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Designing a Uniaxial Tension/Compression Test for Springback Analysis in High-Strength Steel Sheet

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The property data and constitutive laws available for the complex high strength steels and aluminum alloys required for automotive light weighting are often limited, leading to inaccurate models of the mechanical behavior during sheet metal forming. The inability to reliably model this behavior, particularly at large strains, creates a significant obstacle that impedes the widespread incorporation of these alloys. Prediction of springback is one of the more difficult modeling challenges in sheet metal forming. Springback generally results from residual stresses produced by the complex loading during stamping, and tends to cause large spatial distortions in stamped parts after forming. Changes in the yield strength due to a directional dependence of the stress distribution (i.e., the Bauschinger Effect), is known to have a strong influence on springback. It has been generally attributed to an inherent directionality of the dislocation structures that accumulate at barriers and produce dislocation pile-ups and tangles within a deformed polycrystalline material. Hence, accurate predictions of formability require an accurate determination of the residual stress distribution in the sheet to properly compensate for springback.

New models and test methods are being developed to address these data needs and to improve the reliability of the numerical predictions. In particular, material models that are based solely on isotropic hardening are generally insufficient for springback prediction because real stampings undergo a combination of isotropic and kinematic hardening. Hence, property measurements under reversed loading are needed to determine the appropriate ratio of the isotropic and kinematic hardening and while several tests have been designed for this purpose, bidirectional, in-plane testing is the preferred method because it produces a homogeneous stress/strain distribution in the gauge area of the specimen. This enables a better assessment of the residual stresses and, ultimately, the springback that will occur during forming.

Many bidirectional test protocols have been developed; however, proper assessment of the lateral forces required to prevent buckling during compression and for compensation of the ensuing friction remains a considerable measurement challenge. Our approach addresses this issue by using two opposing piezoelectric actuators in closed-loop control to simultaneously apply and measure the forces on the anti-buckling guides. Each actuator is capable of applying up to 30 kN of force and can maintain position with an accuracy of ± 1 nm. With this design, the actuators can also fully retract the anti-buckling guides during the tensile segments of the load cycle and eliminate the contact with the specimen. During compression, the positions and corresponding lateral forces applied to the anti-buckling guides are sampled in real-time, enabling direct assessment of the local contact conditions. In addition, the uniaxial load is measured at both ends of the specimen, which enables direct monitoring of all the principal forces applied to the specimen throughout the test and improves the accuracy of the friction compensation. In addition, this approach allows for variability in the specimen shape, the amount of applied strain, and the strain rate.

Deforming a sheet metal specimen to large strains in both tension and compression requires careful design of the specimen, even with the use of anti-buckling guides. Extensive finite element analysis (FEA) was performed to identify a suitable specimen geometry and to refine the parameters of the test. Similar to the work by Boger, et al[1], our FEA model simulated the behavior of a DP590 steel specimen over a wide range of specimen parameters, such as gauge width, gauge length, and tab width. During specimen design, the simulations were performed with the lateral forces fixed at 10 kN. However, once the specimen geometry was adopted, we modified the model to apply a variable restoring force to more accurately represent the behavior of the sheet under 'real' test conditions. The data derived from the simulations were then used to predict the magnitude of the contact forces during compression. Fig. 1a shows a simulated fully reversed, stress-strain cycle and the ensuing response of a DP590 steel specimen. Fig. 1b shows the ε_{yy} strain distribution after the application of 0.1 tensile strain, followed by 0.1 compressive strain in the specimen. Note the model predicts that the specimen will fail before the cycle is complete, but the model only considered isotropic hardening in the specimen, so the addition of kinematic hardening is likely to predict a higher level of achievable strain before failure of the DP590. The data from the tension-compression test will determine the ratio of isotropic and kinematic hardening for the test material, which will then be used to correct the FEA model.

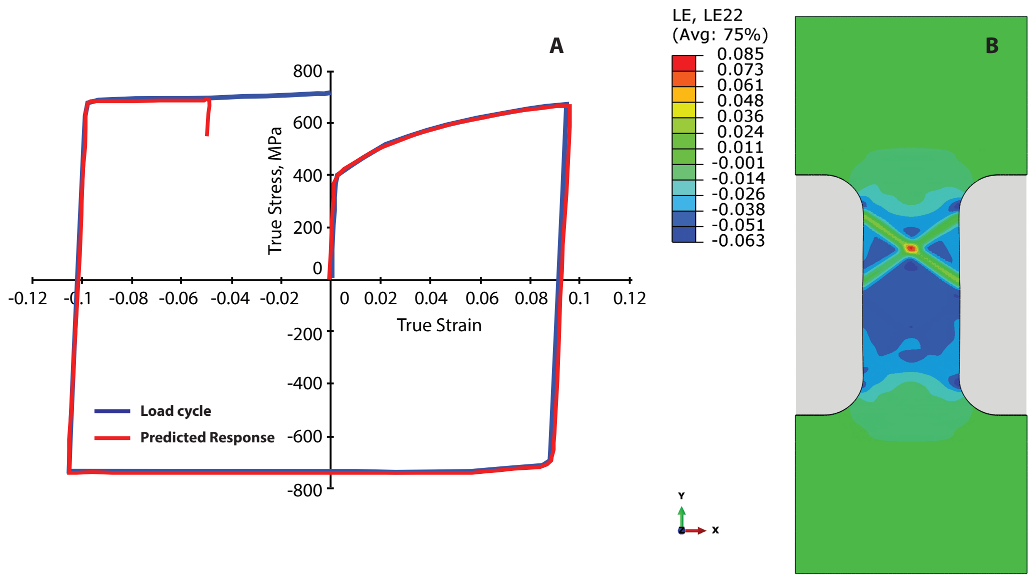

Figure 1. FEA simulation of DP590 steel in a fully reversed 0.10 strain cycle

Even though this test was specifically designed to provide much needed data for the automotive industry, it is also capable of addressing several materials-based questions that are difficult to answer with other approaches. That is, our goal is a measurement technique that improves our understanding of material behavior under complex loading schemes. Some of the materials issues we intend to explore include: a) Does the material behavior vary for different reversed loading schemes (i.e., does the strength of the Bauschinger Effect change), and if so, what mechanism or phenomenon is controlling the behavior (e.g., dislocation creation/annihilation[2]) and b) How do changes in grain size, initial pre-strain, and orientation with respect to the rolling direction of the sheet alter the behavior?

References

[1] R. K. Boger, R. H. Wagoner, F. Barlat, M. G. Lee, and K. Chung: 'Continuous, large strain, tension/compression testing of sheet material', *I. J. Plasticity*, 2005, **21**(12), 2319-2343.

[2] F. Yoshida, T. Uemori, and K. Fujiwara: 'Elastic–plastic behavior of steel sheets under in-plane cyclic tension–compression at large strain', *I. J. Plasticity*, 2002, **18**(5–6), 633-659.