# I. Tribology

*Project Manager: Pat V. Villano*
*Auto/Steel Partnership*
*2000 Town Center Drive, Suite #320*
*Southfield, MI 48075-1123*
*(248) 945-4780; fax: (248) 356-8511; e-mail: pvillano@a-sp.org*

*Project Chairman: Alan Pearson*
*General Motors Corporation*
*Metal Fabricating Division*
*2000 Centerpointe Pkwy., Mail Code 483-520-042*
*Pontiac, MI 48341*
*(248) 753-2056; fax: (248) 753-2344; e-mail: alan.pearson@gm.com*

*Technology Area Development Manager: Joseph Carpenter*
*(202) 586-1022; fax: (202) 586-1600; e-mail: Joseph.Carpenter@ee.doe.gov*
*Field Technical Manager: Philip S. Sklad*
*(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov*

---

*Contractor: U.S. Automotive Materials Partnership*
*Contract No.: FC26-02OR22910*

---

## Objectives

- Conduct stamping simulation tests to study the effects of tribological conditions on the stamping performance of advanced high-strength steels (AHSS). Stamping performance in this project is defined as minimizing die wear and maximizing dimensional stability. The understanding of the contribution of lubricants to errors in springback prediction when using finite-element analysis (FEA) will also improve dimensional performance.
- Include these ultimate benefits:
  - Improve test procedure to simulate springback and die wear.
  - Improve control of springback and die wear.
  - Optimize lubricant/die combinations for AHSS.
  - Maintain common lubricants among automotive companies and steel suppliers.
  - Conduct a study to examine wear rates of different die materials.

## Approach

- Compare the die wear rate with various HSS, AHSS, and lubricants.
- Correlate other process indicators such as restraining force, temperature, and contact area to wear on the draw beads.
- Correlate the data with the friction test results from Phase 1.
- Build on the extended knowledge gained in Phase 1 and Phase 2. Phase 2 established a baseline of wear data from three sheet steel materials, and two lubricants, with one die material.

## Accomplishments

- Completed Phase 1 report “Enhanced Stamping Performance of High Strength Steels with Tribology.”
- Completed Phase 2 report “Effect of Stroke Length and Penetration on Die Wear.”

- Used steel coils of galvannealed AKDQ, HSLA340, and DP600 supplied by partner companies. The material is used in the wear tests for Phase 3.
- Collected data for the eight test conditions.
- Completed Phase 3 report "Enhanced Stamping Performance of High Strength Steels with Tribology—Report on Phase 3 Testing."

## Future Direction

- Develop wear rate model to predict die life.
- Gather wear test data to substantiate model.
- Correlate model with production data as AHSSs come into production.

---

## Progress Report

Phase 3 of this study examines die wear for three different sheet steel materials on three die surface treatments to understand how die life will be affected with advanced high-strength steels (AHSS).

Stamping die design, development, and buyoff represents a considerable portion of the cost and time in product development for the automotive industry. Yet, after the dies go into production, little is known of how die wear affects part quality and production costs. Because die wear is mainly a function of die temperature and contact stress, previous work by this project team suggests that die wear with AHSS will bring production issues to the forefront. Indeed, early experiences implementing DP500 and DP600 show that die wear will need to be addressed.

Findings in Phase 1 (2001) and Phase 2 (2002) of this project highlighted potential issues with the stamping of AHSS. Drawbead tests revealed much higher restraining forces and elevated temperatures with DP600 over aluminum-killed draw quality (AKDQ) and high-strength low alloy (HSLA). How will the higher contact stress and elevated part temperature associated with AHSS affect die life? How will part geometry be affected? What process changes such as lubricants and die treatments can be used to increase die life and improve process capability?

The Die Wear Test was developed by TribSys, Inc., to measure die wear at production volumes and rates. Phase 2 showed measurable and significant wear rates for different process variables (sliding distance and bead penetration). The Phase 3 plan was to compare die wear of DP600 with HSLA and AKDQ galvannealed sheet steels. For each test, one coil, or the equivalent of 9,000 parts, was processed.

Data collection and analysis on this scale of experiment poses many challenges. The experimentalist must balance the "purity" of the laboratory with the "reality" of the production environment. Environmental factors, test interruptions, and material variability are factors that are representative of production. These factors raise statistical variance and complicate analysis.

Temperature and restraining force data were gathered throughout the tests and compared to wear indicators on the dies. The die temperatures obtained should not be considered absolute measurements because many factors will affect heat buildup in a die. Rather, these data can be used to evaluate relative effects of changes in sheet materials and dies.

Restraining force was highest for the DP600 sheet, particularly on the flame-hardened dies where restraining force measurements were 27% greater than the AKDQ and HSLA. Die surface treatment had a significant effect on restraining force with the DP600 and HSLA showing opposite trends (see Figure 1). The opposite trends may be related to differences in the galvannealed coating. The HSLA (and AKDQ) galvannealed produced more powder on the dies, while the DP600 galvannealed coating tended to pickup, rather than form, powder. This difference would be a critical consideration when drawing conclusions from the results.

The higher restraining force was accompanied by a corresponding increase in sheet and die temperature. Interestingly, die temperature and strip exit temperature varied inversely. This was observed where poor heat transfer conditions prevented the

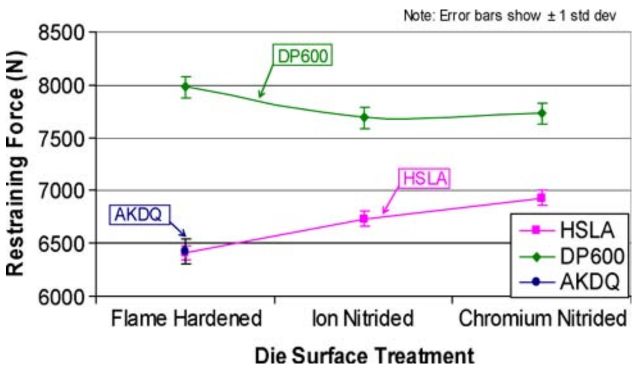


**Figure 1.** Average restraining force vs different die surface treatment and steel sheets.

heat in the strip from moving to the die. The resistance to heat transfer appeared to result from the chromium nitride coating (a ceramic) or zinc pick-up that prevented continuous contact of the sheet with the die.

Contact area on the strip and die were measured. Strip contact area measurements with the galvannealed coatings were difficult and unreliable. Die contact was clear, and significant differences in contact between the sheet material types were observed.

As strip strength increased, contact decreased (see Figure 2). This decrease has several sometimes opposite effects on lubrication and die wear:

1. Contact stress increases—increasing tendency for wear.
2. Heat transfer decreases—however local temperatures that drive thermal stress may increase and heat in part is not dissipated.
3. Lubricant performance should improve with the reduced sliding distance and the opportunity for lubricant replenishment.

The extended testing (18,000 parts) on the chromium nitrided dies (the best performing surface treatment) with the DP600 sheet shows the

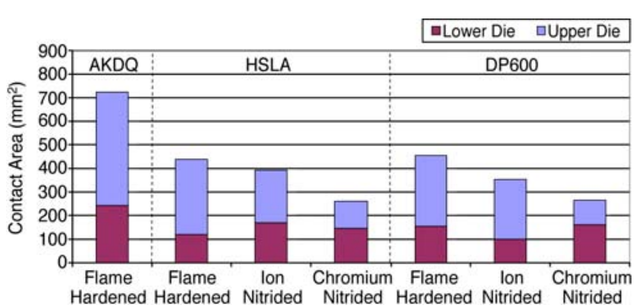


**Figure 2.** Contact area on die surface.

restraining force initially decreasing and then increasing after 14,000 parts (see Figures 3 and 4). This rise suggests the coating may be beginning to wear at this point. Further examination with the scanning electron microscope would confirm this hypothesis.

Strip curl is a good indicator of potential for sidewall curl and, in some cases, springback. The greatest variation in strip curl was between materials with DP600 showing much higher strip curl than either the AKDQ or the HSLA (see Figure 5). Strip curl varied throughout the tests with changing die conditions and could be related directly to changes in restraining force brought about by changes in die radius or friction. The most dramatic change was with the AKDQ on the flame-hardened dies where curl changed from a 600-mm radius to 300-mm radius. This change was attributed to the change in die radius as a result of wear. These results confirm findings in Phase 1 where strip curl in the drawbead simulator was observed and measured for a large number of materials, lubricants, and die surface treatments.

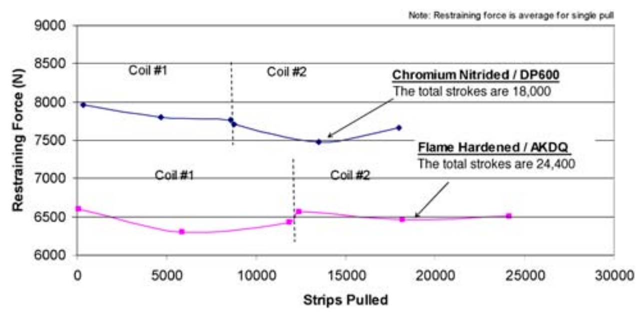


**Figure 3.** Extended die wear test—restraining force.

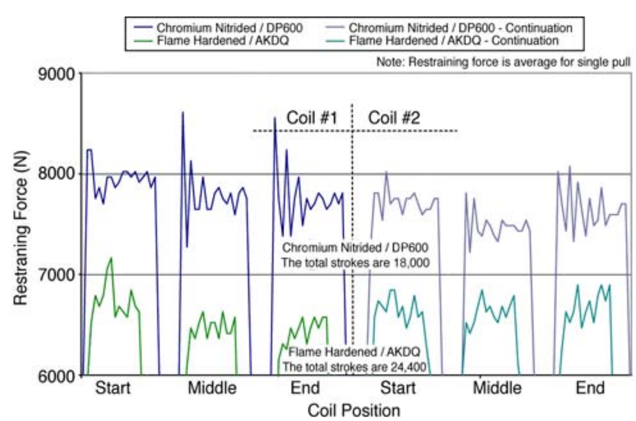


**Figure 4.** Extended die wear test—restraining force profiles.

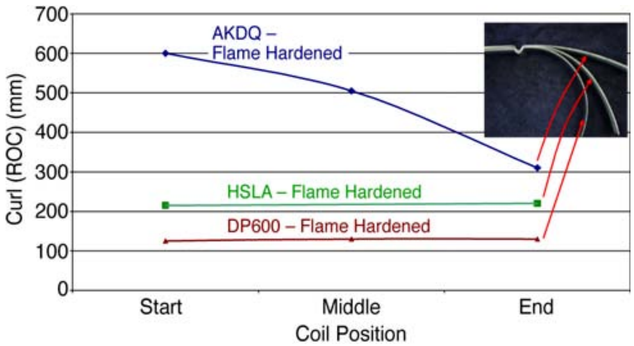


**Figure 5.** Strip curl with AKDQ, HSLA, and DP600 on flame-hardened dies.

Analysis of the data shows that die wear and process conditions with DP600 differs dramatically from HSLA and AKDQ (Figure 6 and Figure 7). This difference will affect AHSS implementation

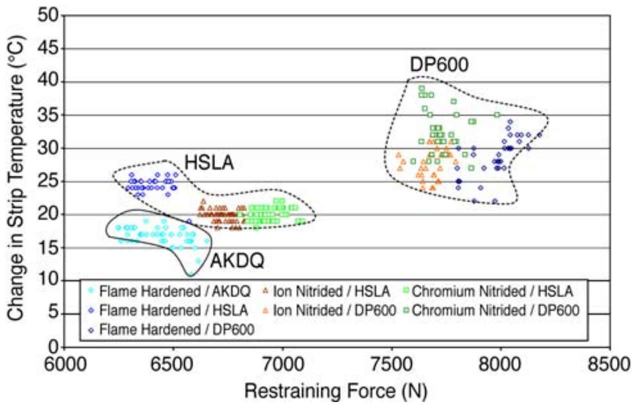


**Figure 6.** Restraining force vs the changes of strip temperature.

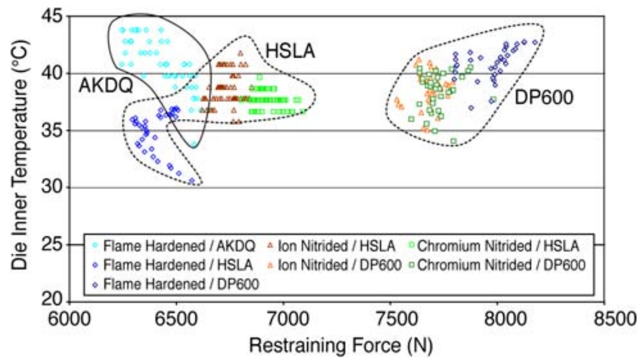


**Figure 7.** Restraining force vs die inner temperature.

from die design to production. Further, the analysis shows that die life, process capability, and part geometry will be affected by process factors such as sheet material choice, die material and surface treatment, and production run size.

The results of Phase 1 indicated that lubricant was a significant factor in process control. A logical question arises from Phase 3 results: how would choice of lubricant affect die life and process capability?

## Future Work

The plan for 2005 includes a study to investigate wear behavior of AHSS with the goal of developing a basic wear model. Key parameters have been identified, and the choice of die materials and coatings has been completed. The Department of Energy will examine 6 variables at 2 levels for a total of 16 tests.