Forming Trends in the Automotive Industry and Their Impact on Lubrication

The Drive to Lightweight Materials

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Introduction

New, lightweight materials are at the center of the global drive for improved vehicle fuel economy. These new materials require new manufacturing techniques, creating a challenge and an opportunity for lubricant manufacturers.

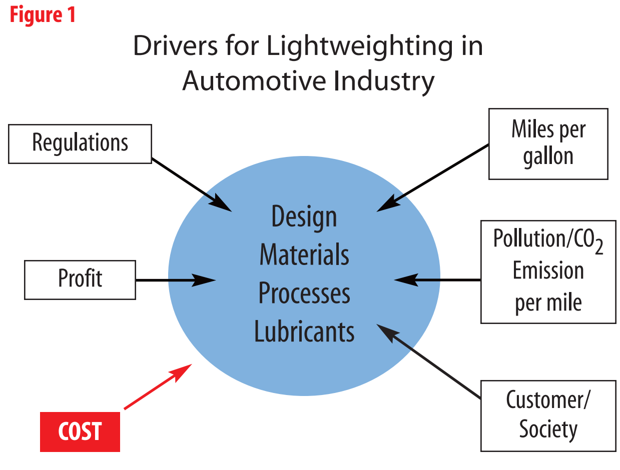
During Afton Chemical's Key Driver Seminar in May 2015, Dr. Taylan Altan, Director of the Center for Precision Forming at The Ohio State University, presented the following information on current industry initiatives and new test methods for selecting lubricants in the future.

Background

The automotive industry is increasingly emphasizing the use of lightweight materials in stamping, such as Advanced High Strength Steels (AHSS), Aluminum alloys, and carbon fiber composites. This trend presents new challenges and opportunities for suppliers of stamping lubricants and additives. The use of these materials requires not only detailed information about material properties but also new lubricant systems that are appropriate for forming them.

In selecting lightweight materials, the automotive designers, must consider several important factors including regulations, fuel consumption, pollution, customer satisfaction, crush resistance, and materials and processing costs **(Figure 1)**.

Figure 1



New Materials

New high-strength and lightweight materials, used extensively today in forming and stamping, include Advanced High Strength Steels (AHSS) and various Aluminum alloys. These materials are formed "cold," i.e. initially at room temperature or at elevated temperatures; for example, special steels are formed at 900 degrees Celsius and high-strength aluminum (Al) alloys (2000 and 7000 series) are formed at about 400 degrees Celsius. During stamping, depending upon the material and forming conditions, relatively large pressures and temperatures are developed at the sheet material interface.

During forming, the mechanical energy used for deformation is transformed into heat and temperature increase at the sheet/die interface. As a result the lubrication conditions are affected. For example, in deep drawing of a round cup (**Figure 2**), a relatively simple operation, temperatures of about 80 degrees Celsius are generated, due to plastic deformation and friction, when forming an AHSS, DP590 at moderate forming speeds **(Figure 3)**. In practical production operations, the temperature of the tools increases to reach 200 to 300 degrees Celsius, depending on material and stroking rate (strokes per minute) used in the process. Therefore, requirements on stamping lubricants, and needed additives, increase with increasing use of high-strength, low-weight materials.

Importance of Lubrication

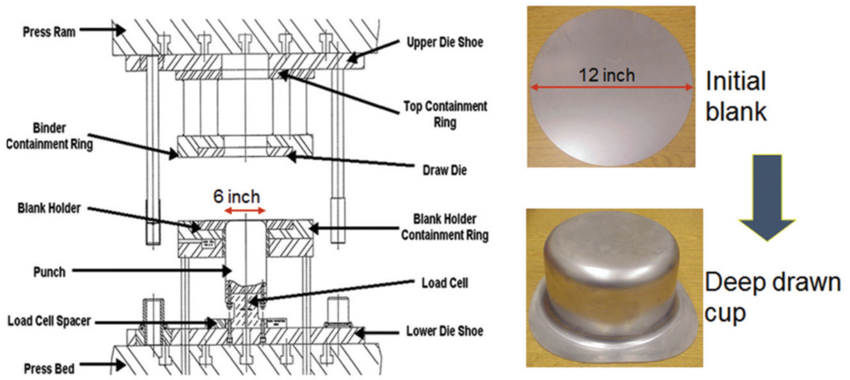
Lubrication plays an important role in stamping, as it reduces friction at the tool-workpiece interface. Reducing friction also reduces die and tool wear in large-volume production, which in turn increases tool life. It also allows smoother flow of the sheet material into the die cavity and reduces the energy and load required to form the part. At various locations in the stamping tool, the lubricant is expected to perform under various conditions of pressure, temperature, and sliding speed **(Figure 4)**, page 48.

With good lubrication, failures associated with wrinkling and premature fracture can be reduced or even prevented. It is extremely important to use a lubricant well-suited to the tool-workpiece interface and the process parameters.

Several types of lubricants are used in stamping, i.e. synthetic water-based and petroleum oil-based liquid lubricants as well as dry coatings, the latter especially in forming Al alloys. These lubricants use different types of additives such as emulsifiers, extreme-pressure additives, thickeners to alter viscosity, anti-foaming and antimicrobial agents, corrosion inhibitors, etc. From a very practical point of view, stamping lubricants must prevent corrosion, be easily removable prior to painting, and must not adversely affect welding.

Figure 2

Cup Drawing Test (CDT)

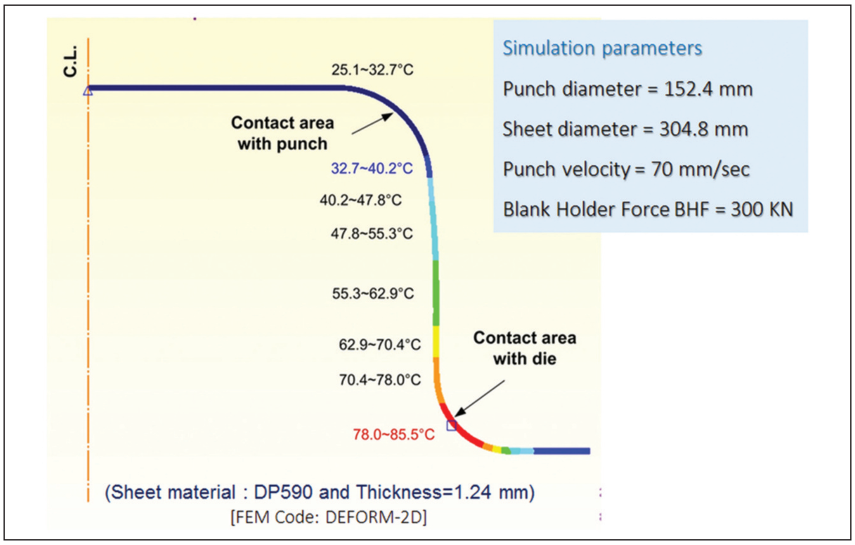


Schematic of Cup Drawing Tooling to evaluate the performance of Stamping lubricants.

Figure 3

FE (Finite Element) simulation of cup drawing

- Temperature distribution at the final drawn cup



Predicted Temperatures in a drawn round cup – sheet material DP980 (1.24 mm thick), FEM Code: DEFORM-2D.

Evaluation of Lubricants and Additives

As seen in **Figure 5,** (page 48) there are several commonly used tests to evaluate the performance of lubricants. Most of these tests are derived from standard tribology tests. While they are very useful in evaluating the basic properties of lubricants, the tests do not include the effects of processing in stamping, i.e. plastic deformation of the sheet that generates temperature and pressure at the tool/material interface.

• *Pin-on-disk Test*

The standard pin-on-disk test (**Figure 5a**) is used to determine wear in sliding material pairs, to evaluate lubricants, or to determine the coefficient of friction. Since the material pair is in contact with the same surface (which is not the case in sheet metal forming), some modified tests, such as the slider-on-sheet test (Figure 5b), were introduced in which tool material is in contact with fresh sheet material throughout the test.

Although the sliding speeds and normal forces (and therefore the contact pressure) can be adjusted to a level that is similar to sheet metal forming processes, the effect of plastic deformation is ignored in these tests. Therefore, the results may not emulate the progression of tool wear in sheet metal forming.

Analysis of the pin-on-disk test is standardized in ASTM G99, "Standard Test Method for Wear Testing with a Pin-on-disk Apparatus," with respect to volume loss. The volume loss can be measured directly from the specimen dimensions before and after the test, or it can be calculated from mass loss. If galling is present, volume loss may not reflect the tool wear, so this test method should not be used.

• *Strip-reduction Test*

In a strip-reduction test **(Figure 5c)**, the thickness of a metal strip is reduced while it slides against the tool material. This test is used to determine the galling tendency of a pair of materials (tool and sheet) and to evaluate lubricants. For the first application, the length of strip that could be drawn using a given tool material without galling is recorded. The results are compared within the evaluated tool materials to determine which tool material and coating are best for drawing and reducing a specific sheet material. The change in the surface finish of the tool after a reduction test can be used as a criterion for evaluating the performance of tool materials, coatings, and lubricants. Strip-reduction tests include the effect of plastic deformation. Nevertheless, the state of deformation is limited to thickness direction only. However, in deep-drawing operations, the deformation is biaxial, and the sheet material undergoes thinning, thickening, and bending. All of these operations may change the surface texture, which cannot be emulated by strip-reduction tests.

• *Strip Draw Test*

In the strip draw test **(Figure 5d)**, a lubricated strip is drawn through two flat dies that are pressed against the strip at a selected force and pressure. The force, necessary to draw the strip is measured and the Coefficient of Friction is calculated.

• *Draw Bead Test*

In this test, **Figure 5e,** a lubricated strip is drawn between a tool that emulates a draw bead that is used often in deep drawing low strength materials. The force needed to draw the strip is measured and it is an indication of the performance of the lubricant under bending conditions.

• *Twist-compression Test (TCT)*

In a twist-compression test (TCT), a rotating button (tool material) is pressed against a fixed metal sheet. Rotation speed and pressure may be adjusted to simulate the metal forming process. However, similar to the pin-on-disk test, the tool material is rotating on the same surface, not on a fresh sheet surface as in metal forming. Thus, surface conditions of sheet metal forming or stamping operations cannot be emulated. This test is used to evaluate lubricant performance very quickly and to determine threshold galling stress for given sheet and die materials. To evaluate lubricant performance, transmitted torque is recorded in time, enabling the calculation of the change in coefficient of friction (μ) in time. As a rule, when the coefficient of friction reaches 0.3, the test is stopped.

• *Cup Draw Test (CDT)*

In CDT, sheet blanks coated with a lubricant are drawn with different blank holder forces until fracture occurs in the drawn part. The lubricant that allows fracture-free drawing with the largest blank holder force is selected to be the "best" lubricant. Increasing blank holder pressure allows more severe and sensitive friction conditions at the flange areas of a drawn part. After the cup is drawn to a selected depth, the perimeter of the remaining flange is measured. The smaller this perimeter, and the larger the blank holder force, for a successfully drawn cup, the better is the lubricant.

Figure 4

Different tribological tests may be necessary to evaluate the performance of lubricants at various die locations

Region 1: flange deformation; Region 2, bending and unbending; Region 3, bending and stretching; Region 4, large friction with little deformation

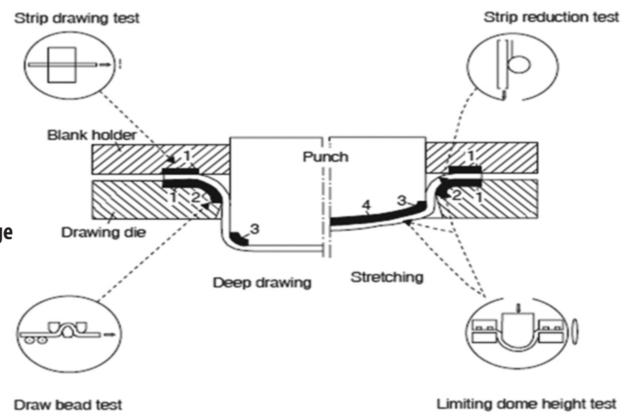
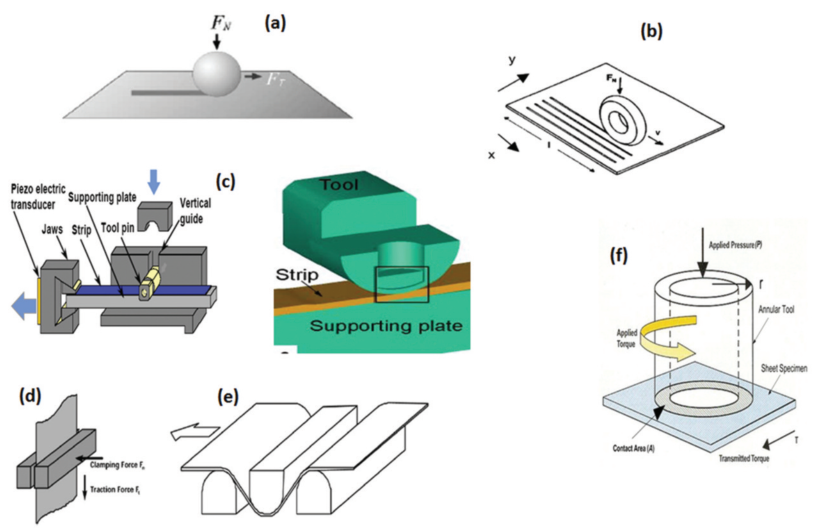


Figure 5

Tribological Tests Used to Evaluate the Performance of Lubricants:



a) Pin-on-disk, b) slider on sheet, c) strip reduction, d) strip draw, e) draw bead, (f) twist compression.

Trends and Conclusions

To increase crush resistance and to improve fuel consumption OEM's are using high strength steels (AHSS) and Al alloys (Hot Stamping of Mn-B steels, AHSS, use of servo drive presses, cold and warm forming of Al alloys).

It is necessary that laboratory tests used to evaluate the performance of lubricants (and additives) emulate the production conditions at material/tool interface (i.e. pressure, relative velocity, temperature, surface/coating conditions). Of the tests available for rapid and preliminary evaluation of lubricants, the Cup Draw Test, conducted to emulate the interface conditions (pressure, velocity, temperature) encountered in production, appears to give best results in evaluating the lubricity of various lubricants.

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