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SHAPING & FORMING OF ADVANCED HIGH STRENGTH STEELS

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Advanced high-strength steels (AHSS) are of great interest to the transportation industry to help meet increasingly restrictive fuel economy and emissions regulations. Since the mid-1990s, the properties of steels used in automotive structures have changed dramatically, and in some cases the tensile strength levels have increased more than fivefold: current press-hardened grades achieve strengths of 1500 MPa or more relative to mild steel sheets with strengths of less than 300 MPa. New AHSS grades have a wide variety of sophisticated microstructures carefully designed to produce a desired combination of mechanical properties. As such, there are significant challenges in the understanding of microstructure effects on mechanical response of these steels during manufacturing and in service. To give a few examples, the effects of strain rate, predictions of springback, measurements of phase stability, and assessments of stretch flangeability have all become more challenging with increasing microstructural complexity. In addition, there are continuous efforts to further improve the properties of steel sheets, and density modification via alloying may allow for materials with similar strengths but decreased weight, further improving the specific strengths of sheet materials. Here, we have selected a set of articles that address some of the challenges associated with current AHSS, and also look into possible pathways for future grades.

In the first article, “Strain Rate Effect on Tensile Flow Behavior and Anisotropy of a Medium Manganese TRIP Steel,” by Rakan Alturk et al., the authors evaluate the effects of strain rates from quasi-static (0.005/s) to crash-relevant (500/s) in AHSS sheets that exhibit transformation-induced plasticity (TRIP) and yield point elongation. In addition, the relative effects of strain rate as a function of test orientation in the sheet are probed. They have found significant orientation effects on the strength, planar anisotropy, and normal anisotropy, showing the need to incorporate these effects into analyses of forming operations, in order to accurately predict material response and material condition after forming. Discussion of the possible mechanistic causes of this behavior supports their description of supplementary mechanical tests that are needed to more fully characterize the mechanical response of these complicated materials.

The authors of “Split-Ring Springback Simulations with Non-associated Flow Rule and Evolutionary Elastic-Plasticity Models,” use a combination of finite element modeling and split-ring springback experiments to further understand the use of anisotropic constitutive relationships to predict springback. Their analyses show that the inclusion of yield stress and planar anisotropy evolution, along with apparent modulus variations, are necessary for improved accuracy in the prediction of springback. This work highlights the increasing difficulty of predicting springback in AHSS, evaluating the response of a dual-phase DP490 grade consisting of approximately 0.07 volume fraction martensite (balance ferrite). The complex mechanical response of increasingly high-strength AHSS necessitates a deeper understanding of the effects of mechanical response on springback in order to produce components with desired geometries.

Another material response of interest in AHSS is the ability of sheets to resist fracture when edges are present and undergo deformation, commonly called stretch flangeability. The next two manuscripts, “Small-Scale System for Evaluation of Stretch-Flangeability with Excellent Reliability,” Jae Ik Yoon et al., and “Effects of Testing Method on Stretch-Flangeability of Dual-Phase 980/1180 Steel Grades,” by Mykal Madrid et al., contribute to the understanding of this material response by the

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development of a small-scale test for stretch flangeability and by examining the hole expansion ratio (HER) of DP980 and DP1180 grades as a function of test geometry and edge condition. Small-scale testing of stretch flangeability allows more rapid and economical assessments of material response, and the thorough combined experimental and modeling approach to develop the test resulted in a methodology that is reproducible and that reliably measures edge fracture resistance in a way that can be directly compared to full-scale hole expansion testing. Evaluations of very high-strength DP steels have shown that there are unexpected trends in HER as a function of strength. Here, the authors find that punch geometry and edge condition have significant effects on the stretch flangeability of high-strength DP steels, but common predictors of HER, such as yield and tensile strength, total elongation, strain hardening exponent, and normal anisotropy, may not be good indicators in these AHSS grades.

The authors of "Probing the Evolution of Retained Austenite in TRIP Steel During Strain-Induced Transformation: a Multi-Technique Investigation," by G.N. Haidemenopoulos et al., provide further understanding of retained austenite fraction measurement by comparing the use of x-ray diffraction, magnetic force microscopy, and saturation magnetization on a TRIP700 steel grade as a function of tensile strain. The multi-technique evaluation highlighted that the retained austenite grain size in this material decreases as a function of strain, supporting the concept that larger retained austenite grains have lower mechanical stability and transform at lower strains. These findings can be used to more accurately develop models of microstructure development during deformation, and to provide a fundamental understanding of morphology effects on phase stability that can be used to optimize the design of microstructures to tailor properties and meet desired mechanical response targets.

Finally, the use of alloying to reduce the density of steels is discussed in "An Overview of the Effects of Alloying Elements on the Properties of Lightweight Fe-(15–35) Mn-(5–12) Al-(0.3–1.2) C Steel", by Jia Xing et al. Once the strengths of AHSS are optimized, the only pathway to higher specific strength is to reduce density in steels while retaining the desired mechanical response. The authors provide a review of the current state of development in steels with significant weight fractions of aluminum and densities as low as 6.5 g/cm^3, a decrease of over 15%. Single-phase austenite or multi-phase ferrite–austenite microstructures are possible, and the primary strengthening mechanism is reported to be κ-carbide precipitation. Strain hardening occurs via shear band-induced plasticity, microband induced plasticity, and slip band refinement-induced plasticity, resulting in multiple pathways toward the design and optimization of the mechanical response of these materials as the understanding of alloying and processing effects develops.

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- "Strain Rate Effect on Tensile Flow Behavior and Anisotropy of a Medium Manganese TRIP Steel," Rakan Alturk, Louis G. Hector, Jr., C. Matthew Enloe, Fadi Abu-Farha, and Tyson W. Brown.
- "Split-Ring Springback Simulations with Non-associated Flow Rule and Evolutionary Elastic-Plasticity Models," Kijung Lee, Yumi Choi, Hongjin Choi, Jeong-Yeon Lee, and Myoung-Gyu Lee.
- "Small-Scale System for Evaluation of Stretch-Flangeability with Excellent Reliability," Jae Ik Yoon, Jaimyun Jung, Hak Hyeon Lee, and Hyoung Seop Kim.
- "Effects of Testing Method on Stretch-Flangeability of Dual-Phase 980/1180 Steel Grades," Mykal Madrid, Chester J. Van Tyne, Sriram Sadagopan, Erik J. Pavlina, Jun Hu, and Kester D. Clarke.
- "Probing the Evolution of Retained Austenite in TRIP Steel During Strain-Induced Transformation: a Multi-Technique Investigation," G.N. Haidemenopoulos, M. Constantinou, H. Kamoutsi, D. Krizan, I. Bellas, L. Koutsokeras, and G. Constantinides.
- "An Overview of the Effects of Alloying Elements on the Properties of Lightweight Fe-(15–35) Mn-(5–12) Al-(0.3–1.2) C Steel," Jia Xing, Yinghua Wei, and Lifeng Hou.