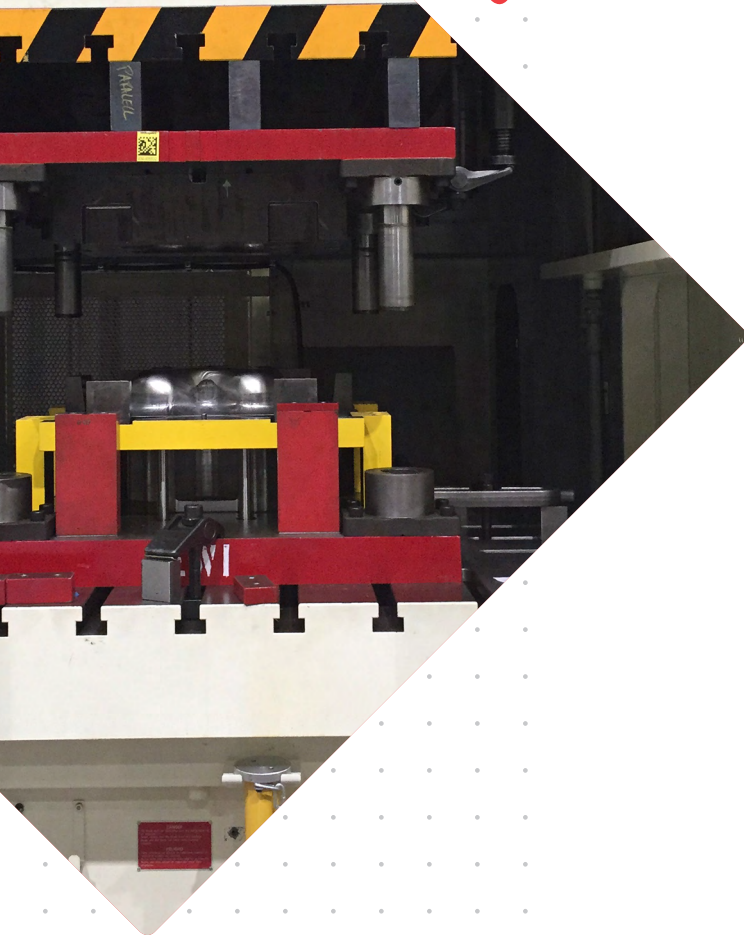


The EWI Guide to

Formability of New and Sophisticated Materials

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Sheet metal forming (shaping a flat sheet of metal with an applied force) offers a highly flexible, low-cost method for mass producing parts.

The technology, however, is subject to a set of common problems, including cracking, wrinkling, and springback.

One frequent cause of these issues is material variation from batch to batch and or coil to coil, especially for advanced high-strength steels (AHSS) and less-ductile aluminum alloys. While material variation can be limited by controlling the material's chemistry, this is expensive and increases cost.

Process Simulation

Process simulation has become widely accepted by manufacturers in validating the stamping part and tool design. Early in the design process, it is used to determine if a part shape is feasible. Later, simulation can make the stamping process more robust and help to find practical solutions for the part quality issues due to material and environment variations.

The key to an accurate simulation is material data. Many simulation packages come with a material database that may be appropriate for early feasibility studies. However, sheet material properties are process dependent and will vary from one supplier to another, from one coil to the next, and even in the same coil. Material testing is required to have a reliable simulation result.



Currently, there is a lack of understanding in industry of how material variation can affect design and process.

Tensile Testing

Tensile testing is the first step in determining material properties. Tensile samples are tested in three orientations (0°, 45°, and 90° to rolling direction) to capture the anisotropy that is introduced during material processing (Figure 1).

The tensile test will determine the material’s Young’s modulus, yield strength (YS), ultimate tensile strength (UTS), hardening curve, elongation, and anisotropy. For low-carbon steel, tensile testing is all that is required; property variation is relatively low, and much research has been conducted to extrapolate the tensile measurements to data required for simulation. AHSS, aluminum, and magnesium alloys, however, require additional testing.

Material variation causes quality issues when “bad” material enters the process and starts to show splits, wrinkles, or altered springback results. In reality, there is no “good” or “bad” material; it is material variation that affects the outcome and should be considered during the design process. Measuring tensile data over time is an excellent way to prepare for material variation. The YS, UTS, and elongation will have a Gaussian distribution where the greatest probability of material properties is at the peak of the curve. A wide distribution has more variation than a narrow distribution (Figure 2). A common approach is to consider the material data that falls within 6x standard deviations of the middle of the distribution. This approach captures 99.9997% of the material variability.

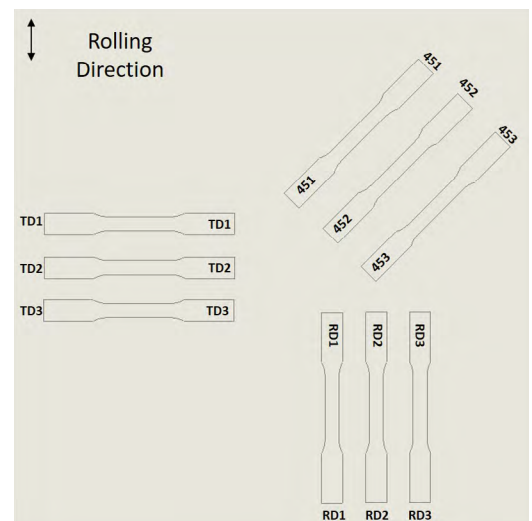


FIGURE 1 Tensile sample directions.

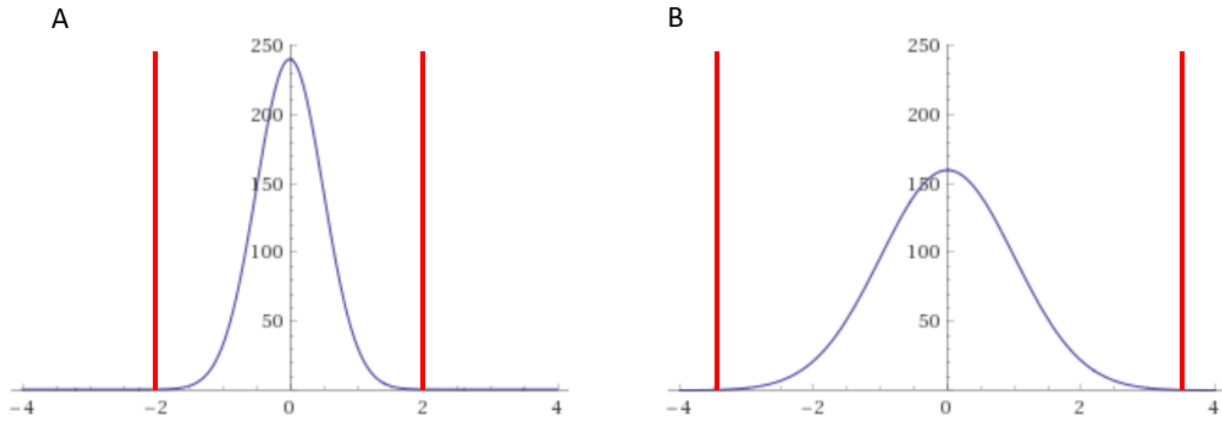


FIGURE 2 Gaussian distribution with relatively lower (A) and higher (B) variation.

There are two ways to apply tensile test data measured over time:

1. Use tensile data to simulate the average properties, then simulate the upper and/or lower limits individually.
2. Use a design of experiments tool with the FEA software. Computing power and simulation efficiency have increased to the point where dozens or hundreds of simulations can be run from a single setup and the data can be pulled together into a single post-processing interface.

With the full material variation output, design changes can be incorporated that are resilient to material changes.



Beyond the Tensile Test: Comprehensive Formability Evaluation

FIGURE 3

Erichsen Universal Sheet Metal Testing machine used by EWI to perform FLC, HET and half dome testing.

Limitations of tensile testing for advanced alloys include:

- Material variability – *Tensile testing* should be conducted randomly over time to establish the range of material properties.
- Yield criterion – Additional yield data can be measured with *bulge testing* to determine the biaxial yield value. The criteria can be validated by comparing simulation results to stamped panels with ARGUS strain measurements.
- Hardening curve – A bulge test is required to measure the hardening response at large strain values seen in stamping.
- Forming limit diagrams – *Forming limit curve (FLC)* testing establishes the formability of the material.
- Edge cracking – *Hole expansion (HET)* and/ or *half dome testing* can be used to determine the critical strain that initiates edge cracks.

A yield criterion is used to describe where the material transforms from elastic deformation to plastic deformation.

This parameter is critical to properly produce the strains that will be used to detect failure and predict springback. There are many yield criteria available, and the proper yield criterion is material dependent and driven by material testing. As seen in Figure 4, the tensile test only measures two points on this surface. The yield surface is extrapolated from these two data points. Performing a bulge test can deliver a third point and dramatically improve the accuracy of the yield surface.

The bulge test can also deliver flow stress data at higher strain values compared to tensile testing.

Figure 5 shows tensile flow stress that ends when the tensile sample begins to neck. This data must be extrapolated to higher strain values that are achieved in stampings. Flow stress data from the bulge test does not require extrapolation and reduces the amount of uncertainty in the material data.

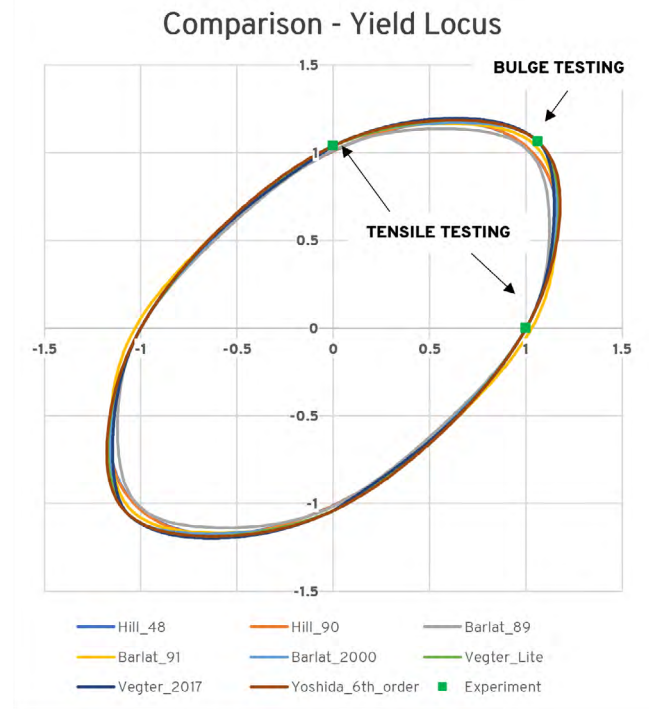


FIGURE 4 Yield criteria in ESI MatWizard.

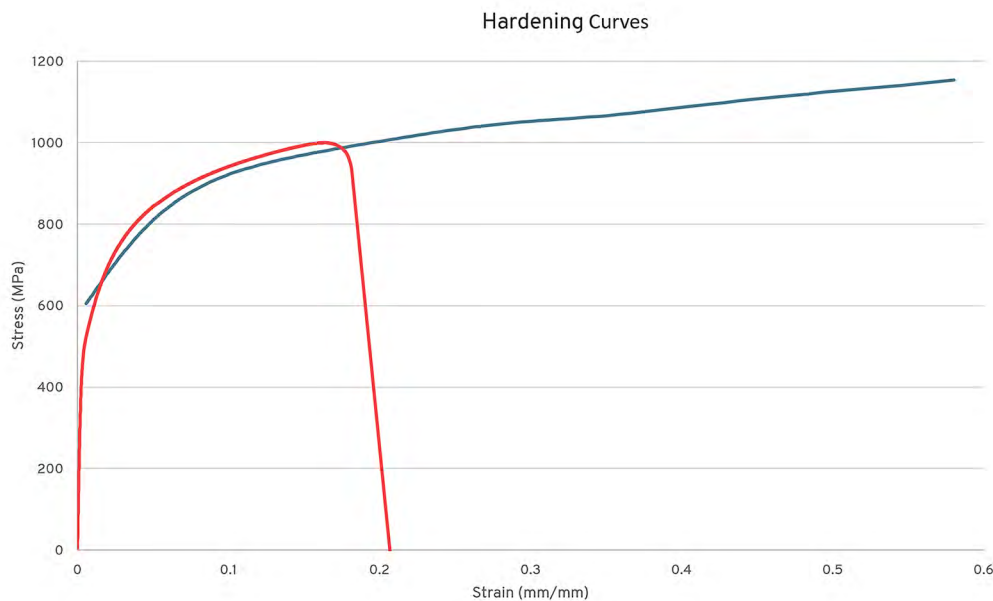


FIGURE 5 Flow stress data from tensile and bulge testing.

Forming limit diagrams (FLDs) are used to evaluate the formability of materials by analyzing the maximum major and minor strains at different strain paths using different sample shapes (Figure 6).

EWI incorporates digital image correlation (DIC) to measure the strain history during testing. The FLC represents the material's maximum deformation ability.

Another major formability issue associated with AHSS, sheared edge cracking, cannot be predicted using FLD because failure is observed below the FLC. Using hole expansion or half dome tests, the edge formability of a material can be studied. Edge cracking tests should replicate the shearing clearance of the production environment.

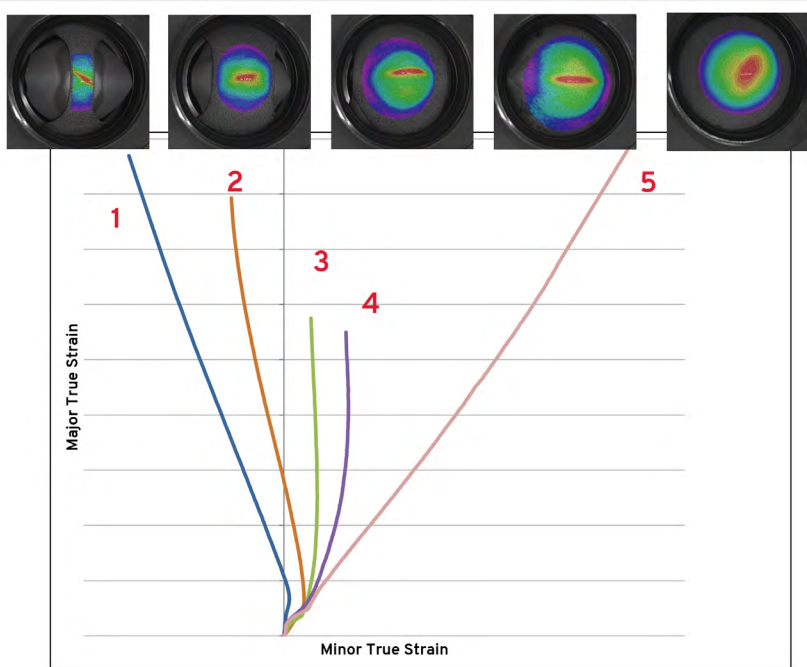


FIGURE 6 Nakajima samples are used to test the various strain paths that make up the FLC

The hole expansion test (HET) uses a conical punch to stretch a hole to failure. The through-thickness failure is then used to determine the hole expansion ratio. Based on the final diameter and thickness, the failure strain can then be calculated. Half dome testing (Figure 7) calculates failure strain using a DIC system, which measures strains and thinning at the onset of edge cracking. The edge cracking failure strain from HET or half dome testing can then be input into the simulation material card to predict cracking in FEA.

Once a material card is created using all the necessary data, the next step is to simulate a stamping process and validate the results with a stamped part. When simulating the stamping process, the new material card and press parameters - slide motion, blank holder force, and coefficient of friction values between the sheet and tooling surface - should to be included. When validating a simulation, the final formed strains of the physical part must be measured.

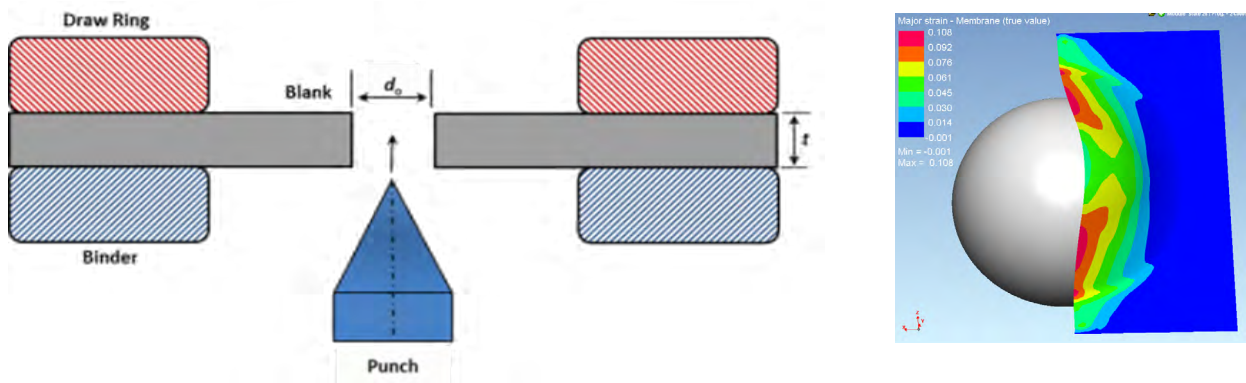


FIGURE 7 | Hole expansion test (left) and half dome test (right).

EWI uses a system called ARGUS that applies photogrammetry to measure an etched pattern on the sheet.

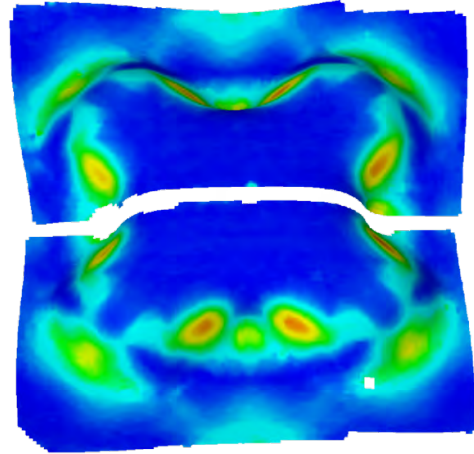
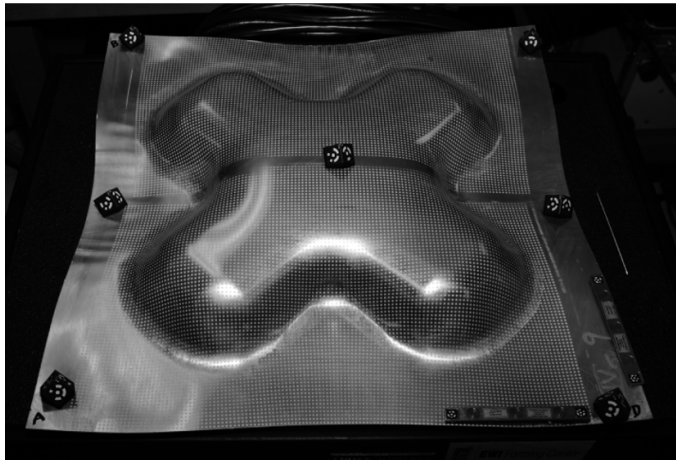
ARGUS delivers major strain, minor strain, and thinning as a 3D plot of the final formed part (Figure 8). These results provide the detailed strain data to critical areas that could lead to the quality issues. The FLC of the tested material can be imported into ARGUS to verify how close the part is to failure. The ARGUS strain analysis data can then be compared to the simulation results.

Confirming the part accuracy is also useful when validating simulation results. EWI uses a blue light scanner called ATOS Triple Scan to measure springback.

The scan data created from ATOS can be used to compare the 3D differences from the simulation data part. If the results match, the material card accuracy is confirmed. If the results do not match, the simulation input parameters must be evaluated.

Material data and friction are typical areas that require scrutiny. Typically friction is adjusted to match the draw-in measurements and unknown material properties can be adjusted to match strain values.

FIGURE 8 ARGUS Strain Analysis.



Conclusion

Comprehensive material testing is required to fully evaluate a new or challenging material for use in sheet metal forming applications. Tensile test data alone is not enough to evaluate how advanced materials will perform during the forming process. EWI recommends a combination approach using tensile, hydraulic bulge, FLC, and edge cracking (hole expansion and half dome) tests to determine the feasibility of a new or unusual material for successful forming.

Tom Feister, Applications Engineer, came to the EWI Forming Center in 2017 with a broad background in sheet metal forming, materials testing, lightweight materials evaluation, stamping, forging, and metal forming software. He honed his expertise in finite element analysis (FEA) in previous positions at KTH Parts, Scientific Forming Technologies Corporation (SFTC), and AutoForm Engineering. Tom specializes in developing forming processes through simulation and optimizing these process through DOE studies.

Laura Zoller, Project Engineer, specializes in processing, measuring, and analyzing sheet metal forming in the EWI Forming Center. She operates EWI's stamping presses, leads quality inspection testing, and conducts material formability tests and research on aluminum and steel sheet metal. Prior to joining EWI in 2017, Laura was a quality engineer at Honda of America.

Get Started

For more information on testing the formability of new sophisticated materials, talk to one of our experts by calling **614.688.5000**. You can also learn more about our sheet metal forming capabilities, the EWI Forming Center Consortium, and more technical resources.

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