MULTI-LEVEL MATERIAL CARDS FOR SHEET METAL FORMING SIMULATIONS

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OUTLINE

1) Introduction

2) Simulation Input
   a) Material Card
   b) Process Data

3) Multi-Level Material Cards

4) Experimental Validation with 3rd Gen 980

5) Conclusions and Future Work
INTRODUCTION - BMF

Founded by Dr. Eren Billur in 2015. Located in Ankara and employs 3 engineers.

Consulting, engineering, training and simulation services around sheet metal forming processes and different sheet metal grades.

Core-competence: Hot stamping of steel and aluminum, new generation AHSS.

Customers from USA, Germany, Japan and China accounting over 60%.

«Cutting Edge» column in Metalforming Magazine since 2020

Contribution to WorldAutoSteel’s AHSS Guidelines.
INTRODUCTION - COŞKUNÖZ

Founded in 1968 as one of the first tier 1 suppliers and die makers in Turkey.

CKM was formed in 1983 as the die maker of the group.

The group owns a total of 5 companies around the globe only in automotive sector (a total of 12 with others).

Supplies parts and dies to numerous OEM’s around the globe.

One of the most advanced R&D facilities in metal forming research in Turkey.
### SHOP FLOOR VS. SIMULATION

<table>
<thead>
<tr>
<th>Factor</th>
<th>Shop Floor</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet metal properties</td>
<td>Complex</td>
<td>Simplified</td>
</tr>
<tr>
<td></td>
<td>Not constant through the coil, or coil-to-coil</td>
<td>Assumed constant within the coil and between coils</td>
</tr>
<tr>
<td>Press speed</td>
<td>Not constant</td>
<td>Assumed constant or neglected</td>
</tr>
<tr>
<td>Friction (tool-sheet)</td>
<td>Dependent on: oil quantity, surface roughness, contact pressure, sliding velocity, average temperature.</td>
<td>Typically considered constant – recently tribology add-on’s are used.</td>
</tr>
<tr>
<td>Temperature</td>
<td>Increases due to heat generation</td>
<td>Typically considered constant</td>
</tr>
<tr>
<td>Tool and press</td>
<td>Elastic</td>
<td>Considered rigid</td>
</tr>
</tbody>
</table>

Ref: Roll 2008
In the automotive industry, the most common method for simulation is:

- **Receive a material card from the material supplier or the OEM**
  - Considered constant for different coils, head to tail!

- **Assume constant friction, neglect press speed,…**
  - In reality, press Strokes per Minute – SPM, affects part quality (whether it be wrinkles, splits or springback).
  - Link-motion and servo-drive presses offer significant advantages, which would be neglected.

### Material Card

<table>
<thead>
<tr>
<th>Material Card</th>
<th>Level 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardening Curve</td>
<td>Supplied</td>
</tr>
<tr>
<td>Yield Locus</td>
<td>Supplied</td>
</tr>
<tr>
<td>FLC (or TFC)</td>
<td>Supplied</td>
</tr>
<tr>
<td>Strain Rate / Temperature dependent data</td>
<td>Typically not included</td>
</tr>
<tr>
<td>Kinematic Hardening</td>
<td>Typically not included</td>
</tr>
<tr>
<td>Failure / Fracture Max Edge Strain</td>
<td>Typically not included</td>
</tr>
</tbody>
</table>

### Process

<table>
<thead>
<tr>
<th>Process</th>
<th>Level 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Model</td>
<td>Constant</td>
</tr>
<tr>
<td>Press</td>
<td>Neglected</td>
</tr>
</tbody>
</table>
Lowest Cost and fastest:

1) Requires 3-direction tensile tests (a minimum of 3 repetitions is advised)

2) DIC is advised (at least in RD)

3) Mixed model extrapolation is advised. (Swift/Hockett-Sherby, Hollomon/Voce or similar)

4) Plastic strain ratio (r-values) must be recorded, (Both for yield locus and FLC estimation)
HARDENING CURVE

1.5 mm Uncoated 3rd Gen 980

3 repetitions in 3 directions

Shown here: Rolling direction
HARDENING CURVE

1.5 mm Uncoated
3rd Gen 980

Combined
Swift/Hockett-Sherby
model
In low-level cards, FLC can be generated using built-in macro's, using:

1) $A_{80}$ total elongation values,
2) $r$ – plastic anisotropy coefficients.
In low-level cards Hill 48 is the easiest to use.

This model is not advised for materials with r<1.

3rd Gen 980 tested had all r values less than 1!
In addition to Level 1:

1) Strain rate sensitivity (m-value) is determined with at least 3 tensile tests at different strain rates.

2) The press stroke-time curve is modeled.

Possible improvement:

If material itself may have SPM-related problems.

Real SPM optimization may require friction and thermal data!
3 different strain rates were tested.

Constant m-value fit was done.

\[ \sigma = \sigma_0 \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)^m \]
Without strain rate, and friction model, there would be no difference between these!
LEVEL 3

<table>
<thead>
<tr>
<th>Material Card</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardening Curve</td>
<td>Supplied</td>
<td>Test-data</td>
<td>Test-data</td>
<td>Test-data</td>
</tr>
<tr>
<td>Yield Locus</td>
<td>Supplied</td>
<td>Only Hill 1948</td>
<td>Only Hill 1948</td>
<td>Bulge Test</td>
</tr>
<tr>
<td>FLC (or TFC)</td>
<td>Supplied</td>
<td>Estimated</td>
<td>Estimated</td>
<td>Experimental</td>
</tr>
<tr>
<td>Strain Rate / Temperature dependent data</td>
<td>Typically not included</td>
<td>Not included</td>
<td>Strain rate tested</td>
<td>Strain rate tested</td>
</tr>
<tr>
<td>Kinematic Hardening</td>
<td>Typically not included</td>
<td>Not included</td>
<td>Not included</td>
<td>Not included</td>
</tr>
<tr>
<td>Failure / Fracture Max Edge Strain</td>
<td>Typically not included</td>
<td>Not included</td>
<td>Not included</td>
<td>Not included</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Model</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>f (V, P)</td>
</tr>
<tr>
<td>Press</td>
<td>Neglected</td>
<td>Neglected</td>
<td>Modeled</td>
<td>Modeled</td>
</tr>
</tbody>
</table>

In addition to Level 2:

1) Yield locus is improved with bulge test: BBC2005 or Vegter Lite.
2) Experimental FLC (based on ISO 12004).
3) Friction tests are conducted to have friction coefficient as a function of contact pressure (p) and sliding velocity (v).
FRICTION TESTS @ COŞKUNÖZ

![Friction Coefficient vs. Sliding Velocity Graph]

- **P = 15 MPa**
- **P = 30 MPa**

*Graph showing friction coefficient (µ) against sliding velocity (V_{rel}) in mm/s.*
In addition to Level 3:

1) Unloading modulus changes with plastic strain.

2) Bauschinger effect and transient behavior is modelled using Yoshida-Uemori model.

Possible Improvement:

1) Significantly improved springback predictions.
Load-unload tests are done to experimentally determine `unloading modulus` as a function of plastic strain.
Load-unload tests are done to experimentally determine ‘unloading modulus’ as a function of plastic strain.

This data is then fit to a “Modulus Decrease Model” proposed by Yoshida, et. al.
TENSION-COMPRESSION TESTS

Starts just like a tensile test.
Continues like a load-unload test.

Until this point can be done in any universal tensile test machine, as there will be no compressive force and risk of buckling.
TENSION-COMPRESSION TESTS

This part requires:

- Special grips to handle compressive forces
- Anti-buckling device
EXPERIMENTAL VALIDATION

S-shape to model stretch and shrink flanging

Modified S-shape for further thinning the material
SIMULATION VS. EXPERIMENT


3-D Visual scans are done after OP15 and OP25 to compare with the simulation.

Circle grid analyses were also done.
Level 0 – Material card from the steel mill

Only 32% of the pre-selected points have less than 0.5 mm deviation between simulation and experiment. About 48% of the points have less than 1 mm deviation.
Level 0 – Material card from the steel mill

Level 4 – Material card with Yoshida-Uemori model.

About 60% of the points have less than 0.5 mm deviation.

Almost 94% of the points have less than 1 mm deviation.
FUTURE WORK

1) Comparison of minor and major strain distribution,

2) Splitting the part with increased Blank Holding Force (BHF) – trying to estimate the splitting BHF tonnage in simulation.

3) SPM-effects will be further investigated.
# FUTURE WORK – LEVEL 5

<table>
<thead>
<tr>
<th>Material Card</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
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</thead>
<tbody>
<tr>
<td>Hardening Curve</td>
<td>Supplied</td>
<td>Test-data</td>
<td>Estimated</td>
<td>Test-data</td>
<td>Strain rate tested</td>
<td>Yoshida-fit</td>
</tr>
<tr>
<td>YL</td>
<td>Supplied</td>
<td>Only Hill 1948</td>
<td>Estimated</td>
<td>Only Hill 1948</td>
<td>Strain rate tested</td>
<td>Yoshida-fit</td>
</tr>
<tr>
<td>FLC (or TFC)</td>
<td>Supplied</td>
<td>Estimated</td>
<td>Strain rate tested</td>
<td>Bulge Test</td>
<td>Experimental</td>
<td>Bulge Test</td>
</tr>
<tr>
<td>Strain Rate / Temperature dependent data</td>
<td>Typically not included</td>
<td>Strain rate tested</td>
<td>Experimental</td>
<td>Strain rate tested</td>
<td>Strain rate tested</td>
<td>Experimental</td>
</tr>
<tr>
<td>Kinematic Hardening</td>
<td>Not included</td>
<td>Not included</td>
<td>Strain rate tested</td>
<td>Yoshida-Uemori</td>
<td>Yoshida-Uemori</td>
<td>Yoshida-Uemori</td>
</tr>
<tr>
<td>Failure / Fracture Max Edge Strain</td>
<td>Not included</td>
<td>Not included</td>
<td>Not included</td>
<td>Not included</td>
<td>Not included</td>
<td>Diabolo Test or similar</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Process</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Model</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>f (V, P)</td>
<td>f (V, P)</td>
<td>TriboForm Plug-in</td>
</tr>
<tr>
<td>Press</td>
<td>Neglected</td>
<td>Neglected</td>
<td>Modeled</td>
<td>Modeled</td>
<td>Modeled</td>
<td>Modeled</td>
</tr>
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</table>
FUTURE WORK

1) Temperature effects

2) Coil-to-coil, head-to-tail variation
CONCLUSIONS

• Full Material and process characterization may be time consuming and costly. Depending on the phase of the project, different levels of simulations may be developed.

• Springback modeling can be improved significantly with tension-compression tests and decaying unloading modulus.

• SPM optimizations may require thermal considerations.

• Digital twin of the coil / or an on-line measurement is required to handle coil-to-coil and intra-coil variations.
FOR MORE INFORMATION

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