Numerical study of the weldability of a dissymmetric assembly during resistance spot welding

Jordan QUEVAL\textsuperscript{1,2}, E. Geslain\textsuperscript{1}, Ph. Rogeon\textsuperscript{1}, L. Cretteur\textsuperscript{3}

S,Marie\textsuperscript{4}

\textsuperscript{1} IRDL Lorient
\textsuperscript{2} PSA AUTOMOBILES
\textsuperscript{3} ARCELORMITTAL
\textsuperscript{4} TRANSVALOR S.A.
Introduction of new families of high strength steel and of very thin sheet in the body in white

Improve structural performance & Achieve lightweighting goals

Weldability difficulties during RSW of dissymmetric assemblies including a very thin cover sheet

Insufficient penetration of the nugget inside the cover thin sheet

Splashing at electrode/sheet and sheet/sheet interfaces
Numerical Simulation of RSW of a 3 sheets assembly including a very thin sheet

With the software

The sheets

<table>
<thead>
<tr>
<th>Position</th>
<th>Name</th>
<th>Type</th>
<th>Thickness (mm)</th>
<th>Coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>upper 1</td>
<td>AM54</td>
<td>LSS</td>
<td>0.57</td>
<td>zinc (10 µm)</td>
</tr>
<tr>
<td>center 2</td>
<td>DP600</td>
<td>AHSS</td>
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<tr>
<td>lower 3</td>
<td>22MnB5</td>
<td>PHS</td>
<td>1.2</td>
<td>Al-Si (30 µm)</td>
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</table>

The process parameters (Reference case)

<table>
<thead>
<tr>
<th>I (A)</th>
<th>F (daN)</th>
<th>t_{welding} (ms)</th>
<th>t_{forging} (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8500</td>
<td>400</td>
<td>350</td>
<td>500</td>
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- Understand the origin of the weldability problems
- Identify the mains factors influencing the nugget formation and growth
- Propose solutions to improve the weldability of the thin sheet
- Understand the causes of the splashing
Numerical simulation of the stages of the process

(1) Clamping
(2) Welding
(3) Forging
(4) Cooling

Load $F$ (daN)
Current $I$ (A)
t$_{\text{welding}}$
t$_{\text{forging}}$

Outline/aims
Numerical model
Results
Conclusion/Outlook
Physical phenomena and couplings

Assumptions
- Metallurgical phenomena with the associated couplings are not taken explicitly into account
- Convection phenomena in the molten pool are ignored
- Reversible evolutions are assumed for contact parameters
**Equations**

**Matter**

**Electrical**

\[
\text{div}\left(\sigma_i \, \text{grad} V_i\right) = 0
\]

**Thermal**

\[
\left\{\rho_i \, Cp_i \, \frac{\partial T_i}{\partial t}\right\} = \text{div}\left(\lambda_i \, \text{grad} T_i\right) + \sigma_i \left(\text{grad} V_i\right)^2
\]

Internal heat flux generated by Joule effect
\[
\phi_{g\_mater} = 1/\sigma * J^2 = \sigma * (\text{grad} V)^2 \quad (\text{W/m}^3)
\]

Properties

For steels and CuCrZr alloy

\[
\sigma (T), \lambda(T), \rho(T), \text{Cp}(T)
\]

**Contact**

\[
J_1 = \frac{V_1 - V_2}{ECR}
\]

**Assumptions**

ECR(T, p), TCR(T, p)

Interfacial heat flux generated by Joule effect
\[
\phi_{g\_contact} = ECR * J^2 \quad (\text{W/m}^2)
\]

Properties

For electrode/sheet and sheet/sheet interfaces

\[
\alpha = 0.5
\]

\[
q_1 = \frac{\theta_2 - \theta_1}{TCR} + \alpha \phi_{g\_contact}
\]
Improvement of weldability of dissymmetric assembly with very thin sheet during resistance spot welding

**Mater**

\[
\text{div} (\sigma) + \rho.f = 0
\]

**Steels**
- TEVP
- TEP

**CuCrZr**

(Assumptions)

Rheological data

**Stress Equations**

\[
E(T), Nu(T), \text{density}(T), \sigma_Y(T)
\]

Flow stress curves given point to point 
\[
\sigma = f(\varepsilon, \dot{\varepsilon}, T)
\]

In the ranges \(\varepsilon[0 – 4], T [20^\circ\text{C} - 1500 ^\circ\text{C}], \dot{\varepsilon} [10^{-3} \text{ s}^{-1} – 10^{+3} \text{ s}^{-1}]\)

**CuCrZr**

\[
E(T), Nu(T), \text{density}(T), \sigma_Y(T), R(T)
\]

Contact conditions

Penalty methods

For clamping; welding; forging:
- sliding

For cooling:
- sliding
- Bilateral-sticking

Assumptions
## Materials properties (Elec/Therm)

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### Outline/aims
- Numerical model
- Results
- Conclusion/Outlook

### Graphs
- **Electrical conductivity vs. T (°C):**
  - AM54
  - DP600
  - 22MnB5
  - High difference at T=20°C

- **Stress vs. True Strain:**
  - DP600
  - AM54
  - 22MnB5
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**Dissimilar materials**

**Different thicknesses**

**Dissimilar coatings**

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**Huge difference (x10)**

**High Difference (x10)**

**Very dissymmetric assembly!**

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**Graphs:**

**TCR(T) à 50 MPa**

- RCT Cu-AM54
- RCT AM54-DP600
- RCT DP600-Usibor 1500
- RCT 22MnB5 - Cu

**ECR(T) à 200 MPa**

- ECR 1
- ECR 2
- ECR 3
- ECR 4

**High Difference (x10)**

**Huge Difference (x30)**
Sensitivity study

Reference Case

- Number of hours = 8-9h
- Number of processor = 1
- Size of RAM = 8 Go

Effect of I

- Caps A0-13-18-R32
  - I=8500 A
  - F= 4000 N
- Caps A0-13-18-R32
  - I=9000 A
  - F= 3000 N
- Caps A0-13-18-R32
  - I=9500 A
  - F= 4000 N

Effect of F

- Caps G0-20-22 R50
  - I=8500 A
  - F= 4000 N
  - I=10500 A
  - F= 4000 N

Effect of R_{curvature}

On the penetration of the nugget inside the thin sheet
Nugget Formation and Growth

Numerical (during welding) versus Experimental (after cooling)

Welding times
- 40 ms
- 60 ms
- 80 ms
- 150 ms
- 300 ms

Quick initiation of the nugget inside the thick PHS sheet at the opposite of the thin LCS sheet

Overheating can be observed during numerical simulation

T > 1535 °C
Nugget Formation and Growth

Maximum thickness $e_{N_{\text{max}}}$

$e_N$ (mm) vs. Time (ms)

$N_{N2/S3}$ (mm) vs. Time (ms)

Numerical model

Results

Conclusion/Outlook

Sheet 1

Sheet 2

Sheet 3
Strong Distortions:
- thickness assembly ($e_A$)
- (E/S) and (S/S) contact radii

**Outline/aims**

- Numerical model
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**Numerical model**

- Cooling $T = 120s$
- $e_A = 2.75\,\text{mm}$

**Results**

- Welding
- Forging

**Conclusion/Outlook**

- EXP
- $e_A = 2.75\,\text{mm}$

**Diagram**

- Time (ms):
  - 0, 200, 400, 600, 800, 1000, 1200, 1400

- eA (mm):
  - 2.8, 2.9, 3.0, 3.1, 3.2, 3.3
Effect of electrode pressure

Weld penetration into the thin sheet

F (kN) \rightarrow (ECR, TCR) \rightarrow Indentation \leftrightarrow p/e_s1
Weld diameter evolution at the thin sheet interface

Effect of electrode pressure

- F = 3.0 kN
- F = 4.0 kN

- Time (ms)
- r_{NS1/S2} (mm)
Effect of the curvature radius of the electrode tip

Caps A0-13-18-R32
I=9,5 kA
F=4 kN

Caps G0-20-22 R50
I=10,5 kA
F=4 kN

Weld penetration into the thin sheet
Weld diameter evolution at the thin sheet interface

Effect of the curvature radius of the electrode tip

Caps A0-13-18-R32
I=9.5 kA
F=4 kN

Caps G0-20-22 R50
I=10.5 kA
F=4 kN
Ejected steel at the interface S2/S3

Ejected steel at the interface S3/E2
Ejected material at the interface DP600/22MnB5
Possible cause of the splashing

New electrode

Wear electrode
Splashing

Possible cause of the splashing

ZF (> 1500°C):
Conclusion

• Strong initial Joule heating observed at PHS sheet interfaces due to Al-Si coating

• The process parameters \(I, F, R_{\text{curvature}}\) can improve the penetration (diameter, thickness) of the nugget inside the thin sheet:

\[
\begin{align*}
I \text{ (kA)} & \quad F \text{ (kN)} & \quad R_{\text{curvature}} \text{ (mm)}
\end{align*}
\]

• Overheating at sheet/sheet and electrode/sheet interface combined with geometrical defects could explain the splashing phenomena
Outlooks

Improvements of the RSW model are necessary to prevent the observed overheating

- Contact resistances RCE and RCT depending on \((T_{\text{max}}, P_{\text{max}})\) instead of \((T, P)\)
- Equivalent Thermal Conductivity increased in the molten pool to take into account convection effects (MHD phenomena)
- Behavior law for Steels and CuCrZr at high temperature \((T > 1200 °C)\)
- Influence of Metallurgy
Thank you for your attention