DEVELOPMENT OF TABLETOP INCLINED SLIDING TRIBOMETER FOR TOOLING OPTIMIZATION

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INTRODUCTION (BACKGROUND)

Die wear and friction coefficient are affected by
- contact pressure between sheet and die
- sliding speed and distance
- tool and sheet materials
- surface finish and coating

Wear mechanisms over the die-sheet (at microscopic scales)
- adhesive
- abrasive
- surface fatigue
INTRODUCTION (BACKGROUND)

Wear mechanisms over the die radius (primarily at macroscopic scales)
- Ploughing (everywhere, highest at 1 and 2)
- Galling (likely at initial portion)
INTRODUCTION (BACKGROUND)

Wear mechanisms over the die radius primarily

- Ploughing (over entire blank contact region, with two distinct zones observed within the overall contact region)
- Galling (at the severe contact pressure & sliding conditions which take place during the stamping process)

Therefore, degrees of ploughing and galling induced failures seem relevant to the die contacting radius (i.e., die-sheet contacting angles) during the stamping operating transient stage.
The die wear frictional energy can be readily obtainable from an incremental finite element stamping simulation package, such as LS-Dyna3d or Autoform.

\[ Friction\_energy = \int_{0}^{T} \tau_{\text{friction}} v_{\text{slide}} \, dt \]

Where:
\( \tau_{\text{friction}} \) is the frictional stress exerted to the die by sheet metal at one particular area (element).
\( v_{\text{slide}} \) is the sliding velocity of the sheet metal.
\( t=0 \) beginning of the forming cycle;
\( t=T \) end of the forming cycle

Both the software LS-Dyn3d and AutoForm are being used at an OEM for the Forming Simulations.
AUTOFORM DIE WEAR PREDICTION

Die Wear Simulation was used on two dies to run high strength steels: Cowl Side Inner RH & LH and Front Tunnel Center

The Die Wear Simulation showed both panels will have high localized die wear on radii. These issues will have to be addressed before construction.
Friction Work (N-mm/mm²): >100

A C-Pillar Reinforcement
Lower Post Die Wear
Simulation Results

Post
AUTOFORM DIE WEAR PREDICTION OF DIE CAVITY

A C-Pillar Reinforcement
Upper Cavity Die Wear Simulation Results

Friction Work (N-mm/mm²): 100 ~ 433
OBJECTIVE

To develop a table-top inclined sliding tribometer
- change contact angles of die material/metal sheet from 0 to 20 degrees
- contact pressure from 0 to 2 GPa
- sliding stroke distance from 0 to 100 mm
- The instrument can have an index stage movement so that the sliding wear track is generated on a fresh metal sheet surface in each sliding stroke
- A data acquisition system can record contact load, friction force and sliding distance
- Severe wear and galling occur when the COF is significantly increased
- The wear behavior of die materials and metal sheets can be observed afterward
- This information is important for better understanding wear behavior at different contact angles and quite valuable for simulation of metal forming
# TABLE-SIZED FRICTION WEAR TESTER DESIGN

1. Loading/Sensor Module
2. Frame Structure Module
3. X/Y/Z Moving Module
4. Motors and Control Module

**Parameters of tribometer**

- X index range: up to 500mm
- Y slide distance variable: (100mm or 200mm)
- Inclined Angle: 0-20 degree adjustable
- Slide Velocity: 0-100mm/s
- Slide line spacing: 1-5mm
- Z axis normal load: 0-800N
A/SP STO Team decides to use this version of design (stronger to hold the bending forces on corners)
Many modifications have been done from conception design to production manufacturing.
TABLE-SIZED FRICTION WEAR TESTER DESIGN

Inclined/Angled Contact between Die and Sheet Surfaces during initial portion of stamping process
(transient contact stage – mainly responsible for the galling wear)

Normal contact
Inclined contact
(larger shear force/ploughing force or tensile stress behind indenter for hard coating cases)
TABLE-SIZED FRICTION WEAR TESTER
(INTEGRATED)

Test Stop Conditions:
COF above: 1.2
COF increase (%): 150
Samples for initial COF: 10
CONTROL SYSTEM BLOCK DIAGRAM – TOUCH SCREEN PC

Automatic Friction Tester

Friction Tester Status
- X axis motor connected, position 125.2 mm
- Y axis motor connected, position 25.2 mm
- Z axis motor connected, position 5.2 mm
- Y axis load cell connected, force 25.2 N
- Z axis load cell connected, force 125.2 N

Configuration page updated:
For user to change test parameters. All the settings will be saved and automatically loaded next time. If needed, multiple settings can be saved.

The user can set 1 or 2 home (starting) positions.

Set Up | Test | Report | About
--- | --- | --- | ---
Z axis Force (N) | 500.0 |  |
Z axis Travel Distance (mm) | 50.0 |  |
Z axis Travel time (s) | 3.1 |  |
Y axis Travel Distance (mm) | 100.0 |  |
Y axis Travel Time (s) | 1.0 |  |
X axis Spacing (mm) | 10 |  |
Test Cycles: | 35 |  |
Repeat Cycles: | 5000 |  |
- Lift Up Friction Head
- One Direction
- Two Directions
- Enable 2nd Home Position

Save Settings | Load Settings

Test Sample X position (mm): 10.0
Test Sample Y position (mm): 10.0
X dimension (mm): 100.0
Y dimension (mm): 100.0

Home 1 Position Adjustment:
- X axis Position (mm): 25.0
- Y axis Position (mm): 20.0
- Z axis Position (mm): 23.0

Home 2 Position Adjustments:
- X axis Position (mm): 25.0
- Y axis Position (mm): 150.0
- Z axis Position (mm): 23.0
SLIDING WEAR TEST RUN

Metal sheet (DP980 bare) provide by A/SP

Counterpart materials: Steel ball (SAE 52100, hardened HRC 60)

Sliding Wear Test Run:
- 200N normal load,
- 100mm each wear track length,
- 3 mm line spacing,
- 100 mm/s sliding speed
SLIDING WEAR TEST RUN

Stage 1: Stable lower friction
Stage 2: Increasing friction
Stage 3: High friction
Galling starts at point X

Galling point “X” is quite dependent on uniformity of metal sheet surface conditions, particularly related to oil/lube conditions on the sheet surfaces.

Three tests:
- 88 wear tracks on sheet 1 continuously (8800mm) +
- 88 wear tracks on sheet 2 continuously (8800mm) +
- 54 wear tracks on sheet 3 continuously (5400mm)

\[ E = (\text{Friction force}) \times (\text{Sliding distance}) \]
## SLIDING WEAR TEST RUN

Optical microscopy images of wear tracks on steel sheets

**Wear track #1**
- at initial stage

- | location | 1 | 2 | 3 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>width (mm)</td>
<td>0.48</td>
<td>0.55</td>
<td>0.54</td>
</tr>
</tbody>
</table>

**Wear track #2**
- before galling

- | location | 1 | 2 | 3 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>width (mm)</td>
<td>0.58</td>
<td>0.58</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**Wear track #3**
- when galling

- | location | 1 | 2 | 3 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>width (mm)</td>
<td>0.79</td>
<td>0.85</td>
<td>0.78</td>
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</tbody>
</table>
SLIDING WEAR TEST RUN

Wear track #1 at initial stage

Wear track #2 before galling

Wear track #3 when galling

SEM images of wear tracks on steel sheets
SLIDING WEAR TEST RUN

Counterpart balls

<table>
<thead>
<tr>
<th>Test</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear scar surface area A (mm^2)</td>
<td>0.81</td>
<td>0.96</td>
</tr>
<tr>
<td>Volume loss (mm^3)</td>
<td>7.06E-4</td>
<td>9.93E-4</td>
</tr>
</tbody>
</table>

Sliding energy density: 
= W/A (Sliding energy / Area)
SLIDING WEAR TEST RUN

Stress and contact analysis at a load - example

200 N normal load, 15 mm steel ball

<table>
<thead>
<tr>
<th></th>
<th>steel/steel</th>
<th>steel/Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Hertzian contact pressure [P_{max}]</td>
<td>2025.4 MPa</td>
<td>1473 MPa</td>
</tr>
<tr>
<td>Max shear stress [T_{max}]</td>
<td>627.9 MPa</td>
<td>456 MPa</td>
</tr>
<tr>
<td>Depth of max shear stress [z]</td>
<td>0.104 mm</td>
<td>0.122 mm</td>
</tr>
<tr>
<td>Circular contact area diameter [2a ]</td>
<td>0.434 mm</td>
<td>0.509 mm</td>
</tr>
</tbody>
</table>
PREDICTION OF NUMBER OF PARTS THAT CAN BE STAMPED BEFORE GALLING

SAE 52100 steel (Die material) / DP980 sheet (as-received, no new lube)

Friction Work (N-mm/mm²): 100 ~ 433

E = (Friction force) x (Sliding distance)

Number of stamped parts possible before galling at X point:
At stress density 400 N-mm/mm²: \((1600000 \text{ N-mm} / 0.96 \text{ mm}^2) / (400 \text{ N-mm/mm}^2)\)

= \(~ 4000 \text{ parts}\)

Better die materials, hard coatings, lube, and lower stresses would increase the number of stamped parts before galling.
SUMMARY ON DESIGN/MANUFACTURING AND OBSERVATIONS OF TEST RUN:

1. Tester has been successfully designed and manufactured
2. Tester can measure coefficient of friction and determine the galling with sliding distances
3. Tester can be used to investigate friction coefficient change with sliding energy
4. Tester can determine the critical sliding energy when the galling occurs
5. The project has studied the typical wear tracks/scars on metal sheets and counterpart balls after galling
6. Each test generates large amount of data which needs post-data treatment
HOW TO USE THE TRIBOMETER (TO BE PROPOSED):

To determine coefficient of friction
To establish sliding energy database for different die materials and coatings
To understand wear behavior of different die material surfaces vs different strength graded steel sheets (such as AHSS, UHSS & 3rd Gen steels).
To understand wear behavior of different heat treated or coated die surfaces vs different galvanized steel sheets.
More importantly, determine sliding energy density (W) of each die material and coating for FEA simulation:

\[ W = \text{Stress} \times \text{(Sliding distance)} \]

W – corresponding to die materials and treated or coated surfaces
   (consider it as a materials property – to be determined the tribometer)
Stress – related to die design and metal strength grades
Sliding distance – related to number of parts to be stamped
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