C. Die Face Engineering Project (DFEP) for Advanced Sheet Metal Forming (AMD 408[i])

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Contractor: U.S. Automotive Materials Partnership
Contract No.: DE-FC05-02OR22910

Objective

- The ultimate goal is to develop robust simulation technology to improve die design and die fabrication/processing so as to reduce manufacturing costs for all sheet-metal parts using lightweight metals such as advanced high-strength steels (AHSSs) and aluminum (Al). The project will demonstrate this goal by generating optimized sheet-stamping dies from computer-aided design (CAD) surfaces (from finite-element modeling (FEM) mesh) that compensate for springback while maintaining formability.
- The project will demonstrate that the simulation advances can eliminate the soft tool prototyping phase and, thereby, significantly reduce the die-tryout phase, with corresponding major reductions in costs and lead time for automotive components.

- The project deliverables include: (1) integrated product-process finite-element analysis (FEA) capability that will more accurately predict springback for both closures (>90%) and structural parts (~80%); (2) test results from simulations, panel trials and springback measurements that will be used to guide and validate the software development (done at private expense by vendors); and 3) capability to automatically and consistently generate a machinable CAD surface of acceptable quality from FEM meshes. The LS-DYNA engineering package is the team's preferred package for demonstrating the technology advances.

Approach

- The collaborating partners include Alcoa, DaimlerChrysler Corporation, Ford Motor Company/Volvo Cars Division, General Motors Corporation, US Steel, Livermore Software Technology Corporation (LSTC), and Technologies Research Corporation of the National Center for Manufacturing Sciences (TRC-NCMS) as Project Administrator.
- The approach has been to work with technology vendors and test laboratories to significantly improve the accuracy of material models for new high-strength, lightweight, sheet materials and to implement and validate the technology to analytically predict springback and formability for a broader range of closure and structural parts.
- The project tasks are being performed and reported in four main technology areas, and overseen by nominated expert team leaders:

  A. Numerical Technology

  B. Material Testing/Modeling

  C. Field Validation

  D. Surface Technology

Accomplishments

- Completed Springback Classification Study of closure and structural parts with information and results pooled from the DFEP team.
- Developed new algorithms (e.g., smooth contact) for better contact treatment and demonstrated improved stress calculation on benchmark parts that improves the efficiency and quality of springback predictions.
- Completed Common Die tryout experiments, and collected needed die and panel scan data for comparison to baseline forming and springback simulations.
- Completed Common Die baseline simulations using baseline FEM code and compared output with stamped AHSS and aluminum panels.
- Completed first-phase, mesh-to-surface morphing technology trials with three CAD vendors, and initiated second-phase improvement projects with one down-selected vendor.

Future Direction

- In the remaining project Year 3, an integrated product design-analysis-formability capability will be demonstrated that combines improved springback-simulation algorithms (material and surface contact) defined by the team and CAD-based die-face modification algorithms, which will be applied to the Common Die component geometry. A new die surface will be generated for tryout and a second set of structural panels formed and measured to validate the prediction and morphing technologies.
- A larger internal validation effort will be undertaken in Year 3 by the OEMs to industrialize "best practices" simulation standards and extend the integrated springback and CAD morphing technology to test additional challenging automotive parts.
- A cost-benefit analysis will be performed, comparing cost, quality and user-effort attributes of the improved simulation and tool-development capability with the conventional (baseline) die build and tryout process.

Introduction

Significant progress was made in this second year. To summarize, in Year 1, the DFEP team identified and classified part categories for which springback is still a challenge to predict (e.g., underbody parts), and then conducted new simulations utilizing significant LS-DYNA improvements (developed at vendor expense) and its linked modules. The end users tested these progressive numerical code enhancements, and identified the attributes of new material models (based on a literature study) needed to predict optimized tool geometry (in FEA mode) along with relevant sheet-material-formability process parameters. A Common Die structural rail geometry was selected to demonstrate technology advances.

In Project Year 2, several test laboratories were contracted to conduct measurements of critical formability and springback properties of AHSS and Al sheet materials being pursued for new vehicle lightweighting initiatives. Material properties determining isotropic and kinematic hardening, such as tension-compression, shear and bending-unbending, were measured and verified using the technical evaluation support of National Institute for Standards and Technology (NIST) experts. The resulting datasets were used to develop or refine several new material models for implementation in predictive computer-aided engineering (CAE) code.

Springback-prediction experiments were run to compare baseline simulations with experimental stamped panels of the Common Die part produced during initial die tryout. In addition, the DFEP team also collaborated with CAD software vendors to evaluate the feasibility of morphing directly from FEA meshes to smooth CAD surfaces. Six challenging automotive parts (two per OEM) with representative geometries were initially evaluated. Performance gaps in this technology were defined and improvement targets set for vendors to meet downstream numerical control (NC) surface-quality requirements.

Significant accomplishments are reported below under each sub-task heading.

Numerical Code Development:

- The DFEP Team conducted simulation experiments on an initial set of closure and structural parts to classify springback behavior, based on several end-user-defined computational and prediction-quality parameters. A consensus Springback Classification Table was developed that is being used to guide predictive-technology developments.
- Conducted extensive benchmark testing of new smooth-contact algorithms for improving geometric descriptions of the products and springback predictive accuracy in FEM. The effect of the number of elements on the tooling radius was studied using benchmark parts. Other studies have involved using different contact scale factors combined with initial coarse mesh, initial coarse mesh with smooth contact, and initial fine mesh with smooth contact.
- The team conducted modeling tests on a new element with improved through-thickness stress variations that may help improve springback prediction.
- Three new material models were formulated and implemented in the code with preliminary testing completed on benchmark parts.
- A follow-up study is underway to understand the impact of various numerical technologies on FEA computational efficiency and prediction accuracy. Different AHSS and Al sheet materials and binder forces have been used to test these new features on real production panel geometries.

Material Testing/Modeling

- Material modeling gap analysis and model development roadmap (prepared in Year 1) were used to drive new experiments and property measurement tasks in Year 2, in order to extract critical material parameters from data plots and to subsequently implement selected models into new FEM code. Candidate models included published, nonlinear, isotropic and kinematic hardening models such as the Chaboche, Vegter and Yoshida models.

- Material test laboratories in Poland, Germany and Japan (possessing domain expertise and proprietary test methodology or equipment)

were contracted for characterization, material testing and model fitting in order to develop a combined isotropic kinematic hardening model that (when implemented into numerical code) can significantly improve springback predictions.

Surface Development

The goal of the DFEP Surface technology development task is to assist the CAE/Stamping Development engineer to rapidly and robustly translate CAE die design (or modification information) directly into CAD data that can be used in machining dies. Year 2 highlights are discussed below.

- The DFEP team held individual technical reviews with each of three CAD vendors that performed Phase 1 morphing trials on six OEM-supplied component product data and target FEM meshes.
- Detailed mesh-to-CAD evaluation criteria were developed and a technical specification finalized.
- Based on the team's assessment of the most promising demonstrated morphing capability, in the second phase of CAD Surface R&D began in Year 2, the team worked with one down-selected vendor to continue more detailed evaluation of algorithmic, surface quality and computational efficiency improvements to commercial mesh-to-CAD software. Up to eleven parts will be tested in this phase. The goal is to develop NC quality die surfaces with minimum user intervention.

Field Validation

At the end of Year 1, a total of 36 Common Die (Figure 1) panels were formed at the team's die tryout facility for further study and specialized measurements in Year 2, including 9 gridded panels.

- The team completed strain reading of all 9 panels, followed by scanning of all draw panels, and then laser-trimmed selected panels for final springback measurements.
- Team members pooled the running of baseline LS-DYNA code and input decks to develop (for selected tryout cases) forming and simulation predictions, which were then compared with panel measurements.
- The team next plans to conduct simulations with the new code release on half-panels (Figure 2) to resolve discrepancies encountered in the comparison of scanned data to simulations.

Figure 1. Illustration of Common Die Panel, indicating 5 datum points.

Figure 2. Close-up of a half-sized D steel baseline panel formed on the Common Die.

[i] Denotes project 408 of the Automotive Metals Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development.