Developments and applications of numerical simulation in resistance welding

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Developments and Applications of Numerical Simulation in Resistance Welding

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Resistance spot welding (material: DC04; \( t_1 = 0.8\) mm / \( t_2 = 1.5\) mm)
Software:

- SYSWELD® (FRAMASOFT S.A./FRAMATOME)
- SPOTSIM® (RWTH Aachen, Tula State University)
- SPOTWELDER® (MPA Stuttgart)
- SORPAS® (SWANTEC Software and Engineering ApS)

Numerical process analysis

**Resistance Welding**

*MODEL FOR NUMERICAL ANALYSIS*

- Geometry
- Material data (Young’s modulus, μ, ...)
- Electrode force
- Welding current
- Material data (c_p, R_k, λ, ρ, ...)

 react

- Structure mechanic Model
- Electric-thermal Model

- Stress distribution
- Deformation
- Temperature distribution

Temperature-field / Design
**Numerical process analysis**

**Mechanical Model - Machine**

- Frame of machine
- Welding head with electrode
- Thermal strain
- Yield behavior
- Creep behavior
- Elasticity

**Data base**

- Physical material properties
- Electrical resistivity $\rho$
- Thermal conductivity $\lambda$
- Heat capacity $c_p$

*Graph showing material properties*
**Database**

**Material Resistance and Contact Resistance**

- $R_0(T) = R_0 + R_0 \frac{T}{T_1}$
- $R_{contact} = \text{Model: MPA Stuttgart}$
- $R_{total} = R_{material} + R_{contact}$

**Numerical process analysis**
**Measurement - transition resistance**

ISO 18594

**Transition resistance**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Transition Resistance / mΩ</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuCrAgFeTiSi, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuCrAgFeTiSi, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-Cu58, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-Cu58, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-Cu58, t = 0.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuZn37, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuZn37, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuZn37, t = 0.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuSn8, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuSn8, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuSn8, t = 0.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuNiCo1Si, t = 0.2 mm</td>
<td></td>
<td></td>
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<tr>
<td>CuNiCo1Si, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuNiSi1Mg, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuNiSi1Mg, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuNiSi1Mg, t = 0.6 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuFe2P, t = 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuFe2P, t = 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CuFe2P, t = 0.6 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(MPA Stuttgart)
Numerical process analysis

Hot staking process

Resistance welding of commutator segments with hook geometry

slot geometry

hook geometry
1984


(Schweißen und Schneiden, 38 (1986), Heft 8, S. 365-369)

Resistive welding of commutator segments with hook geometry

(Lanier)
Resistance welding of commutator segments with hook geometry

(Lanier)
Numerical process analysis
electrotechnic application

FEM Model & Process

(Dölzer)
Projection welding

Stress distribution (von Mises)

Numerical process analysis electrotechnic application

Calculated projection deformation and temperature distribution

(Kußmaul, Blind, Zeng, Greitmann, Schäfer, 1991)
**2001 Alexei Vichtniakov (doctoral thesis): numerical simulation of projection welding**

Calculated movement and temperature distribution

(Vichtniakov, Herold, Greitmann, Roos, 2002 in Mathematical modelling of the weld phenomena)

Numerical process analysis
electrotechnic application

**Projection welding of screw nuts**

Projection welding: screw nuts onto high strength steel sheet

(Bschorr, Cramer, SLV München NL der GSI mbH)
Numerical process analysis
projection welding of screw nuts

Optimization of screw nut geometry

(Bschorr, Cramer, SLV München NL der GSI mbH)

• Square nut welding
Numerical process analysis
Carbide tipped saw blade

1920
band saw (grinded)
stellite hard facing

1960
1992
1985
circular saw
padsaw
padsaw
Brazing (CuAg solder)
resistance welding
Laser beam welding

FE-Model (geometry)
Elektrode
Hartmetall
Elektrodenbacken
Trägersegment
Experimental setup

(Greitmann, Wink)
Numerical process analysis
Carbide tipped band saw

Current distribution
Temperature field

Videoclip

(time: 70 ms)

(Greitmann, Wink)

Carbide tipped saw band

(Hartmetall)

(Sägeband)

(Greitmann, Wink)
Numerical process analysis
Carbide tipped band saw

Temperaturbereich
0°C bis 2000°C

Konturbanstand
100°C

Realtme-Bildfolgezeit
5 ms

Längsschnitt

(Greitmann, Wink)

APPLICATION
Spot Welding

Numerical process analysis
resistance spot welding

R₁, R₂ = Kontaktwiderstand
R₃, R₄ = Elektrodwiderstand
R₅, R₆ = Materialwiderstand
F = Schweißkraft
I = Schweißstrom
Numerical process analysis
resistance spot welding (1996)

Example: Variable sheet thickness
Numerical process analysis resistance spot welding

Spot welding Aluminium

(Pickle: 12% NaOH/60°C/60s; cleaned
Pickle: 25% NaOH/65°C/60s; cleaned
natural Surface
brushed surface

Alloy: AlMg0.4Si1.2; (t = 1.25 mm)

Numerical process analysis resistance spot welding (1996)

Aluminium sheets with variable surface conditions (contact resistance)
Numerical process analysis
resistance spot welding

Temperature distribution

(Greitmann, Wink)

Local temperature–time history

Sheet material: DX54D+Z100
Sheet thickness: 1.0 mm
Electrode material: CuCrZr
Dome radius: 40 mm
Electrode force: 2.5 kN
Welding current: 8 kA
Current-flow time: 240 ms

(Greitmann, Wink)
Spot welding 3-sheets

Microstructure and hardness distribution

Macrophotograph of real weld comparing to simulated weld nugget and martensite distribution

Measured micro hardness comparing to simulated hardness near the weld nugget
Weldability Lobe
Welding process window

Typical Nugget failures

Weld process optimization

Sorpas®
Spot welding – Electrode misalignment
Projection welding
Longitudinal embossment

Square nut projection welding
3D simulation of weld strength testing

- Tensile shear test of weld strength after welding

Tensile shear weld strength test curve simulated by SORPAS® 3D

- Cross tension test of weld strength after welding

- Cross tension test of spot weld strength

Cross tension weld strength test curve simulated by SORPAS® 3D

Cross tension weld strength curve in ISO 14272:2000.
Resistance Welding
Numerical Simulation

• **Process simulation**
  – Weldability of materials, weld nugget sizes
  – Electrode geometry and coatings

• **Process optimisation**
  – Weld growth curves
  – Weldability lobes - welding process windows

• **Process planning**
  – Optimal welding process parameters

• **Weld quality and properties after welding**
  – Microstructures and hardness
  – Weld strengths and fracture modes

• **Welding with adhesives**
  – Fluid adhesives
  – Solid polymer or plastics