Institut de Recherche Dupuy de Lôme
UMR CNRS 6027

CFM 2019

ArcelorMittal

TRANSVALOR

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

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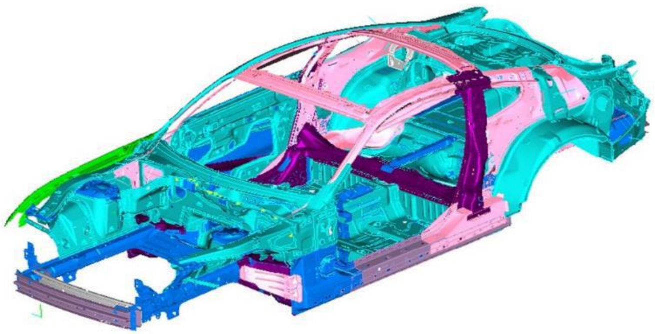
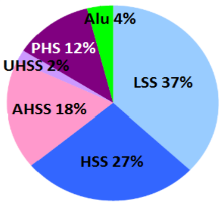
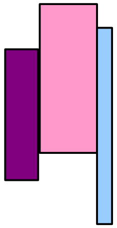
[3] ARCELORMITTAL
[4] TRANSVALOR S.A.

Introduction of new families of high strength steel and of very thin sheet in the body in white



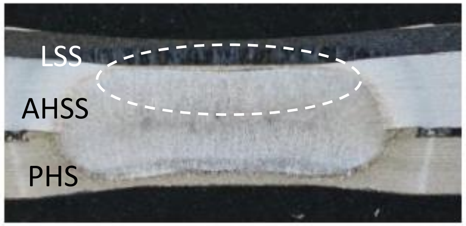


Structure / Structure / Cover

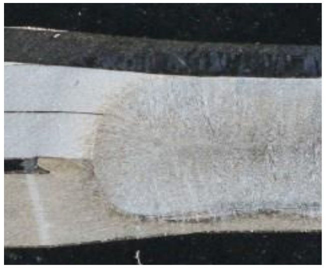


Improve structural performance & Achieve ligthweighting goals

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



Insufficient penetration of the nugget inside the cover thin sheet



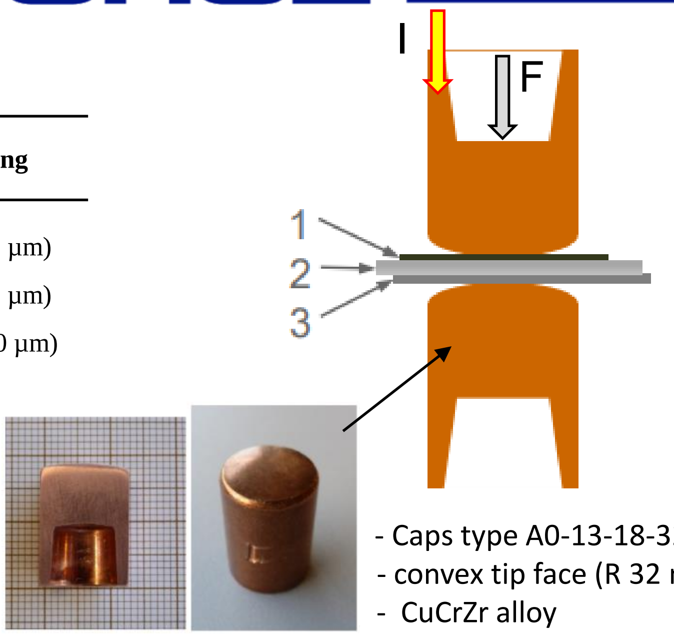
Splashing at electrode/sheet and sheet/sheet interfaces

Numerical Simulation of RSW of a 3 sheets assembly including a very thin sheet

With the software FORGE® NxT 2.0

The sheets

Position	Name	Type	Thickness (mm)	Coating
upper 1	AM54	LSS	0.57	zinc (10 µm)
center 2	DP600	AHSS	1.47	zinc (10 µm)
lower 3	22MnB5	PHS	1.2	Al-Si (30 µm)



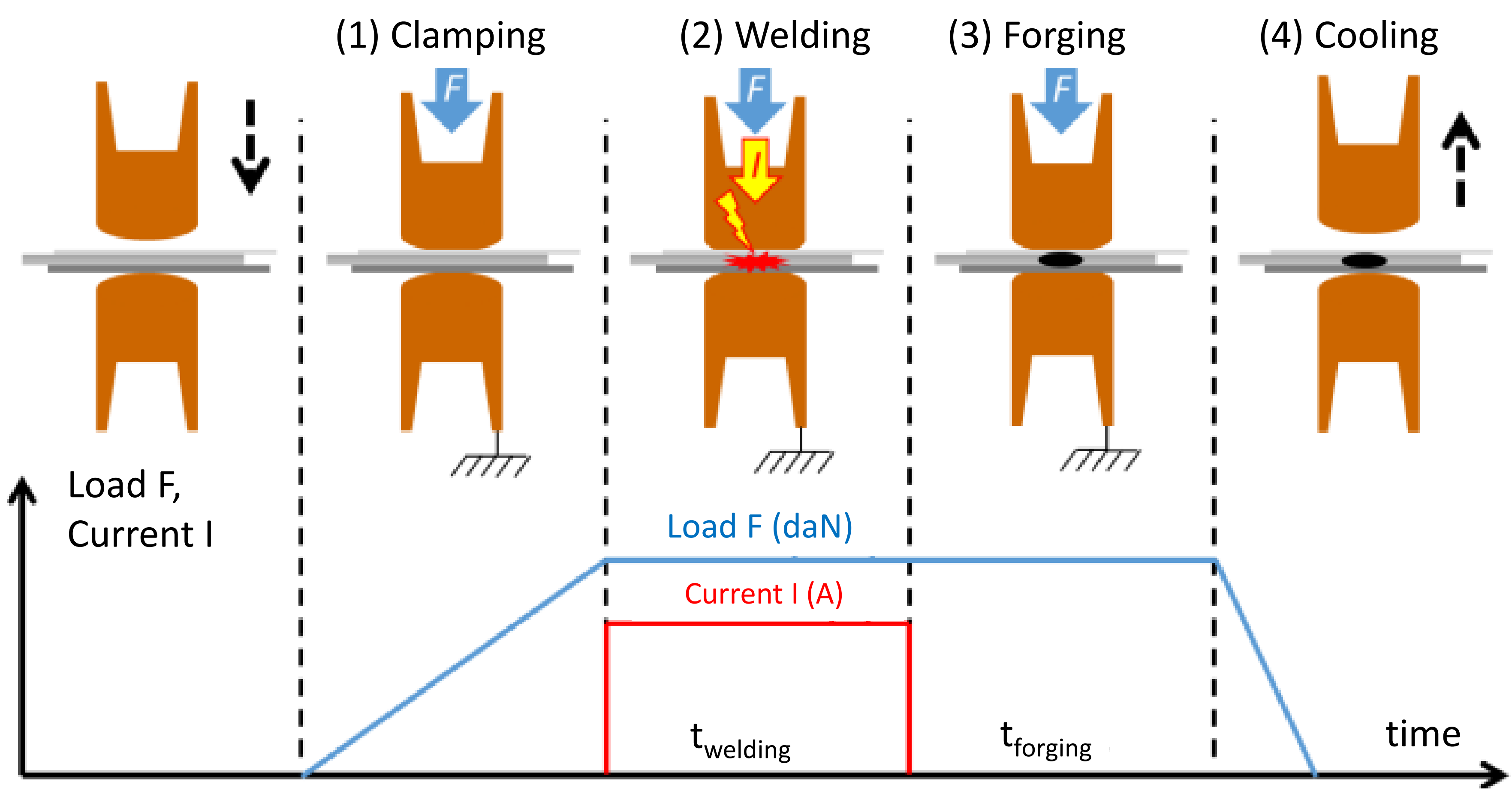
The process parameters (Reference case)

I (A)	F (daN)	$t_{welding}$ (ms)	$t_{forging}$ (ms)
8500	400	350	500

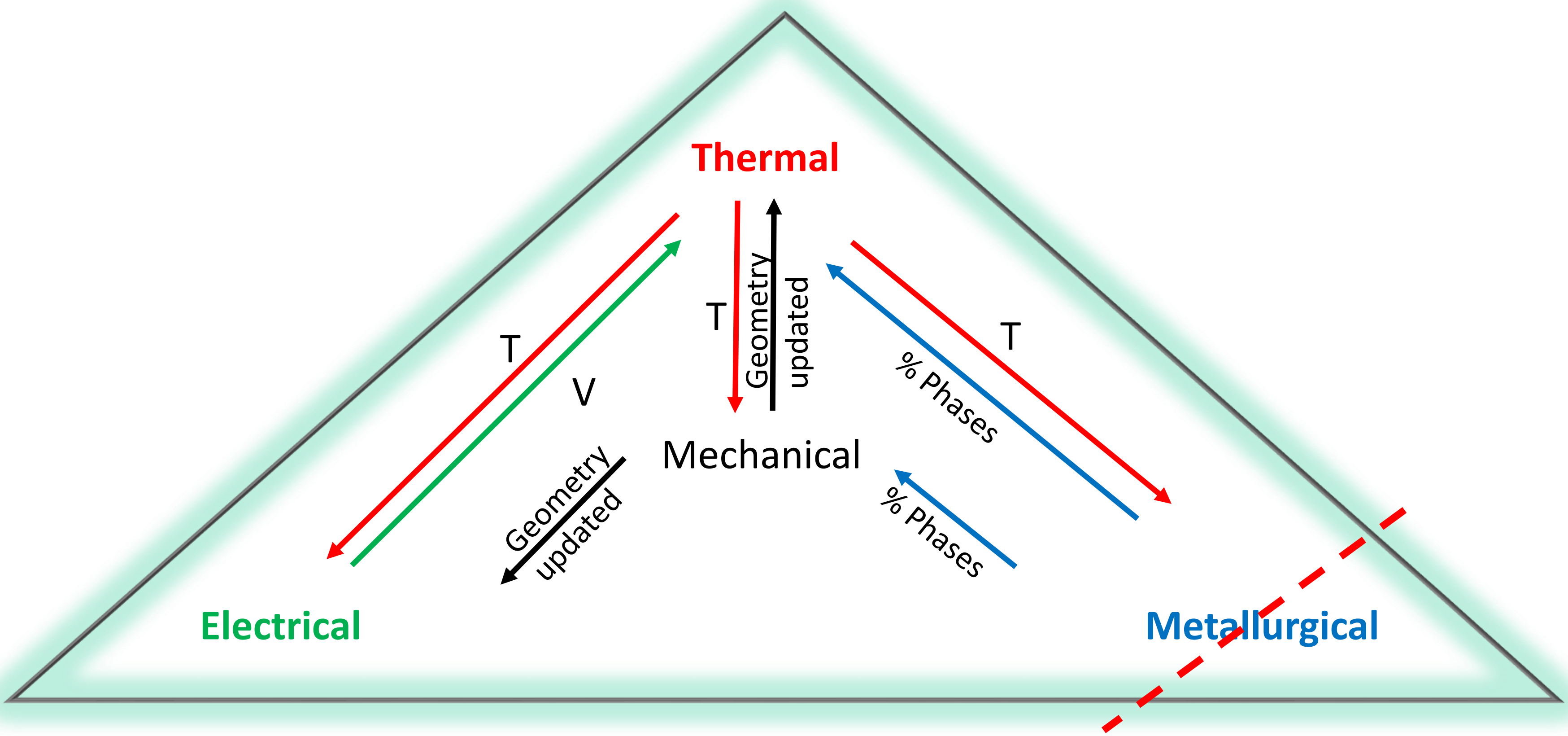
- Caps type A0-13-18-32
- convex tip face (R 32 mm)
- CuCrZr alloy

- 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



Physical phenomena and couplings



Assumptions

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

Equations

Matter

Electrical

$$div\left(\sigma_i \overrightarrow{gradV_i}\right) = 0$$

Thermal

$$\left\{\rho_i Cp_i \frac{\partial T_i}{\partial t}\right\} = div\left(\lambda_i \overrightarrow{grad T_i}\right) + \sigma_i (gradV_i)^2$$

ϕ_{g_mater}

Internal heat flux generated by Joule effect

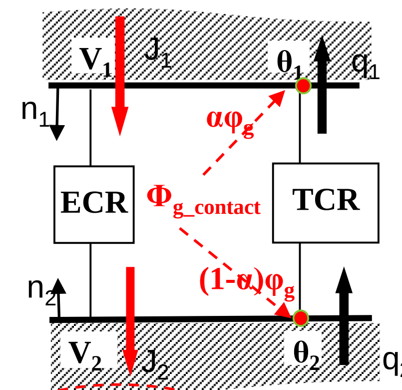
$\phi_{g\_mater} = 1/\boldsymbol{\sigma} * J^2 = \boldsymbol{\sigma} * (\text{grad V})^2$ (W/m³)

Properties

For steels and CuCrZr alloy

$\boldsymbol{\sigma}(T)$, λ(T), ρ(T), Cp(T)

Contact



$$J_1 = \frac{V_1 - V_2}{ECR}$$

$$q_1 = \frac{\theta_2 - \theta_1}{TCR} + \alpha\, \phi_{g\_contact}$$

$$\alpha = 0{,}5$$

$\phi_{g\_contact}$

Interfacial heat flux generated by Joule effect

$\phi_{g\_contact} = ECR * J^2$ (W/m²)

Properties

For electrode/sheet and sheet/sheet interfaces

Assumptions

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

mechanical

Mater

$$\mathrm{div}\,(\boldsymbol{\sigma}) + \boldsymbol{\rho}.\mathrm{f} = 0$$

- Steels
  - TEVP
- CuCrZr
  - TEP

(Assumptions)

Rheological data

Steels

E(T), Nu(T), density(T), $\boldsymbol{\sigma}$Y(T)

Flow stress curves given point to point $\boldsymbol{\sigma} = \mathrm{f}(\,\boldsymbol{\varepsilon}, \dot{\varepsilon},\ T)$

In the ranges ($\mathcal{E}$[0 – 4], T [20°C - 1500 °C], $\dot{\mathcal{E}}$ [$10^{-3}\ s^{-1} – 10^{+3}\ s^{-1}$])

CuCrZr

E(T), Nu(T), density(T), $\boldsymbol{\sigma}$Y(T), R(T)

Contact conditions

Penalty methods

For clamping ; welding ; forging :

- E/S
  - sliding
- S/S
  - sliding

Assumptions

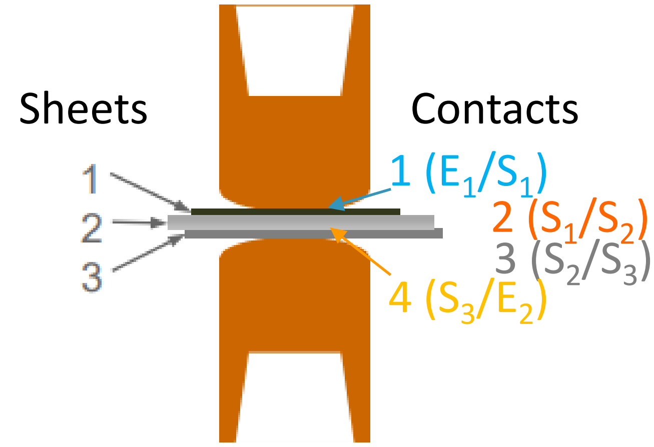
For cooling :

- E/S
  - sliding
- S/S
  - Bilateral - sticking

Assumptions

Materials properties (Elec/Therm)

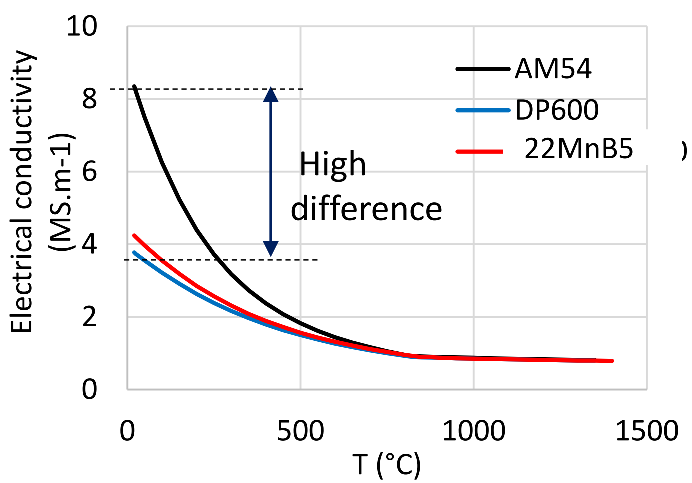
Position	Name	Type	Thickness (mm)	Coating
upper 1	AM54	LSS	0.57	zinc (10 µm)
center 2	DP600	AHSS	1.47	zinc (10 µm)
lower 3	22MnB5	PHS	1.2	Al-Si (30 µm)

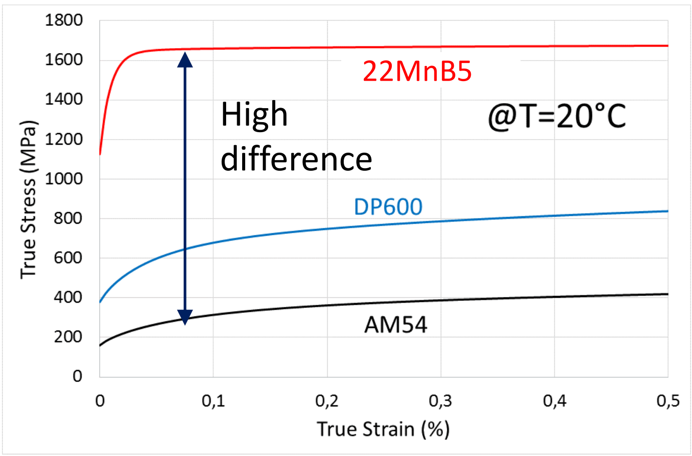


Dissimilar matters

Different thicknesses

Dissimilar coatings





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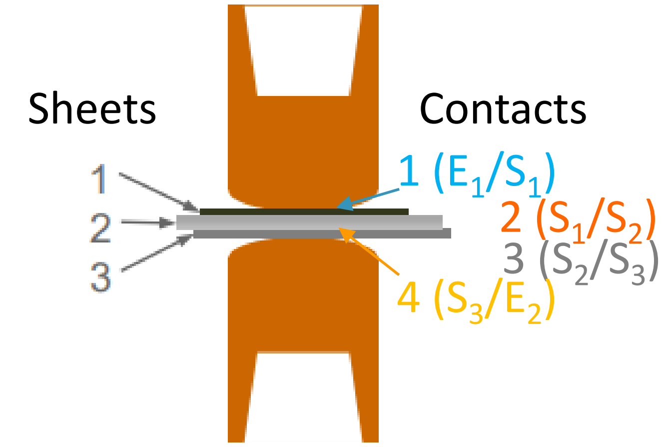
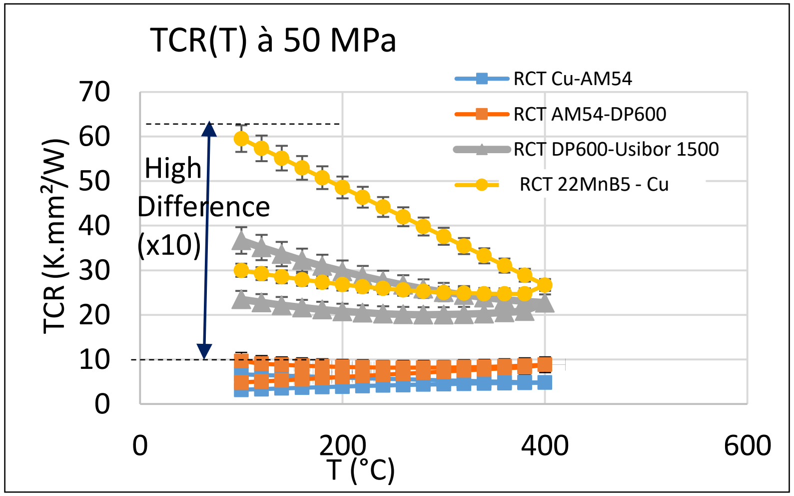
Dissimilar maters

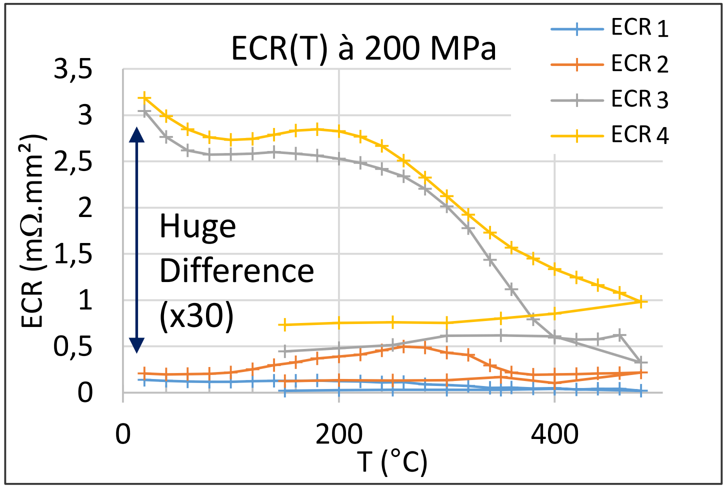
Different thicknesses

Dissimilar coatings



Very dissymetric assembly !



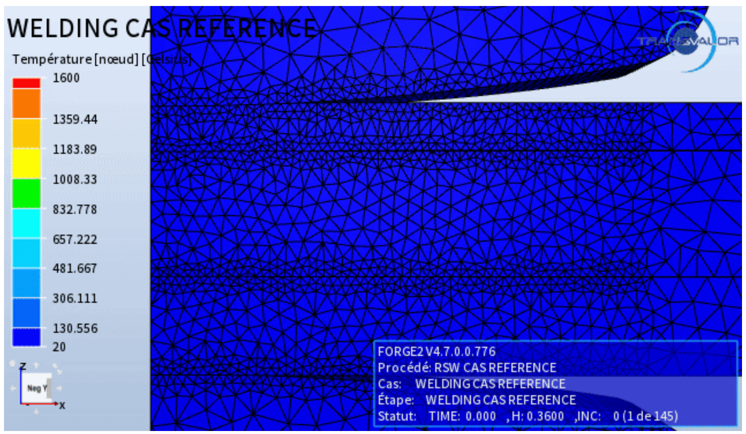


Sensitivity study

FORGE® NxT 2.0

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

Reference Case



I=8500 A, F= 4000 N, Caps A0-13-18-R32

Caps A0-13-18-R32
F= 4000 N

I=8500 A
I=9000 A
I=9500 A

Caps A0-13-18-R32
I=8500 A

F= 4000 N
F= 3000 N

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

Effect of I

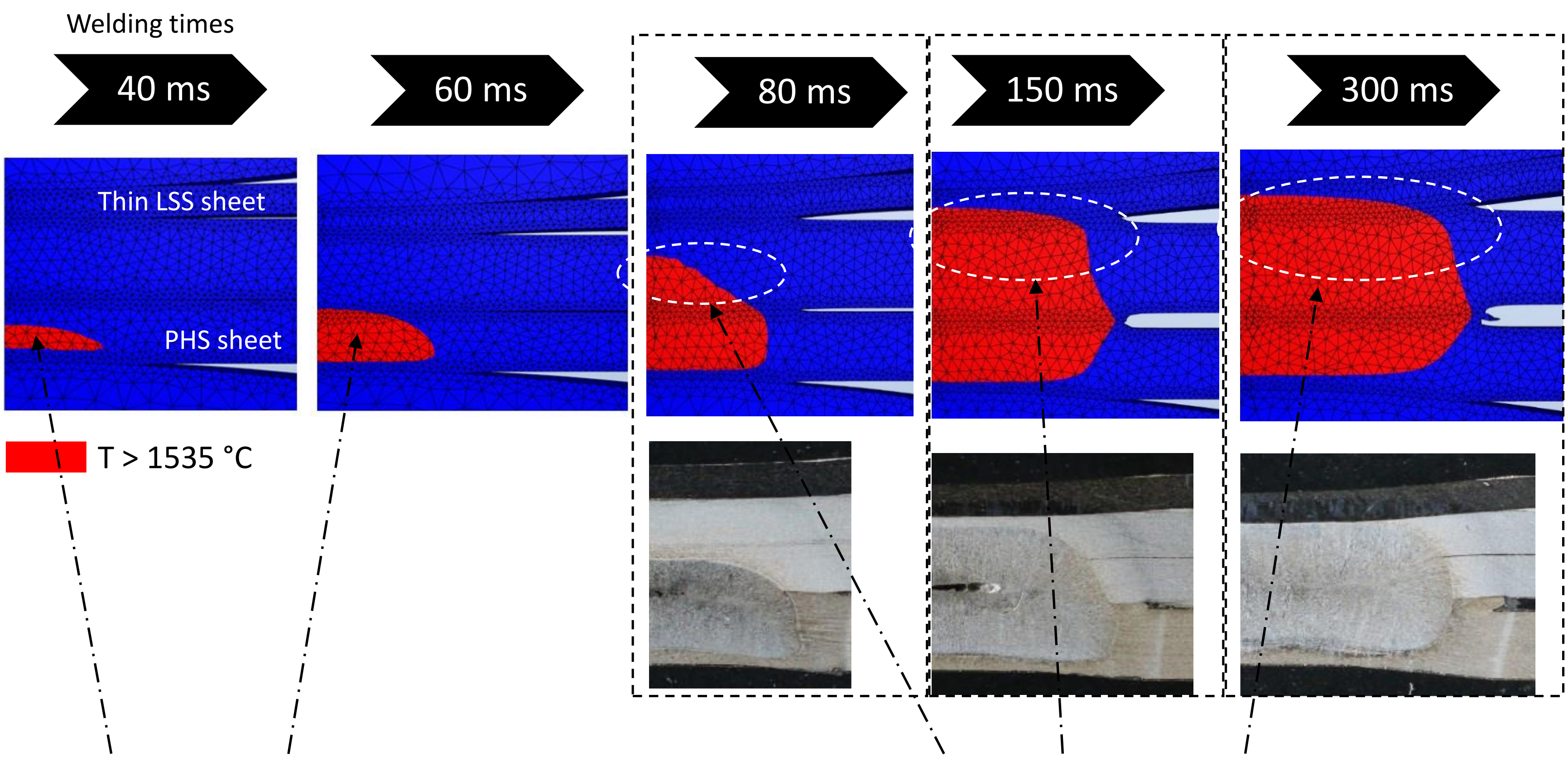
Effect of F

Effect of $R_{curvature}$

On the penetration of the nugget inside the thin sheet

Nugget Formation and Growth

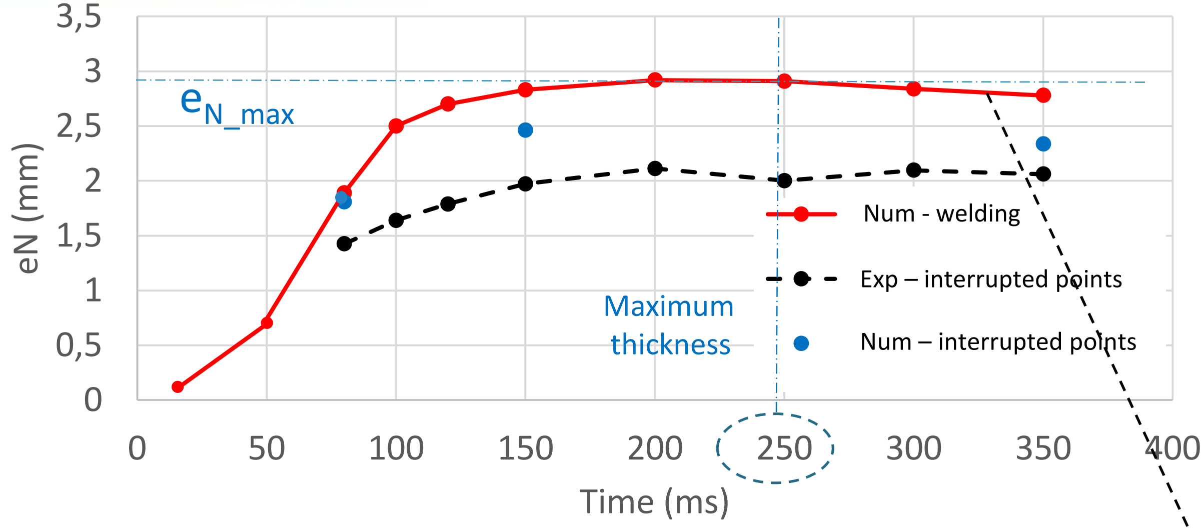
Numerical (during welding) versus Experimental (after cooling)

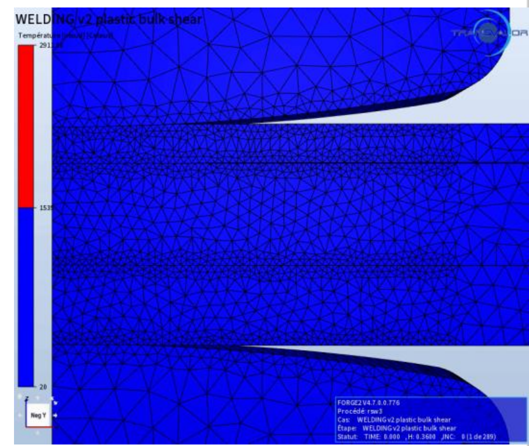


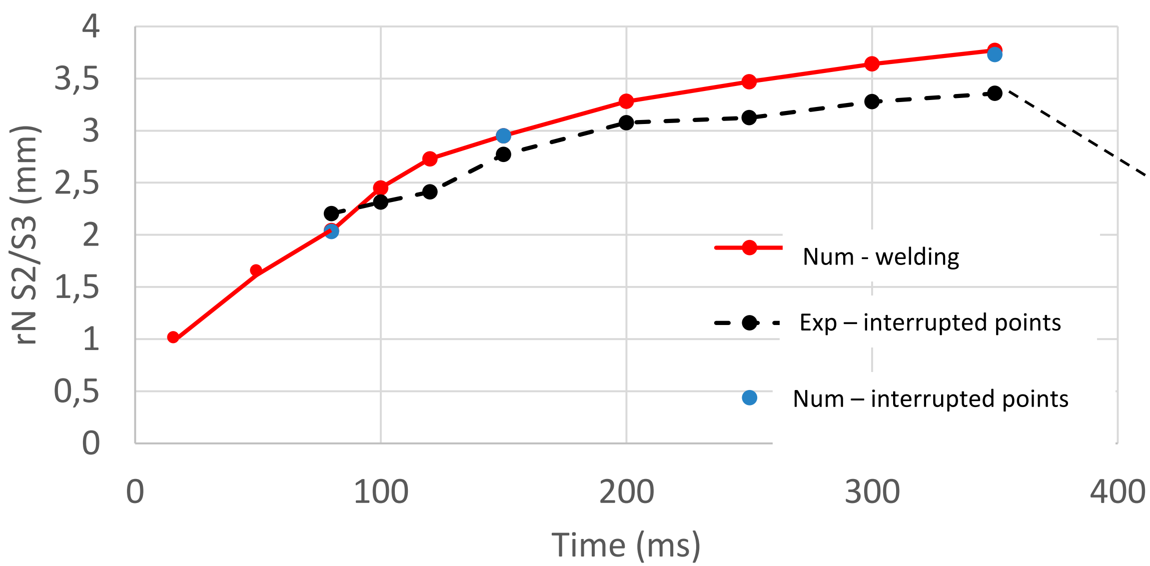
Quick initiation of the nugget inside the thick PHS sheet at the opposit of the thin LCS sheet

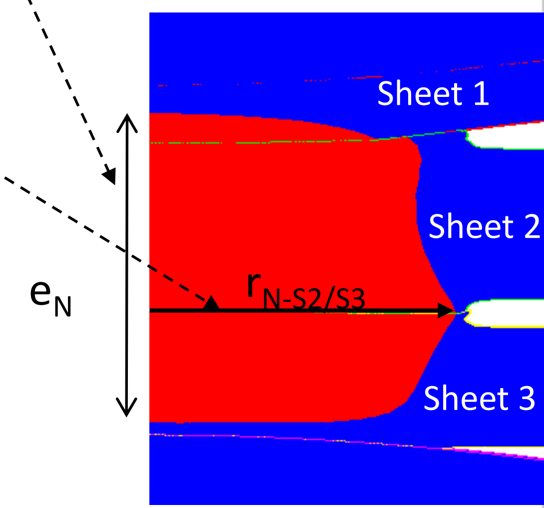
Overheating can be observed during numerical simulation

Nugget Formation and Growth



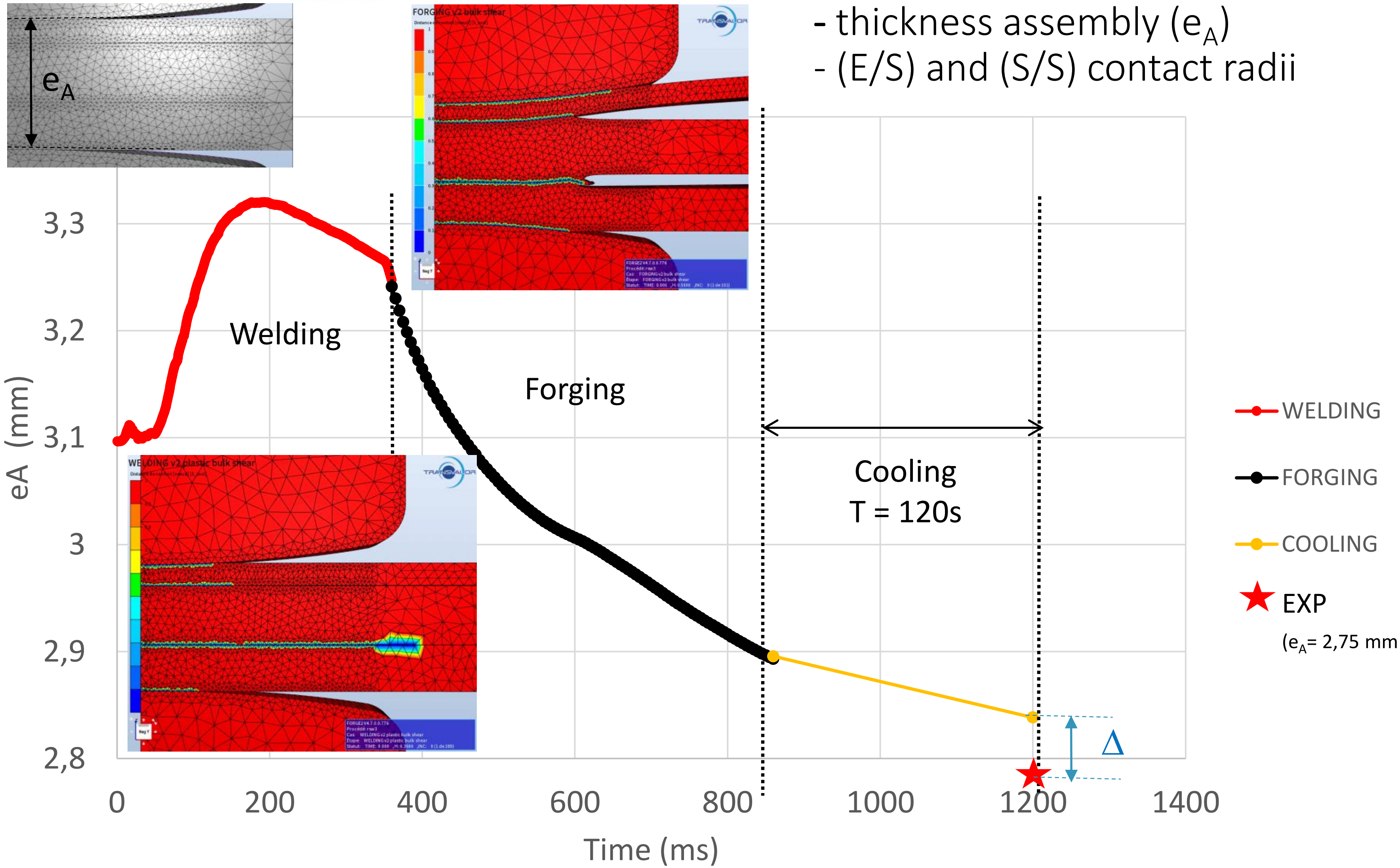




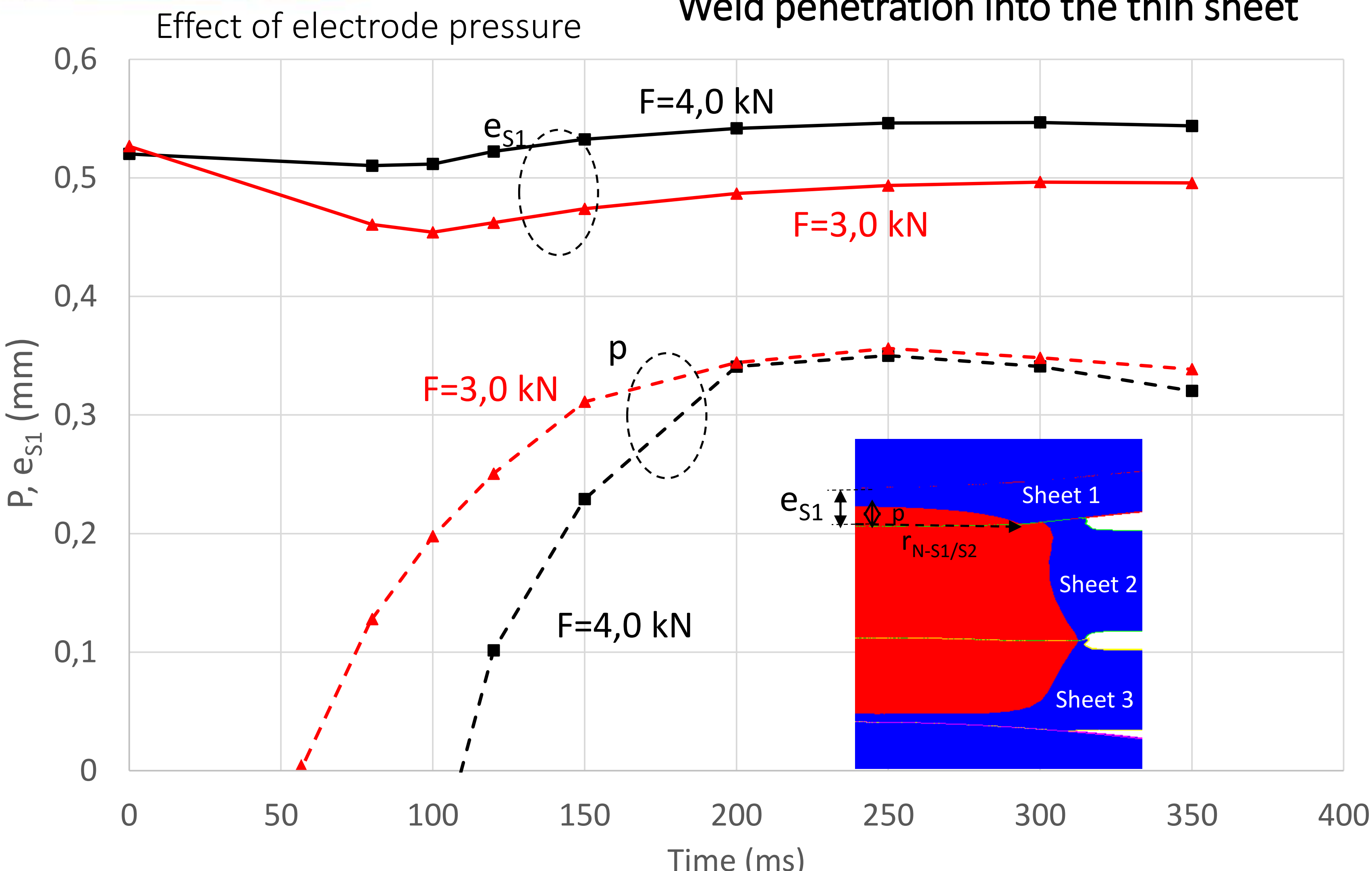


Strong Distorsions :

- thickness assembly (e_A)
- (E/S) and (S/S) contact radii



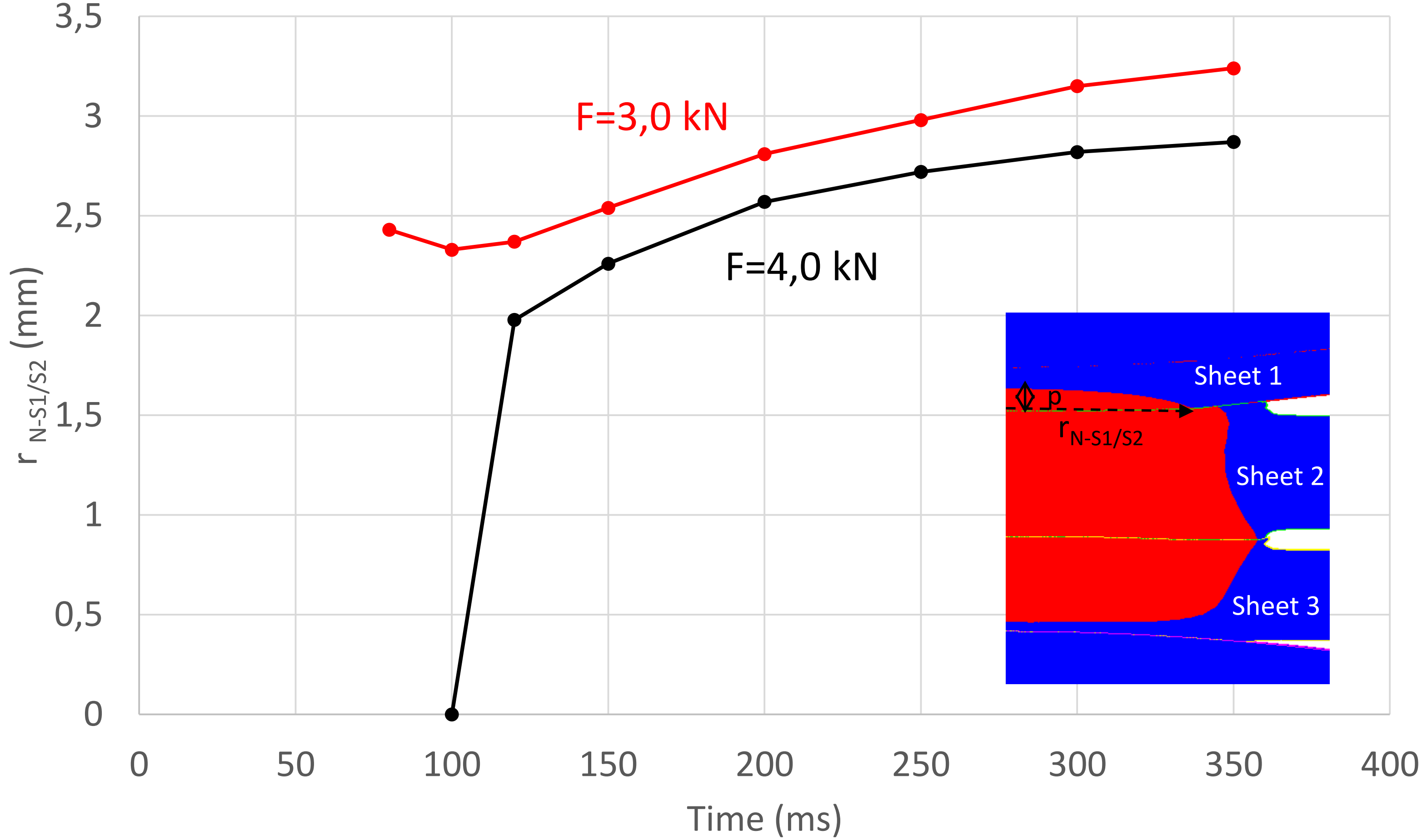
Weld penetration into the thin sheet



F (kN) ↘ ⇨ (ECR, TCR) ↗ Indentation ↗ ⇨ p/e_{S1} ↗

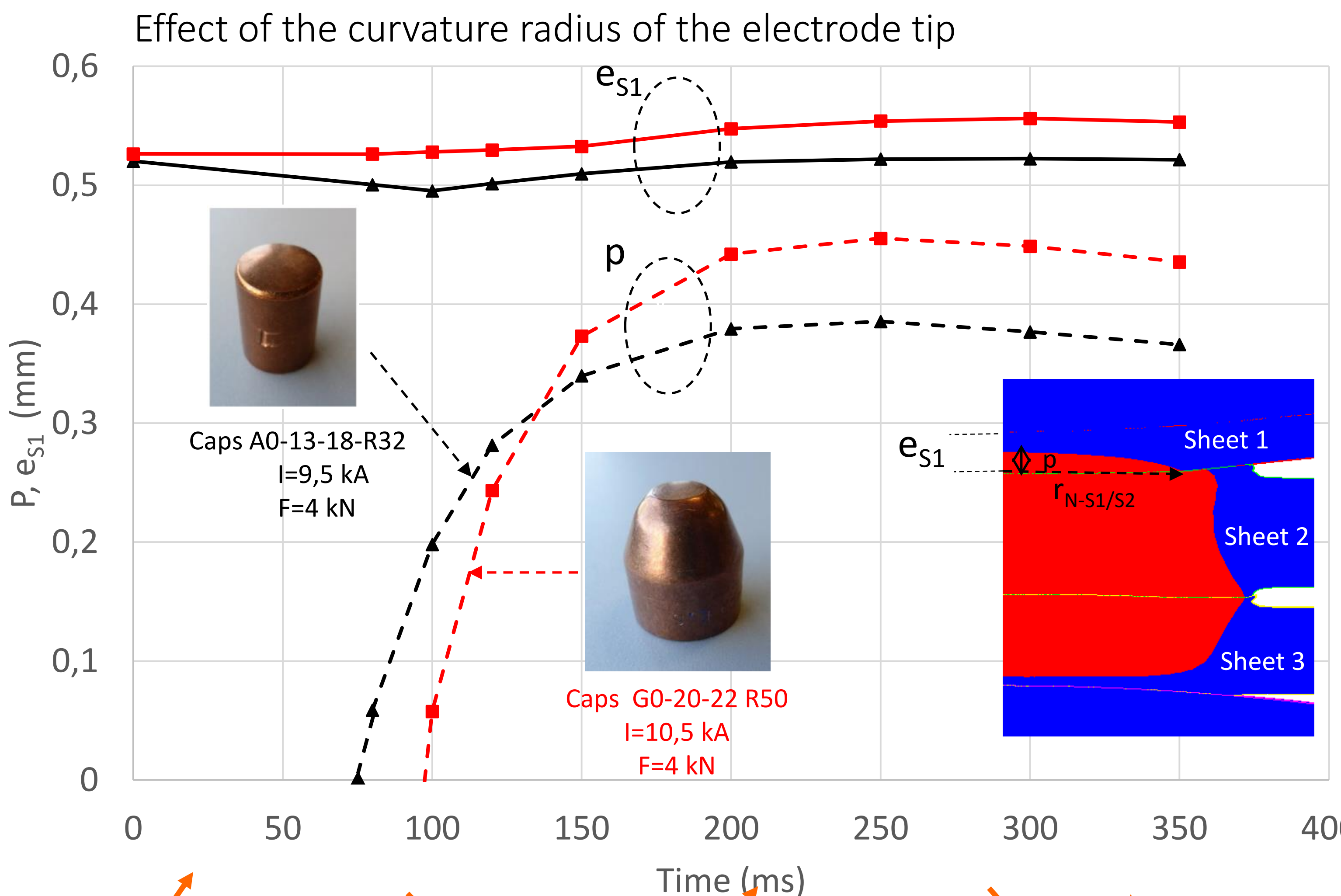
Weld diameter evolution at the thin sheet interface

Effect of electrode pressure



F (kN) ↘ ⇨ (ECR, TCR) ↗ Indentation ↗ ⇨ $r_{NS1/S2}$ ↗

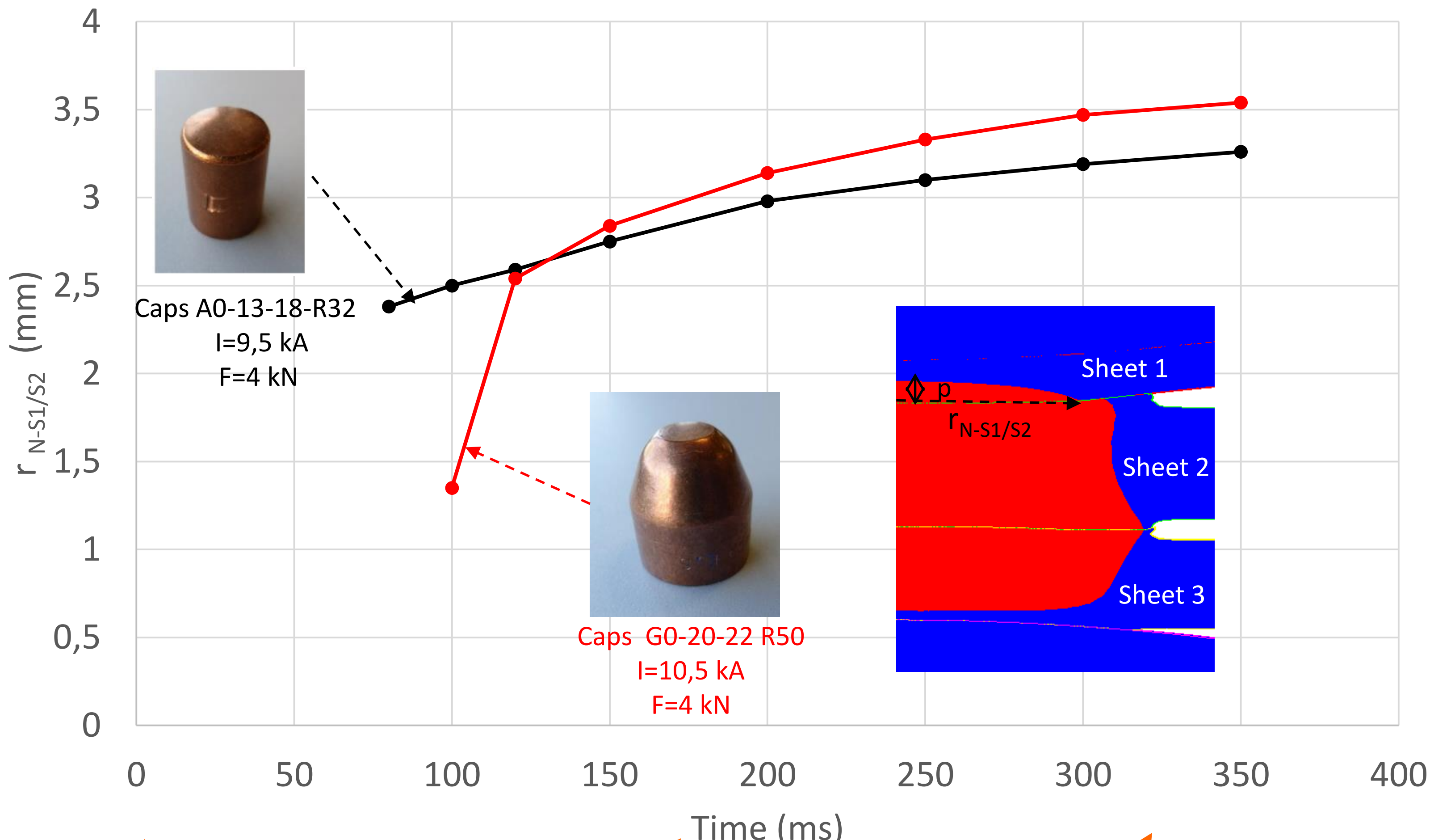
Weld penetration into the thin sheet



$R_{curvature}$ (mm) ↗ ⇨ (P, J) ↘ (ECR, TCR) ↗ Indentation ↘ ⇨ p/e_{S1} ↗

Weld diameter evolution at the thin sheet interface

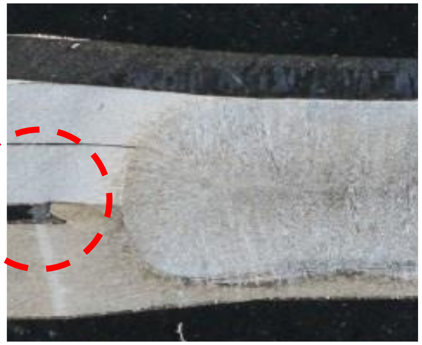
Effect of the curvature radius of the electrode tip



$R_{curvature}$ (mm) ⇒ (P, J) ↘ (ECR, TCR) ↗ ⇒ $r_{NS1/S2}$ ↗

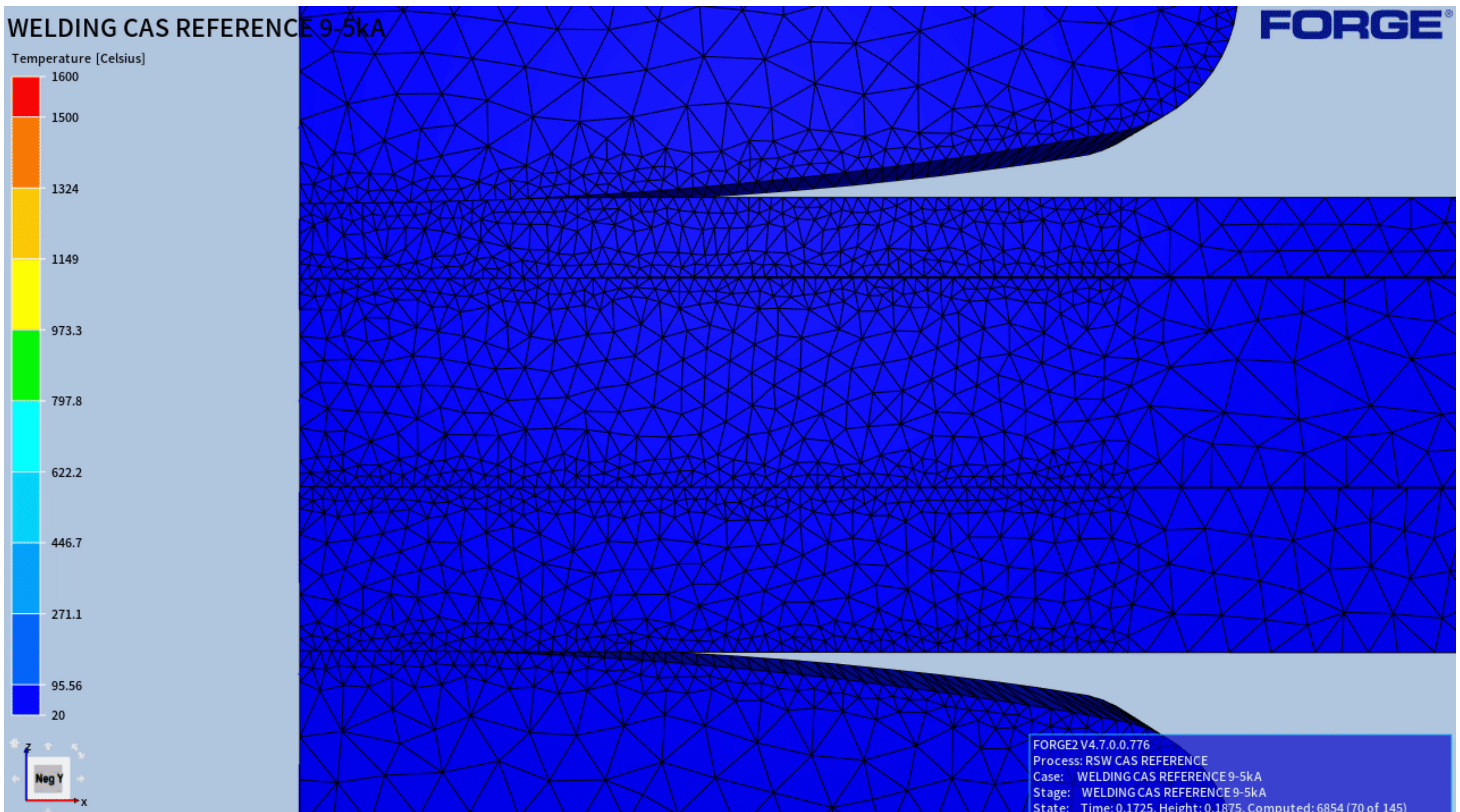
Ejected material

Ejected steel at the interface S2/S3



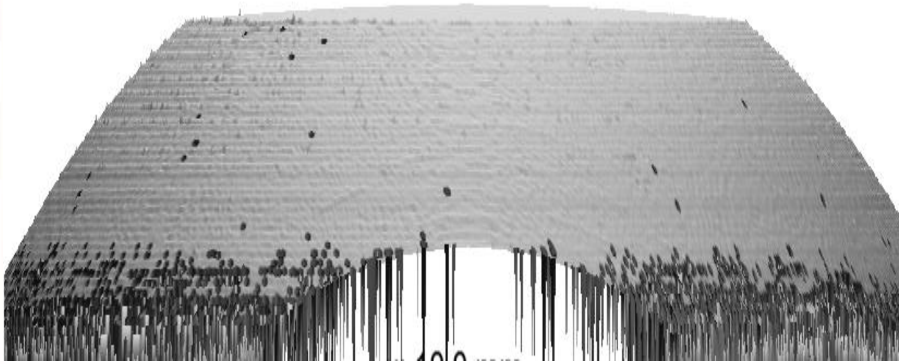
Ejected steel at the interface S3/E2

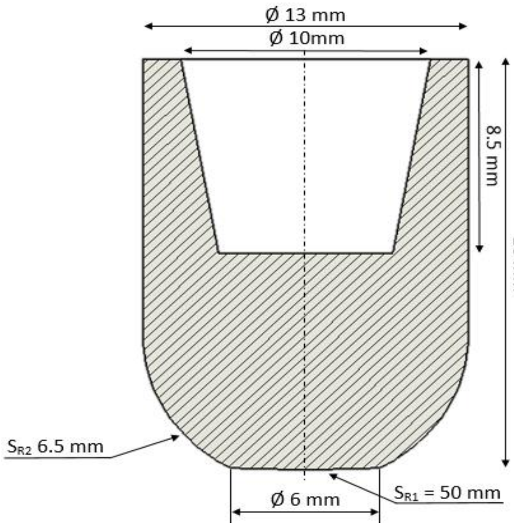
Ejected material at the interface DP600/22MnB5



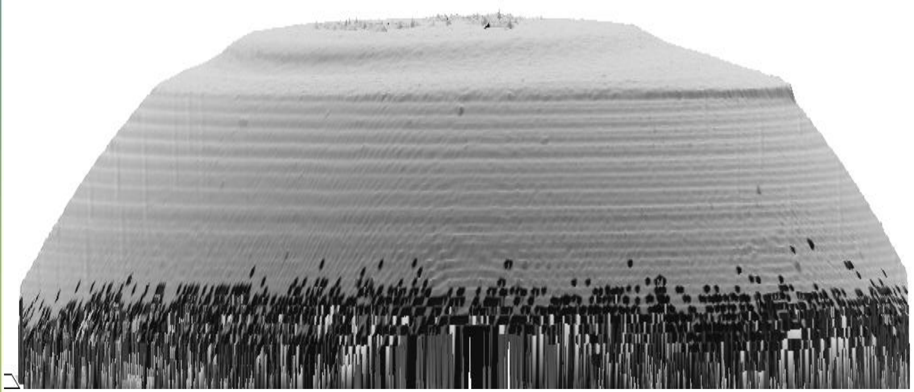
Possible cause of the splashing

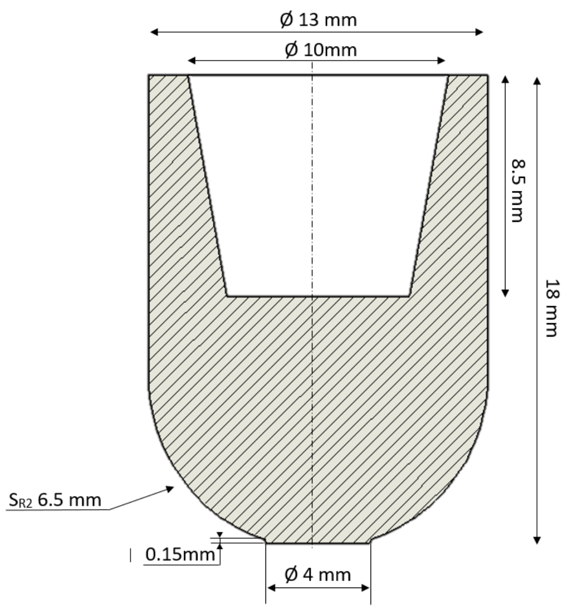
New electrode





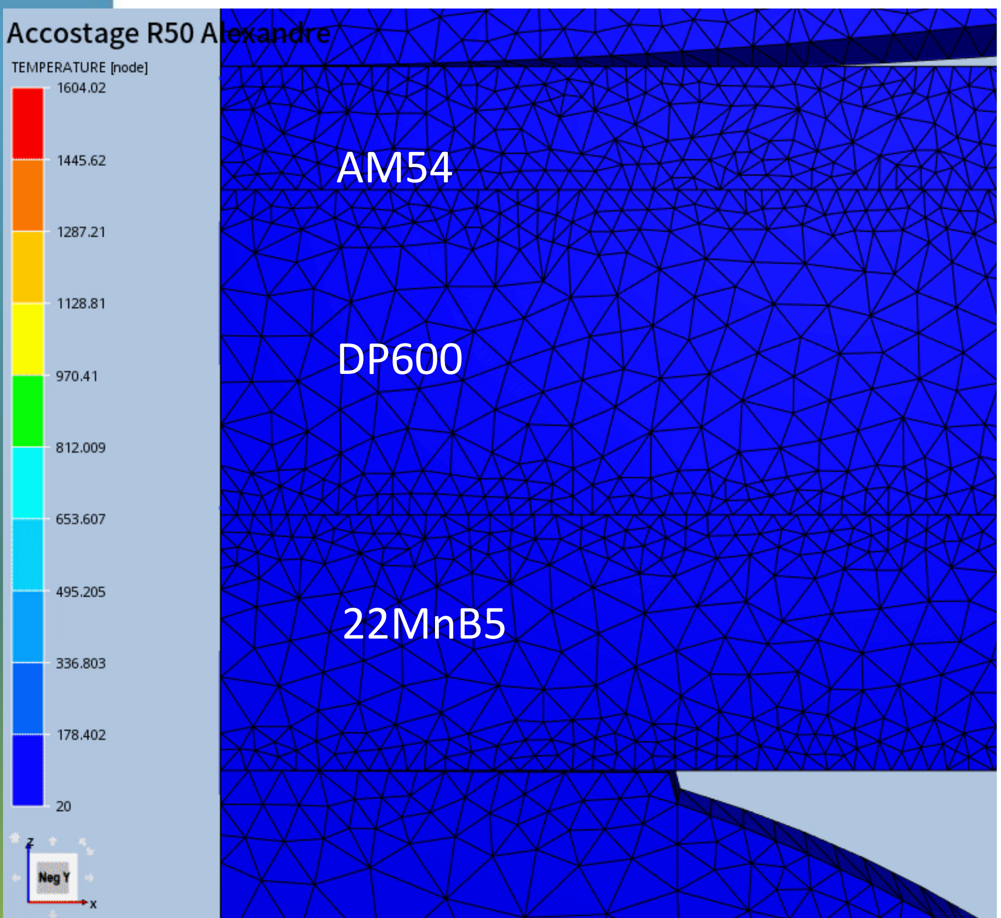
Wear electrode

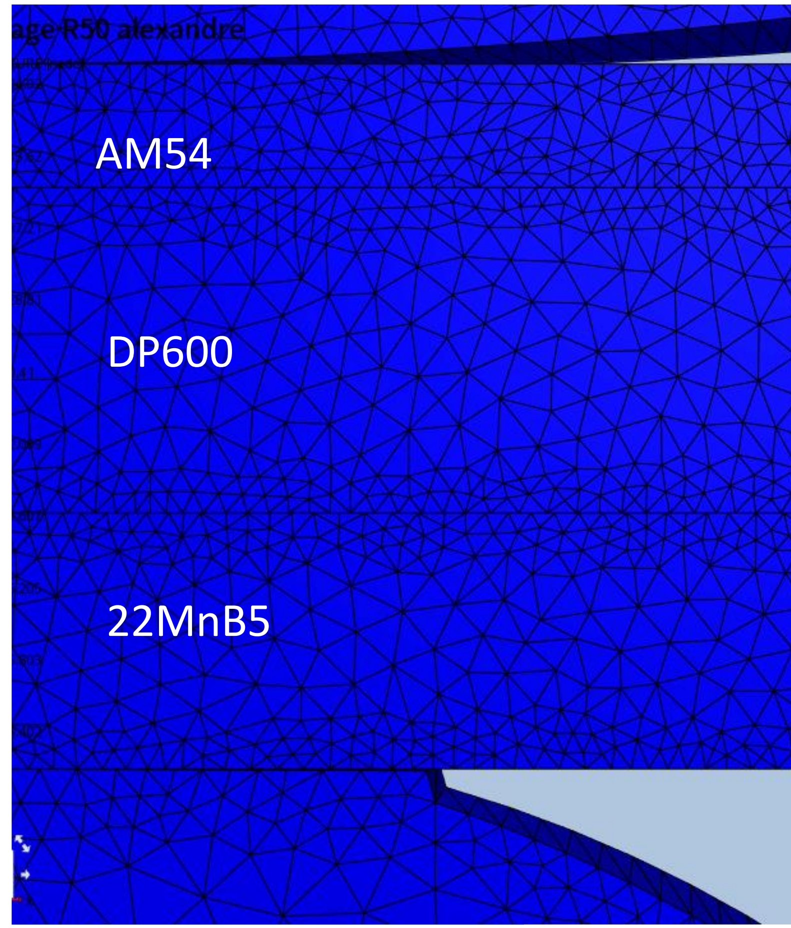




Splashing

Possible cause of the splashing

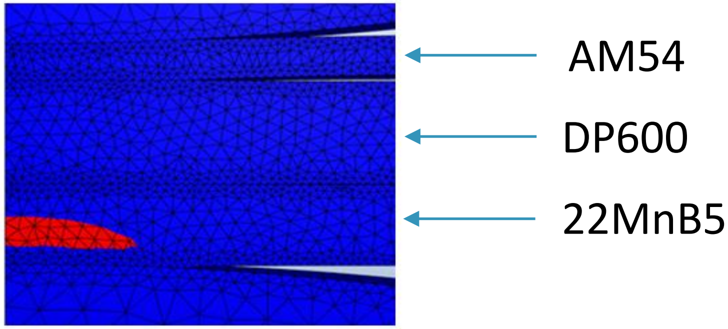


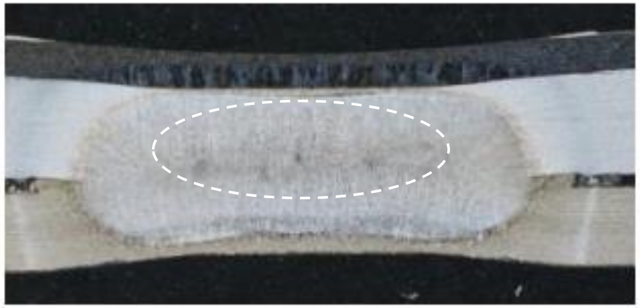


ZF (> 1500°C) :

Conclusion

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





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

I (kA) ↗ F (kN) ↘ $R_{curvature\ (mm)}$ ↗

▪ 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 (Tmax, Pmax) 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

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Thank you for your attention