Process Simulation of Resistance Spot Welding

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Multiphysics in LS-DYNA
17.03.2014
Contents

- coupled mechanical and thermal solvers
  - heat source models

- coupled mechanical, thermal and electro-magnetic solvers
  - motivation, aim of the project
  - model setup, LS-DYNA v7.x - *EM cards
  - model parameter
  - example of a fully 3d process simulation of resistance spot welding
  - challenging problems
Types of welding
coupled mechanical and thermal solvers

Thermal
- Implicit
- Double precision

Temperature

plastic work

Mechanical
- Implicit
- Double precision
GOLDAK’s Double Ellipsoidal Power Density Distribution

- definition of the heat source in LS-DYNA with *BOUNDARY_THERMAL_WELD
- relative movement of heat source and parts
Verschiebung \( u_z \) [mm]  \( t=33.9 \text{ s} \), Darstellung 10-fach überhöht

Time = 33.908
Contours of Z-displacement
\[ \text{min}=-0.609782, \text{at node}\#7557 \]
\[ \text{max}=0.246563, \text{at node}\#23663 \]
max displacement factor=10

Fringe Levels
3.933e-01
2.731e-01
1.530e-01
3.288e-02
-8.725e-02
-2.074e-01
-3.275e-01
-4.476e-01
-5.677e-01
-6.879e-01
-8.080e-01
LS-DYNA: Deformation (t=499.0 s)

Verschiebung u_z [mm]  t=499 s, Darstellung 10-fach überhöht

Time = 498.4
Contours of Z-displacement
min=-0.738878, at node # 14352
max=0.160208, at node # 6528
max displacement factor=10
LS-DYNA: Deformation (t=5000. s)

Verschiebung u_z [mm]  t=5000 s, Darstellung 10-fach überhöht

Time = 5000
Contours of Z-displacement
min = -0.807991, at node# 14362
max = 0.189084, at node# 6528
max displacement factor = 10

Fringe Levels
3.933e-01
2.731e-01
1.530e-01
3.288e-02
-8.725e-02
-2.074e-01
-3.275e-01
-4.476e-01
-5.677e-01
-6.879e-01
-8.080e-01
Types of welding
coupled mechanical, thermal and electro-magnetic solvers
Analysis of the welding process

$R_1, R_7 = \text{Electrode resistance}$

$R_2, R_4, R_6 = \text{Contact resistance}$

$R_3, R_5 = \text{Material resistance}$

$F = \text{Electrode force}$

$I = \text{Welding current}$

[greitmann2013]
coupled mechanical, thermal and electro-magnetic solvers

**EM**
- BEM (Air)
- FEM (Conductor)
- Implicit
- Double precision

**Thermal**
- Implicit
- Double precision

**Mechanical**
- Implicit
- Double precision

- Joule heating
- Temperature
- Forces
- Temperature
- plastic work
- Displacements

[LSTC2013]
coupled mechanical, thermal and electro-magnetic solvers
LS-DYNA - Resistance Welding Simulation

- Double precision
- Fully implicit
- 2D axisymmetric solver / 3D solver
- **strongly coupled mechanical-thermal-EM solver**
- Solid elements for conductors. Shells can be isolators.
- SMP and MPP versions available
- Dynamic memory handling
- Automatically coupled with LS-DYNA solid and thermal solvers.
- New set of keywords starting with *EM for the solver
- FEM for conducting pieces only, **no air mesh needed** (FEM-BEM method)
Typical welding process

- Typical force, current and voltage curves during the resistance spot welding (from [wick2012])
Aim of the process simulation

- Heat generation, temperature history, material structure in dependence of the (contact) resistance

“Furthermore, with aluminium metal being such a good electrical conductor (∼three times more than steel), heat generated during welding is primarily obtained from the contact resistances at the faying surfaces, and not from the bulk material resistance.

Resistance spot welding of aluminium is therefore a **surface-critical process**”

[http://www.answers.com/topic/spot-welding]

\[
Q = \int_{t=t_0}^{t=t_s} I^2(t)R_{ges}(t)\,dt
\]
Aim of the process simulation

- Residual stresses, nugget size [MPA Stuttgart - wick2012]

Radial:
- $\varnothing_{D_{\text{Experiment}}} = 4.26\text{mm}$
- $\varnothing_{D_{\text{Simulation}}} = 4.18\text{mm}$

Axial:

Tangential:

Erweichungszone

22MnB5+AS / 22MnB5+AS, Blechdicke 1.5 mm

22MnB5+AS / 22MnB5+AS, Blechdicke 1.0 [wick2012]
Aim of the process simulation

- Influence of the current type

---

[Wechselstrom]

[Wechselstrom Diagram]

[Mittelfrequenz-Gleichstrom]

[Mittelfrequenz-Gleichstrom Diagram]

["konventioneller" Gleichstrom]

["konventioneller" Gleichstrom Diagram]

[Kondensator-Impulsstrom]

[Kondensator-Impulsstrom Diagram]

[dilthey2006]
Geometry

- 2 Electrods
  - only foot of the electrode meshed
  - electrode shape according DIN 5821
- 2 metal sheets
Mechanical Input

- Part definition
- Material definition (mechanical properties)

*MAT_CWM

This is material type 270. This is a thermo-elastic-plastic model with kinematic hardening that allows for material creation as well as annealing triggered by temperature. The acronym CWM stands for Computational Welding Mechanics, Lindström (2013), and the model is intended to be used for simulating multistage weld processes. This model is only available for solid elements.

- Boundary conditions
- Load conditions - Force
# Mechanical Input

- **e.g. *MAT_CWM**

<table>
<thead>
<tr>
<th>Card 1</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<tbody>
<tr>
<td>Variable</td>
<td>MID</td>
<td>RO</td>
<td>LCEM</td>
<td>LCPR</td>
<td>LCSY</td>
<td>LCHR</td>
<td>LCAT</td>
<td>BETA</td>
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<th>7</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>TASTART</td>
<td>TAEND</td>
<td>TLSTART</td>
<td>TLEND</td>
<td>EGHOST</td>
<td>PGHOST</td>
<td>AGHOST</td>
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</tbody>
</table>

- **RO**: Material density
- **LCEM**: Load curve for Young’s modulus as function of temperature
- **LCPR**: Load curve for Poisson’s ratio as function of temperature
- **LCSY**: Load curve for yield stress as function of temperature
- **LCHR**: Load curve for hardening modulus as function of temperature
- **LCAT**: Load curve (or table) for thermal expansion coefficient as function of temperature (and maximum temperature up to current time)
- **BETA**: Fraction isotropic hardening between 0 and 1
  - EQ.0: Kinematic hardening
  - EQ.1: Isotropic hardening
- **TASTART**: Annealing temperature start
- **TAEND**: Annealing temperature end
- **TLSTART**: Birth temperature start
- **TLEND**: Birth temperature end
- **EGHOST**: Young’s modulus for ghost (quiet) material
- **PGHOST**: Poisson’s ratio for ghost (quiet) material
- **AGHOST**: Thermal expansion coefficient for ghost (quiet) material
- **T2PHASE**: Temperature at which phase change commences
- **T1PHASE**: Temperature at which phase change ends
**Thermal Input**

- Initial temperature
- Material definition (thermal properties)

*MAT_THERMAL_CWM*

This is thermal material type 7. It is a thermal material with temperature dependent properties that allows for material creation triggered by temperature. The acronym CWM stands for Computational Welding Mechanics and the model is intended to be used for simulating multistage weld processes in combination with the mechanical counterpart, *MAT_CWM.*

<table>
<thead>
<tr>
<th>Card 1</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tbody>
<tr>
<td>Variable</td>
<td>TMID</td>
<td>TRO</td>
<td>TGRLC</td>
<td>TGMULT</td>
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<thead>
<tr>
<th>Card 2</th>
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<th>2</th>
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<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
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<tr>
<td>Variable</td>
<td>LCHC</td>
<td>LCTC</td>
<td>TLSTART</td>
<td>TLEND</td>
<td>TISTART</td>
<td>TIEND</td>
<td>HHOST</td>
<td>GHHOST</td>
</tr>
</tbody>
</table>

- **LCHC**: Load curve for specific heat as function of temperature
- **LCTC**: Load curve for thermal conductivity as function of temperature
- **TLSTART**: Birth temperature of material start
- **TLEND**: Birth temperature of material end
- **TISTART**: Birth time start
- **TIEND**: Birth time end
- **HHOST**: Specific heat for ghost (quiet) material
- **GHHOST**: Thermal conductivity for ghost (quiet) material
Electro-Magnetical Input

- **Material definitions (incl. electromagnetic properties)**

  - ***EM_MAT_001**
    
    Purpose: Define the electromagnetic material type and properties for a material whose permeability equals the free space permeability.

  - ***EM_EOS_TABULATED1**
    
    Purpose: Define the electrical conductivity as a function of temperature by using a load curve.

- **Definition of an electrical circuit**

- **Definition of an electro-magnetic contact**
History of the 3d temperature field
Contours and Vector Plot of the Current Density

- Contours and vector plot of the current density
Contours and Vector Plot of the Electric Field

- Contours plot of the electric field
- Contours and vector plot of the electric field
Contours plot of Heating Power and Electrical Conductivity

- Contours plot of heating power

LS-DYNA keyword deck by LS-PrePost
Time = 0.17069
Contours of Ohm heating power
min=2.11007e-18, at node# 45243
max=1.12913, at node# 47821

- Contours plot of electrical conductivity

LS-DYNA keyword deck by LS-PrePost
Time = 0.0046926
Contours of Electrical conductivity
min=6.63712e+06, at node# 38497
max=4.49238e+07, at node# 13416
EM Solver

- 3 EM-Solver available in LS-DYNA v7
  - Eddy Current Solver
  - Induced heating Solver
  - Resistive heating Solver

*EM_CONTROL*

Purpose: Enables the EM solver and sets its options.

<table>
<thead>
<tr>
<th>EMSOL</th>
<th>NUMLS</th>
<th>DTINIT</th>
<th>DTMAX</th>
<th>T_INIT</th>
<th>T_END</th>
<th>NCYCLFEM</th>
<th>NCYCLBEM</th>
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</table>

**EMSOL**: Electromagnetism solver selector:
- EQ.1: Eddy current solver
- EQ.2: Induced heating solver
- **EQ.3: Resistive heating solver**

- Since no diffusive effects are taken into account, there is no limiting CFL condition and the time step can take a very high value.
Electric contacts

- Contact of rough surfaces, cp. [Holm1967]

[vinaricky2002]
EM contact according [holm1967]

*EM_CONTROL_CONTACT

<table>
<thead>
<tr>
<th>EMCT</th>
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**EMCT**: Electromagnetic contact:
- EQ.0: no contact detection
- EQ.1: contact detection

- Due to a user’s request, a contact resistance can be calculated based on the book “Electric Contacts” by Ragnar Holm:

\[
R_{contact} = R_{constriction} + R_{film}
\]
\[
R_{film} = \frac{\rho_{oxy}}{\sqrt{faceA_{film} \times ContactArea}}
\]
\[
R_{constriction} = \frac{\rho_{prob} + \rho_{sub}}{\sqrt{faceA_{cute} \times ContactArea}}
\]

where \(\rho_{prob}, \rho_{oxy}, \rho_{sub}\) respectively probe, film and substrate resistivity, \(faceA_{film}, faceA_{cute}\) are all parameters to be defined by the user.

- The user can then choose to add this calculated contact resistance to the total resistance calculated by the solver of a given circuit or not.
EM contact resistance

*EM_CONTACT_RESISTANCE

<table>
<thead>
<tr>
<th>CRID</th>
<th>CONTID</th>
<th>RHOprobe</th>
<th>RHOsub</th>
<th>RHOoxi</th>
<th>FaceActe</th>
<th>FaceAfilm</th>
<th>CIRCID</th>
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</thead>
<tbody>
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</table>

**CRID** : Resistive contact ID

**CONTID** : EM Contact ID defined in *EM_CONTACT

**RHOon** : Different resistivities

**FaceActe/FaceAfilm** : Scale factors on the constriction area when calculating the constriction and the film resistance. When negative, it becomes time dependent using the absolute value for load curve ID.

**CIRCID** : When defined, the contact resistance will be added to the corresponding circuit ID total resistance and taken into account by the solver in the circuit equations.
Most relevant modell parameters for process simulation

- Electrical contact resistance
  - temperature dependent
  - pressure dependent
Thank you

il@dynamore.de
<table>
<thead>
<tr>
<th>USI</th>
<th>Equivalence ([kg]^α * [m]^β * [s]^γ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>kg</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
</tr>
<tr>
<td>Time</td>
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<td>Energy</td>
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<tr>
<td>Force</td>
<td>N</td>
</tr>
<tr>
<td>Stress</td>
<td>Pa</td>
</tr>
<tr>
<td>Density</td>
<td>(\frac{kg}{m^3})</td>
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<tr>
<td>Heat capacity</td>
<td>(\frac{J}{kgK})</td>
</tr>
<tr>
<td>Thermal Cond.</td>
<td>(J m^{-1}s^{-1})</td>
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<tr>
<td>Current</td>
<td>A</td>
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<tr>
<td>Resistance</td>
<td>Ohm</td>
</tr>
<tr>
<td>Inductance</td>
<td>H</td>
</tr>
<tr>
<td>Capacity</td>
<td>F</td>
</tr>
<tr>
<td>Voltage</td>
<td>V</td>
</tr>
<tr>
<td>B field</td>
<td>T</td>
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<tr>
<td>Conductivity</td>
<td>Ohm(^{-1}) m(^{-1})</td>
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