School of Engineering

Experimental and Numerical Analysis of an Electromagnetic Pulse Welding process

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Plan

I. Electromagnetic Pulse Welding

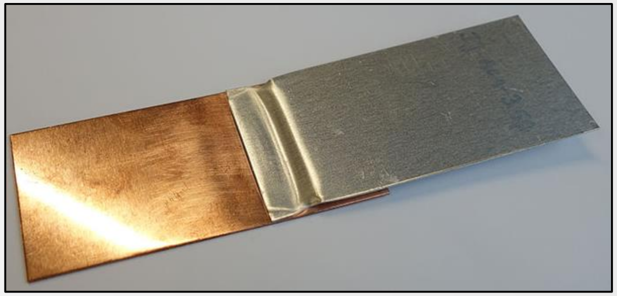
II. Nassiri case study

III. Join'EM case study

IV. Conclusion and Perspectives

Electromagnetic Pulse Welding

- Electromagnetic forming is a high-speed forming technology using the energy density of pulsed magnetic fields in order to apply Lorentz forces to electrically conductive workpieces.
- EMF is a comparably new and attractive technology, which is especially promising for joining / welding, forming and cutting of tubular or sheet metal components.



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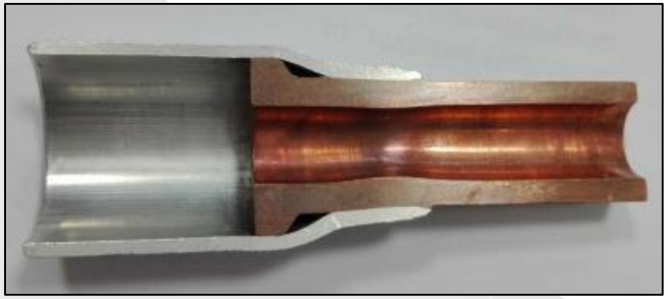

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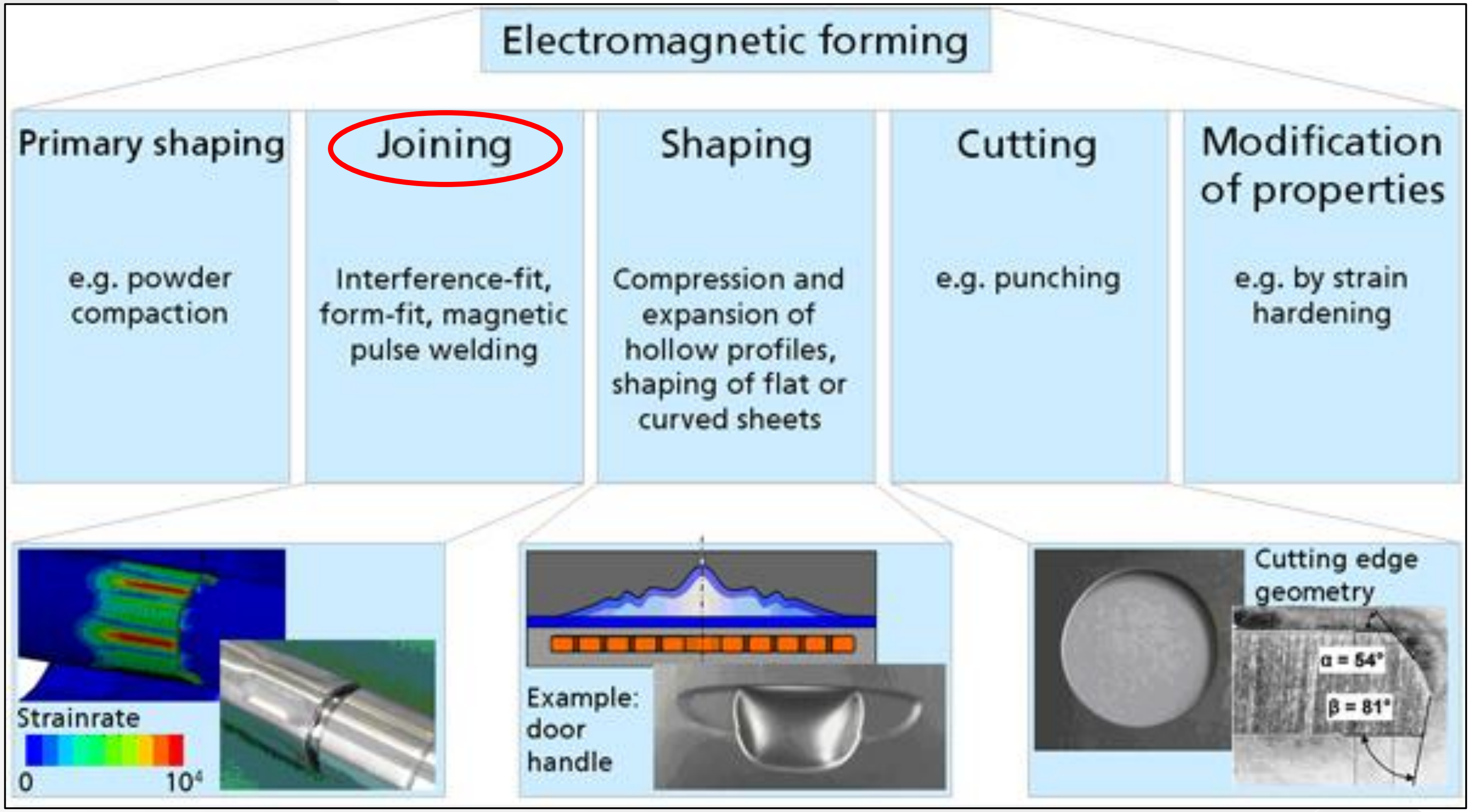
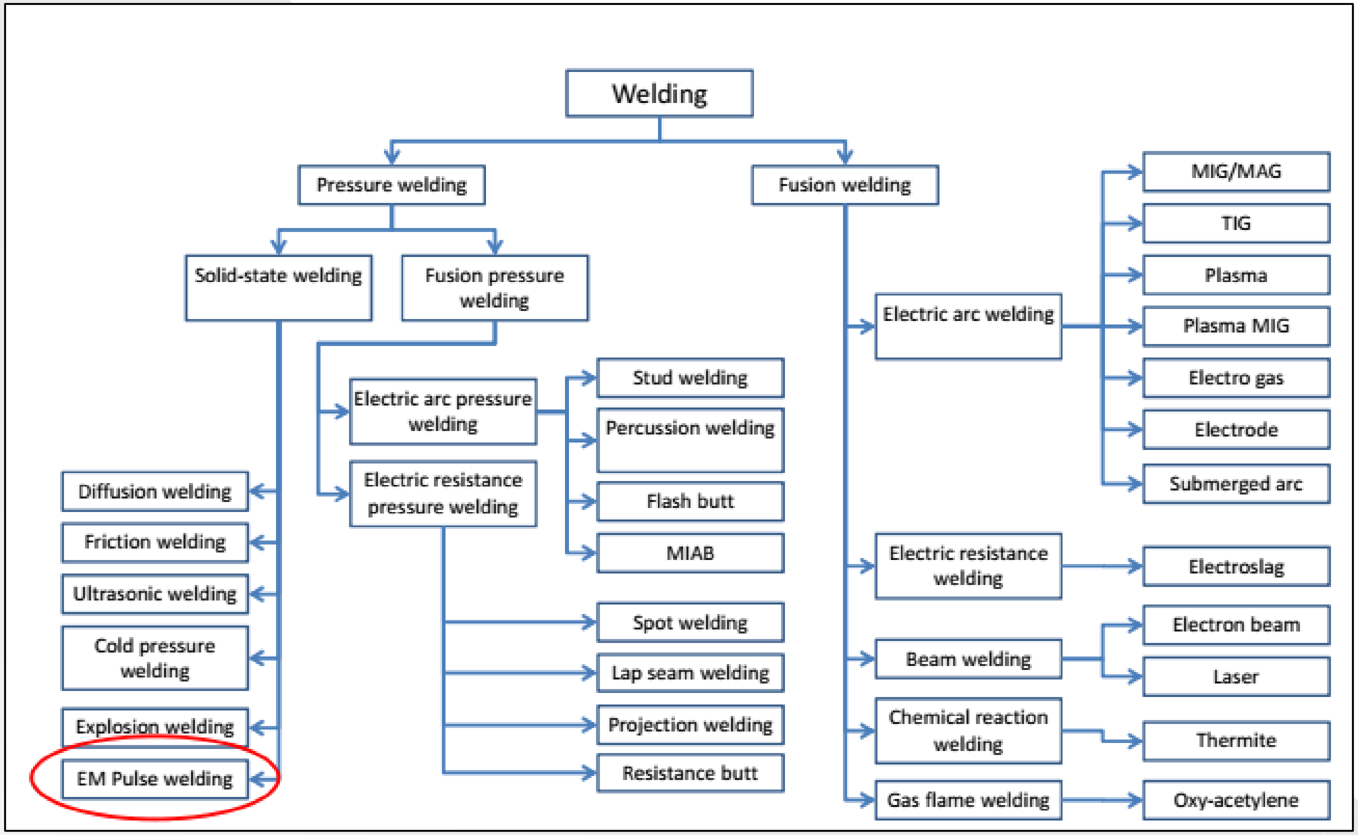
Electromagnetic Pulse Welding

- Electromagnetic forming [1]



Electromagnetic Pulse Welding

- Classification of welding processes based on the energy source [2]



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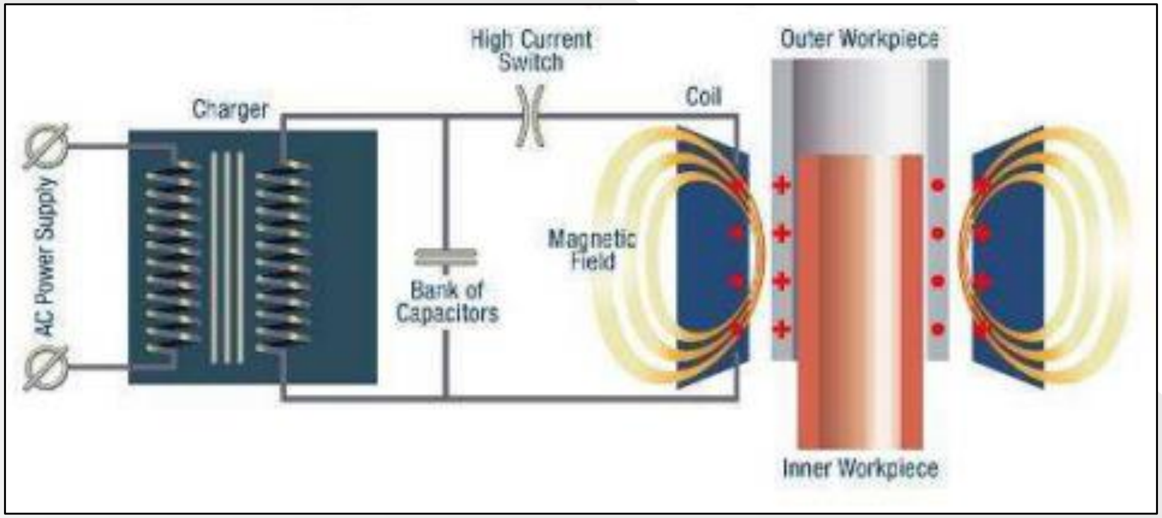
Electromagnetic Pulse Welding

- Electromagnetic Pulse Welding is a pressure/impact welding process.
- MPW is one of the variants of impact welding technologies.
- MPW uses transient magnetic fields to accelerate a conductive flyer metal part towards a fixed part (base).



[3]

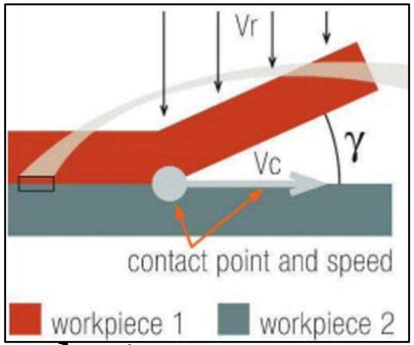
Electromagnetic Pulse Welding

- The quality of the bond at the interface is the result of:

  *The magnetic pressure (The impact velocity).

  *The collision angle

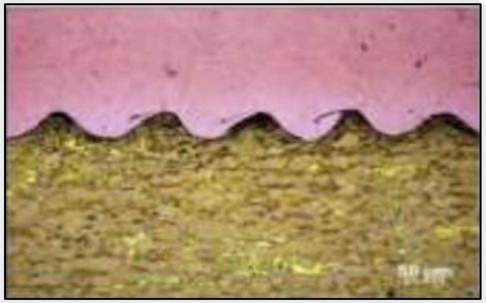
  *The initial standoff distance between the two workpieces.



[3]

- The morphology could be straight, wavy or vortical.

[4]



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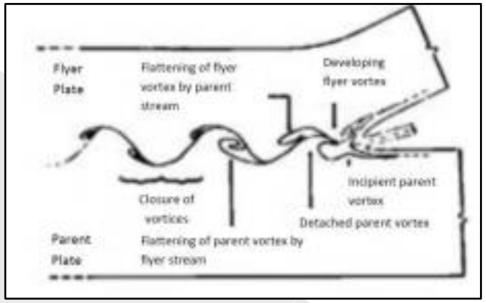

[4]

Electromagnetic Pulse Welding

- Different case studies have been investigated:

*Nassiri & al [5]

*Join'EM (Research project funded by the Union's Horizon 2020 research and innovation programme under grant agreement No. H2020-FoF-2014-677660 — JOIN-EM):

-V 112

-V 82

These two test cases come from the Frauhofer Institute for Machine Tools and forming Technology IWU.

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Nassiri Case Study

- Nassiri : Fully coupled thermomechanical transient analyses of the impact of two inclined plates with Abaqus /Explicit 6.13 (ALE formulation).
- Icam : Same with Marc Mentat 2017 B / Implicit (Lagrangian formulation with remeshing technologies).
- Objectives : Compare our results with Nassiri's results to validate our numerical methodology.

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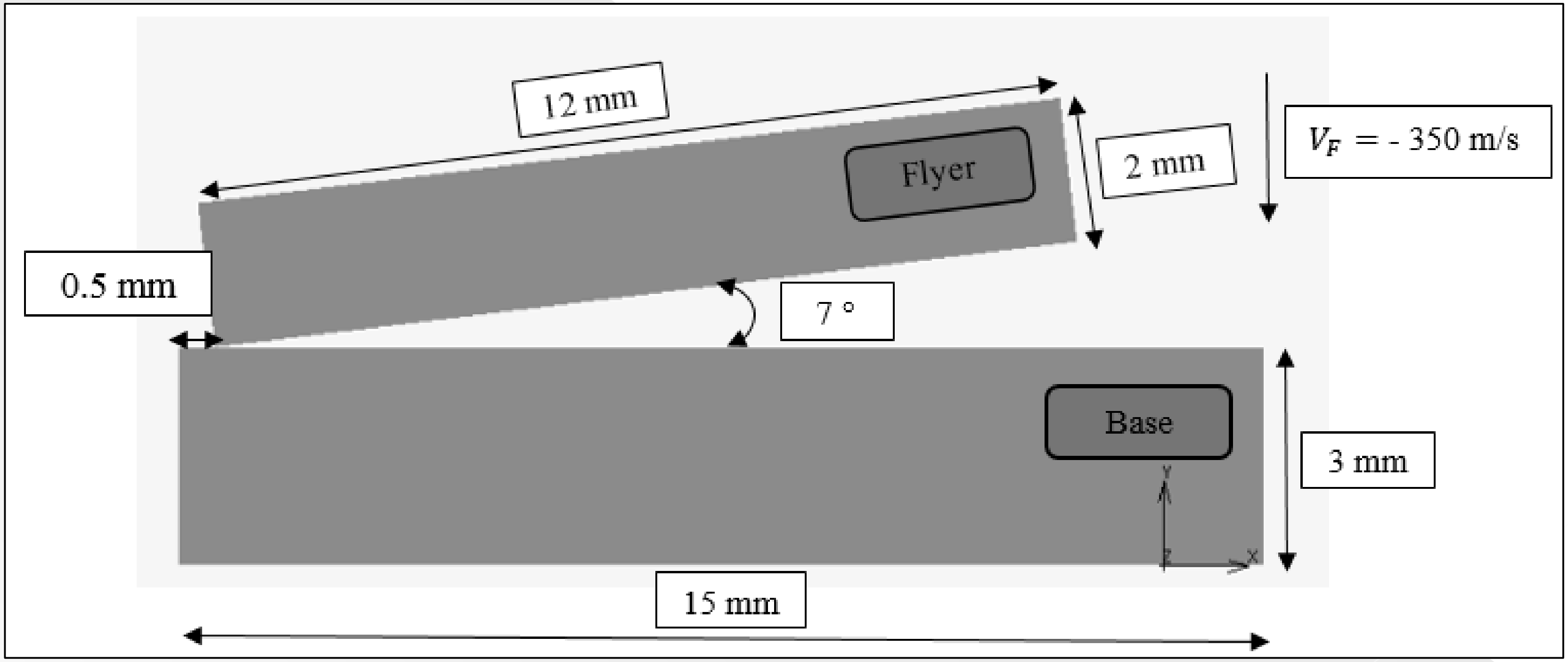
Nassiri Case Study

- The geometry of the flyer, the base and the initial position are given hereafter :



Nassiri Case Study

- Equations to be solved by FEA

Mechanical Analysis

$$\nabla \cdot \sigma + \underset{\text{int}}{\vec{f}} = 0$$

$$\sigma = \mathbf{C}\epsilon^e$$

$$\epsilon = \epsilon^e + \epsilon^p + \epsilon^{\text{th}}$$

with

$$\epsilon^e = \frac{1+\nu}{E}\sigma - \frac{\nu}{E} tr(\sigma)\mathbb{I}$$

$$\epsilon^p = g(\sigma_Y)$$

$$\epsilon^{\text{th}} = \alpha(\theta - \theta_0)$$

Thermal Analysis

$$\rho \frac{dh}{dt} = \nabla \cdot (\lambda \nabla T) + Q_V$$

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Nassiri Case Study

- Units System : mm/tonne/s/K
- 2D mesh, plane strain, elements with reduced integration (type 115).
- Fine mesh near the interface to capture high gradients and remeshing to handle sever deformation.
- Initial conditions :

-Structural :

* a vertical velocity value of -350 m/s imposed on the flyer.

-Thermal :

* a room temperature of 296 K fixed for both the flyer and the base.

Nassiri Case Study

- Boundary conditions:

  -Structural :

  *a null displacement fixed for the bottom of the base.

  *a vertical gravity load for both the base and the flyer.

  -Thermal :

  *a fixed temperature of 296 K for the bottom of the base.

  *a plastic heat generation for both the base and the flyer (Correction factor of 0,9).

  *Adiabatic condition (Only conduction is considered here due to the rapidity of the processes in order few μs).

Nassiri Case Study

- The material for the base and the flyer is Al6061-T6 aluminum.
- The flow rule is the well known Johnson-Cook constitute law :

$$\sigma_y = (A + B\varepsilon_p{}^n)(1 + C ln \varepsilon_p)(1 - T^{*m})$$

ρ (kg/m^3)	E (GPa)	υ	k (W/mk)	C (J/kg°C)
2700	70	0,279	154	860

A (MPa)	B (MPa)	C	n	m	ε_0	T_{melt} (°C)	T_{room} (°C)
289	108	0,011	0,42	1,34	1	653	23

The material properties for Al6061-T6 and the Johnson-Cook model parameters [5]

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Nassiri Case Study

- Two remeshing technologies have been tested:

  - A 2 D solid local remeshing method (*Node In Region*).

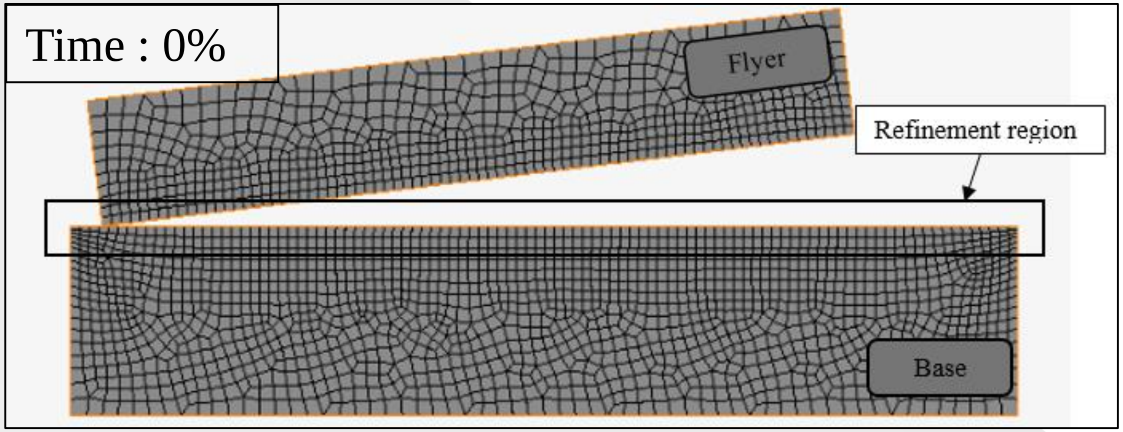
  - A 2 D solid global remeshing method (*Advancing Front Quad*).

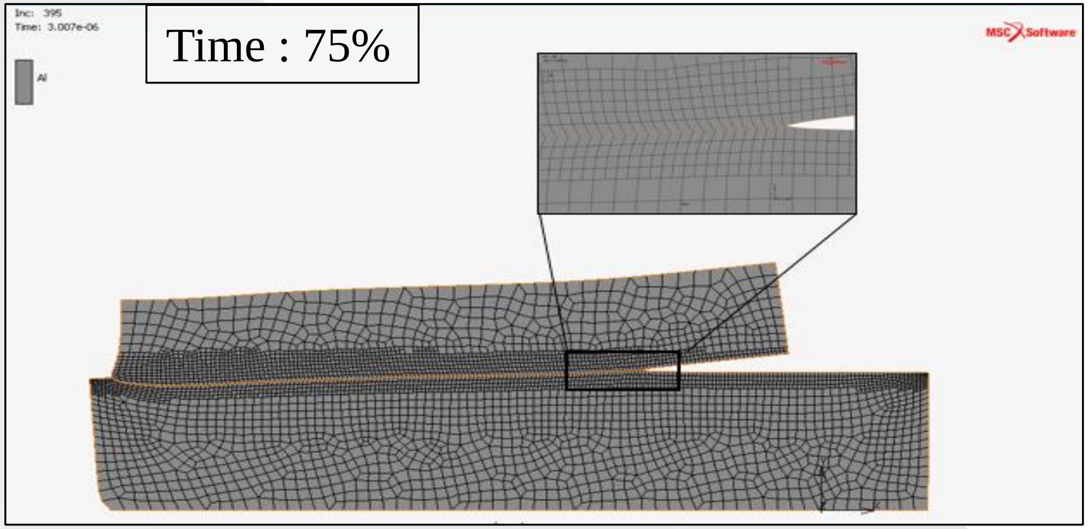
- Process duration : 4 μs

	Local	Global
Initial number of elements	2159	2159
Final number of elements	3740	19065
Wall Time (s)	3838.48	449.56
Minimum Edge Length (MEL) (μm)	60	20

Nassiri Case Study

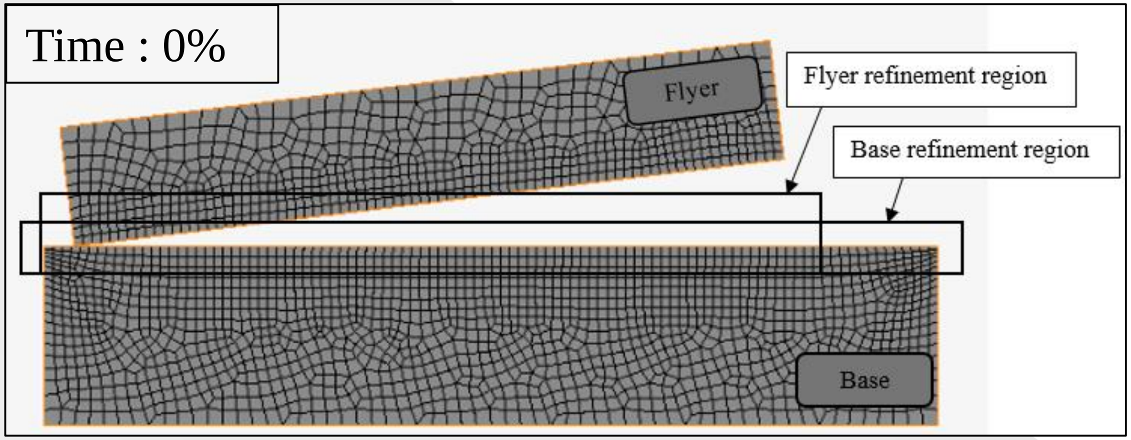
- Mesh evolution due to local remeshing

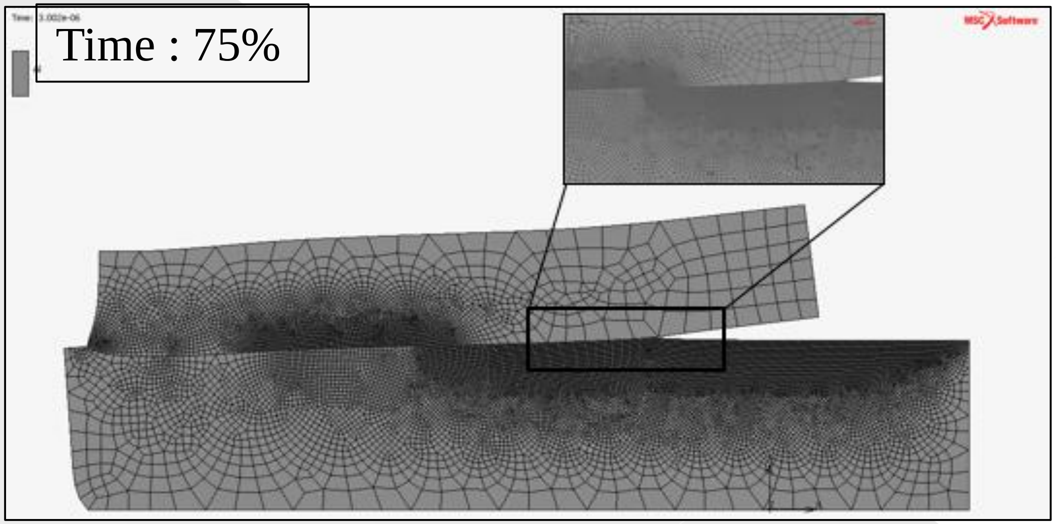




Nassiri Case Study

- Mesh evolution due to global remeshing





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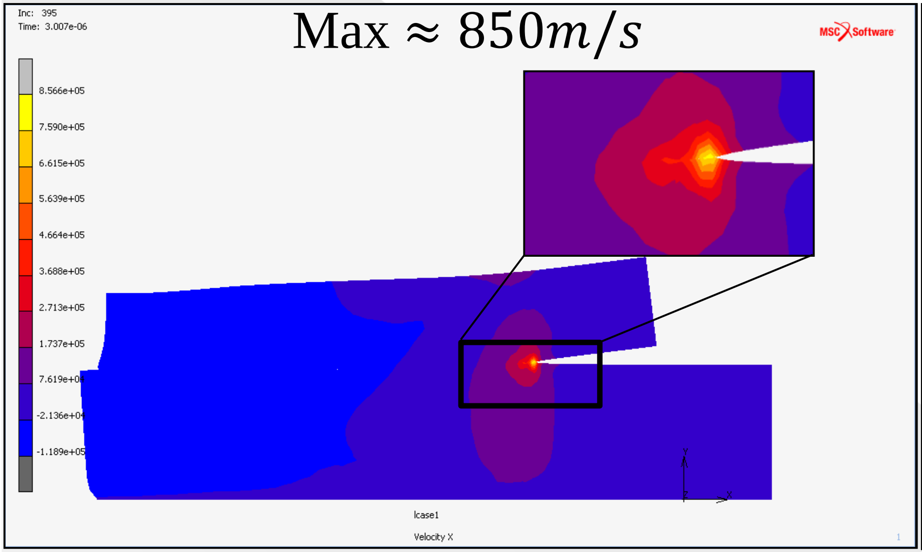
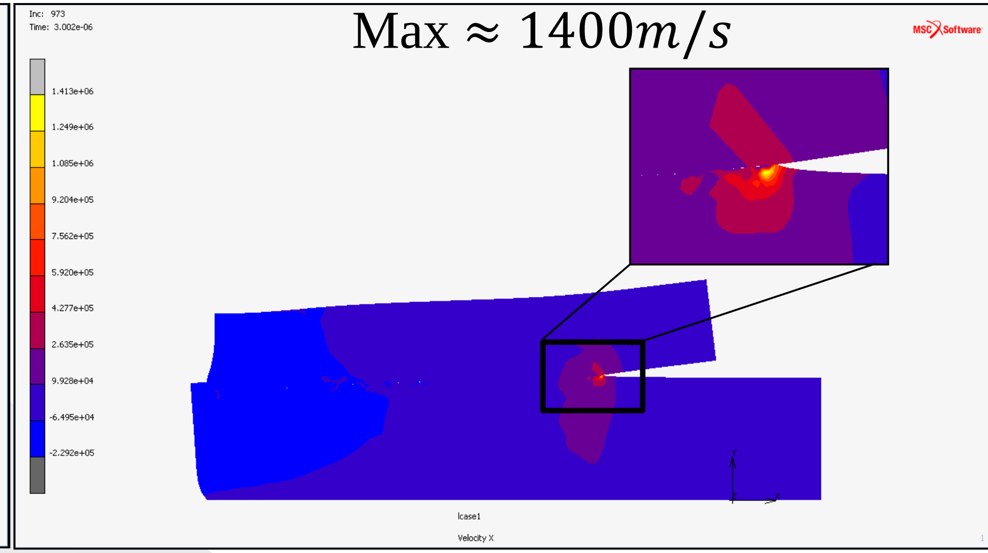
Nassiri Case Study



Velocity X (Local)



Velocity X (global)

- The highest velocity value is at the collision point.
- The difference in the value is easily explained by the difference in MEL (60 μm vs 20 μm).

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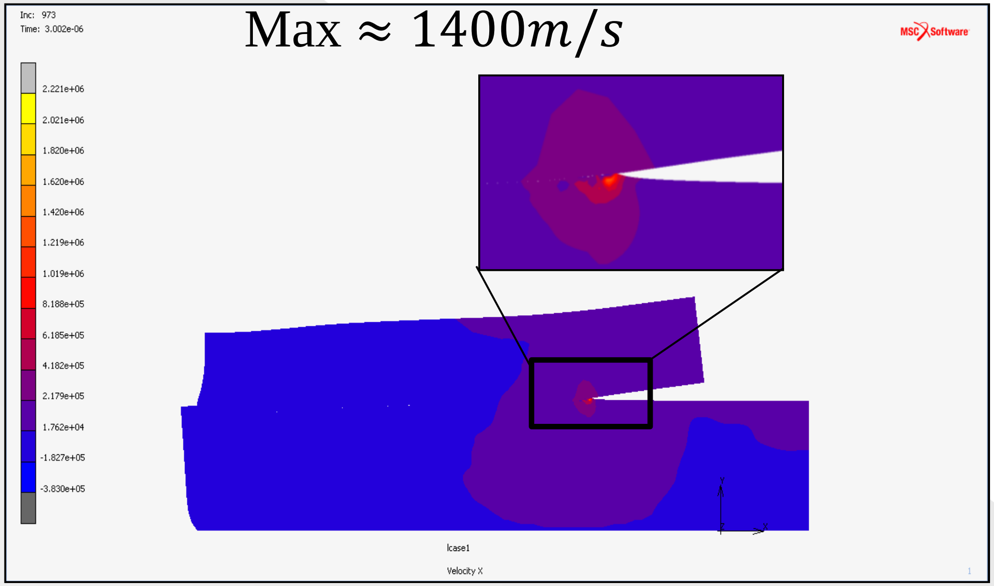
Nassiri Case Study

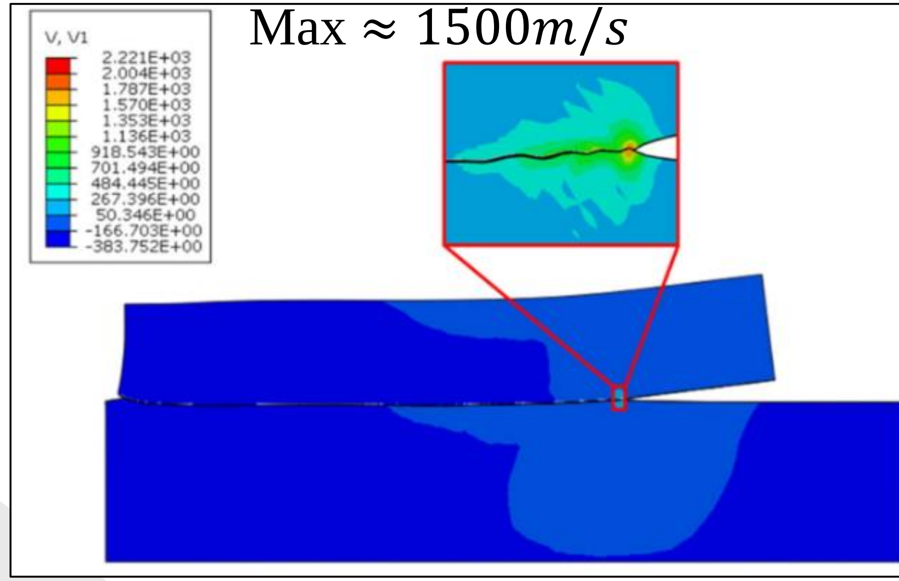
- Theoretically the value of collision velocity V_c could be calculated by the following formula :

$$Vc = \sqrt{\frac{2Re_{transition}(H_{flier} + H_{base})}{(\rho_{flier} + \rho_{base})}} \sim 1400\ m/s \quad [5]$$

- With global remeshing , the value is closer to the theoretical value than the local remeshing due to the lower MEL.

Nassiri Case Study





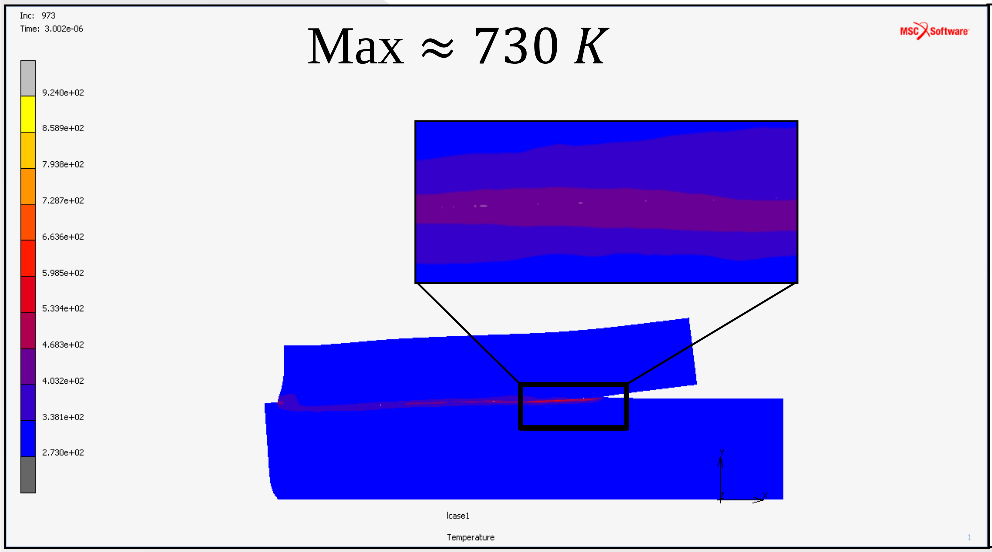
Shear Velocity (Marc)

Shear Velocity (Abaqus)

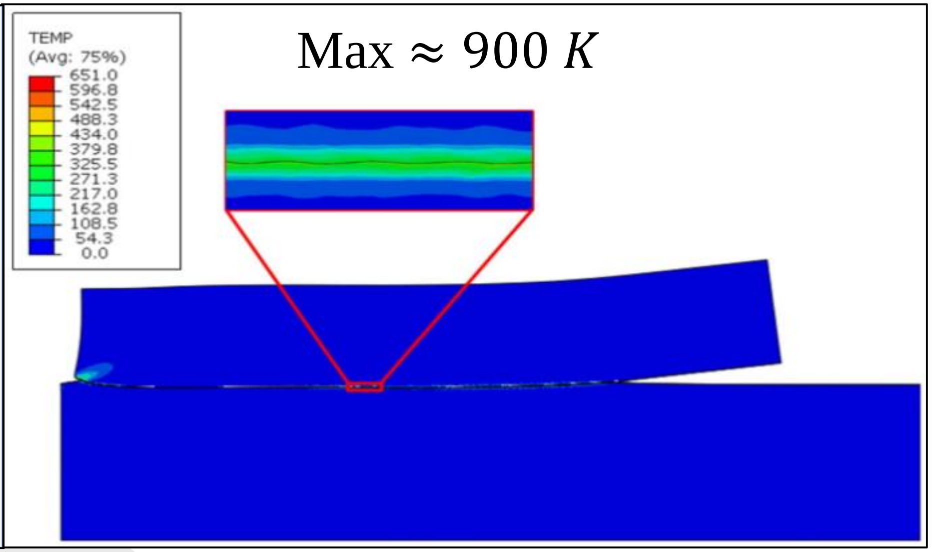
- The value of the shear velocity is about ~ 1400 m/s whereas Nassiri's value is about ~ 1500 m/s.

➔ The small difference is due to the coarser mesh used in our study (5μm MEL for Nassiri versus 20 μm for the current study).

Nassiri Case Study



Temperature (Marc Mentat)



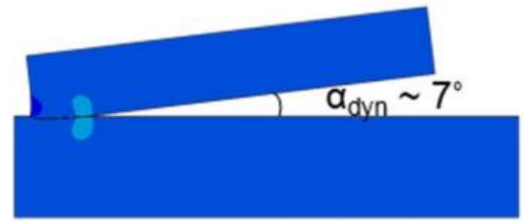
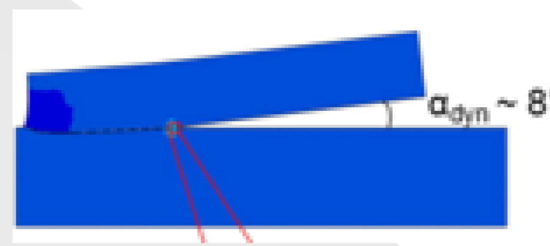
Temperature (Abaqus)

- The results show max temperature value ~ 730 K whereas in the Nassiri case where the value ~ 900 K.
- In the both cases (Marc and Abaqus) the temperature < T_{melt} = 926 K

➔ Cold welding

Nassiri Case Study

- Dynamic impact angle.

	
	
Marc	Abaqus

Nassiri Case Study

Conclusion

- Our results are comparable with Nassiri's results (Temperature, velocity fields,…).
- The small differences observed near the collision point and the interface are related to the coarser mesh used (additional effort should be node to achieve numerical convergence).

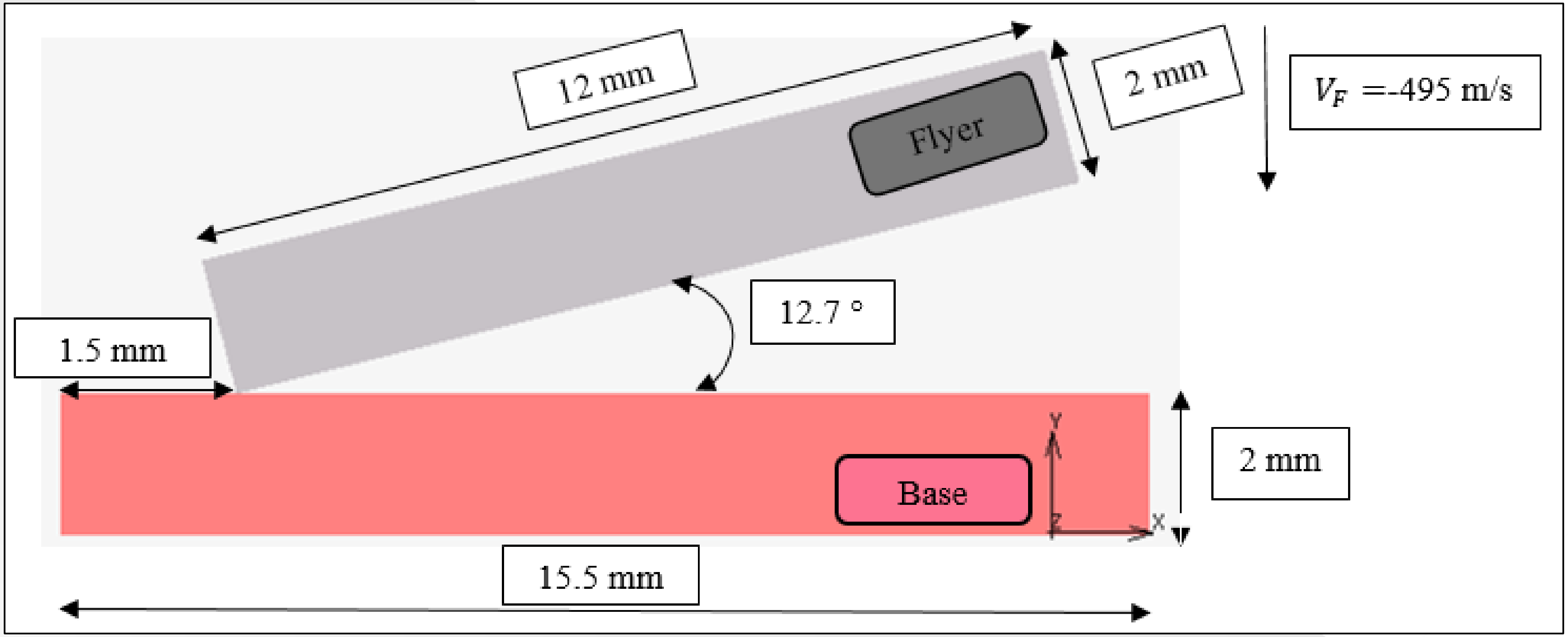
Join'EM case study

- Join'Em is a EU project started in September 2016 which addresses the increasing requirements to join dissimilar materials (aluminium and copper) by electromagnetic fields.
- Its overall goal is to support the development of MPW technologies and to provide an advanced and green manufacturing process to the industry.
- Among the 14 partners of this project, the mechanical department of Icam is involved in package 3 : "Development of Simulation strategies".

http://www.join-em.eu/

Join'EM case study (V112)

- Configuration tested : flyer is in aluminium and the base is in copper.



Join'EM case study (V112)

- 2D solid global remeshing.
- Johnson-Cook constitutive law.
- Process duration : 7 μs.
- Number of elements : 2826 => 7025.
- MEL : 60 μm .

Join'EM case study (V112)

- Initial conditions :

  -Structural :

  * a vertical velocity value of -495m/s imposed on the flyer.

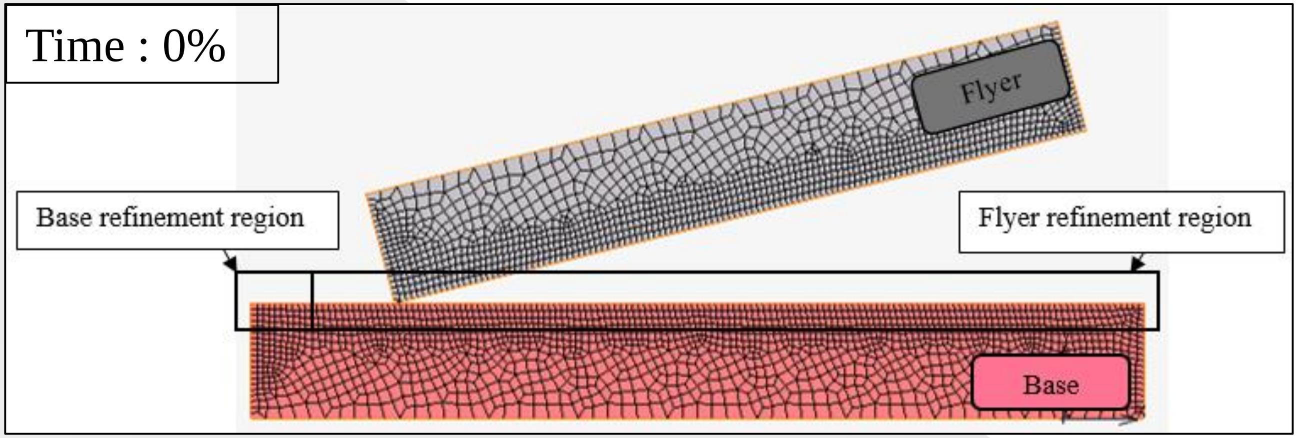
  -Thermal :

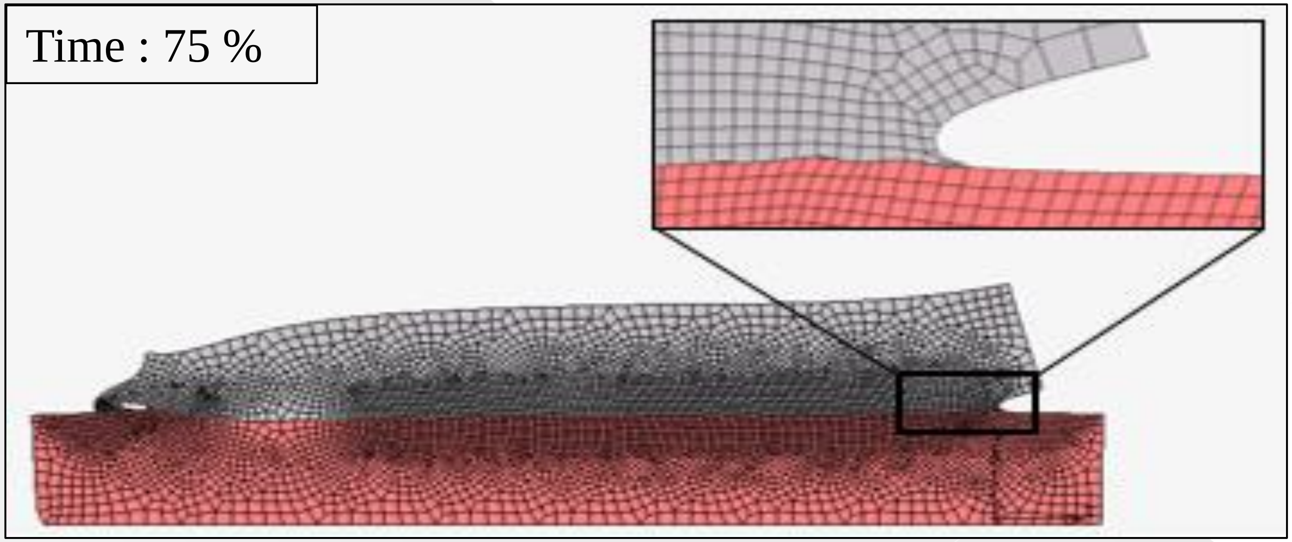
  * a room temperature of 296 K fixed for both the flyer and the base.

- Boundary condition : same as Nassiri's case.

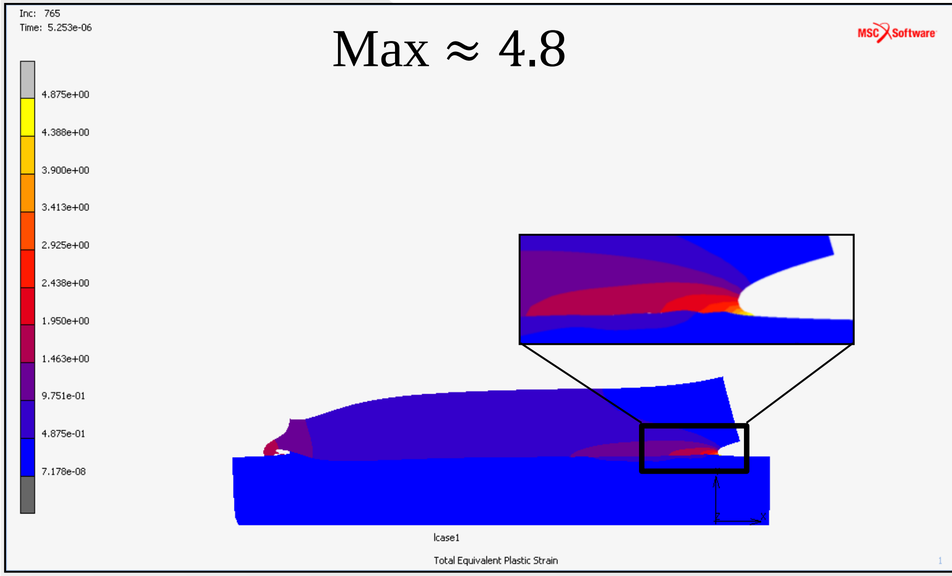
Join'EM case study (V112)

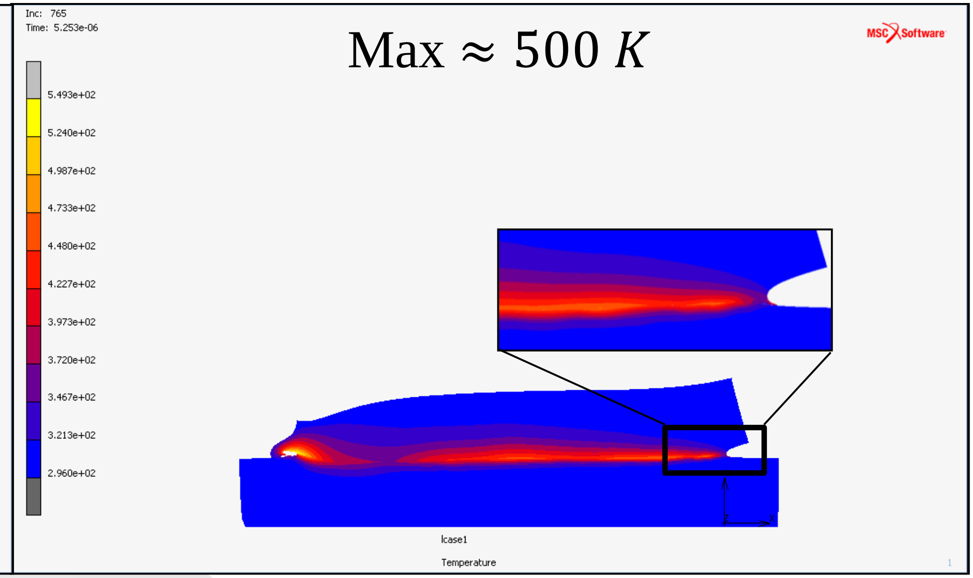
- Mesh evolution due to global remeshing





Join'EM case study (V112)





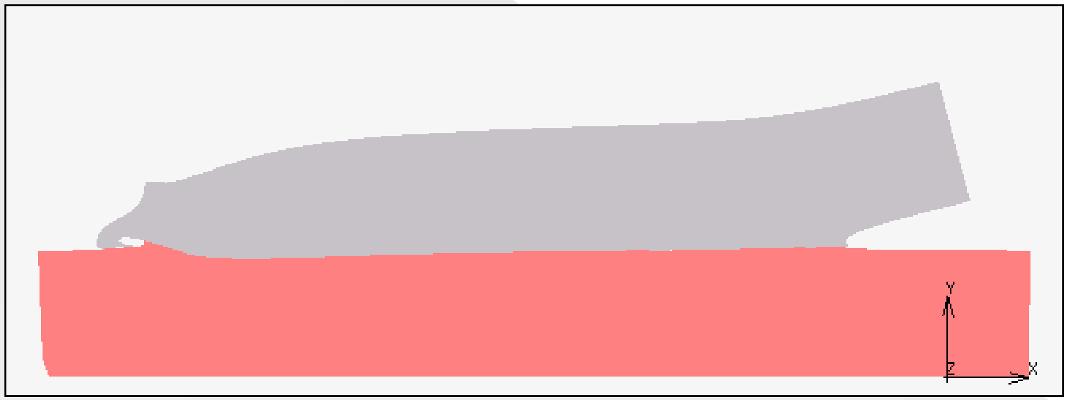
Total Equivalent Plastic Strain

Temperature

- Elevation of temperature is due to plastic strain.
- The temperature of the interface is approximately 500K< T_{melt} = 926K
  ➔ Cold weld

Join'EM case study (V112)

- Experimental validation



Numerical

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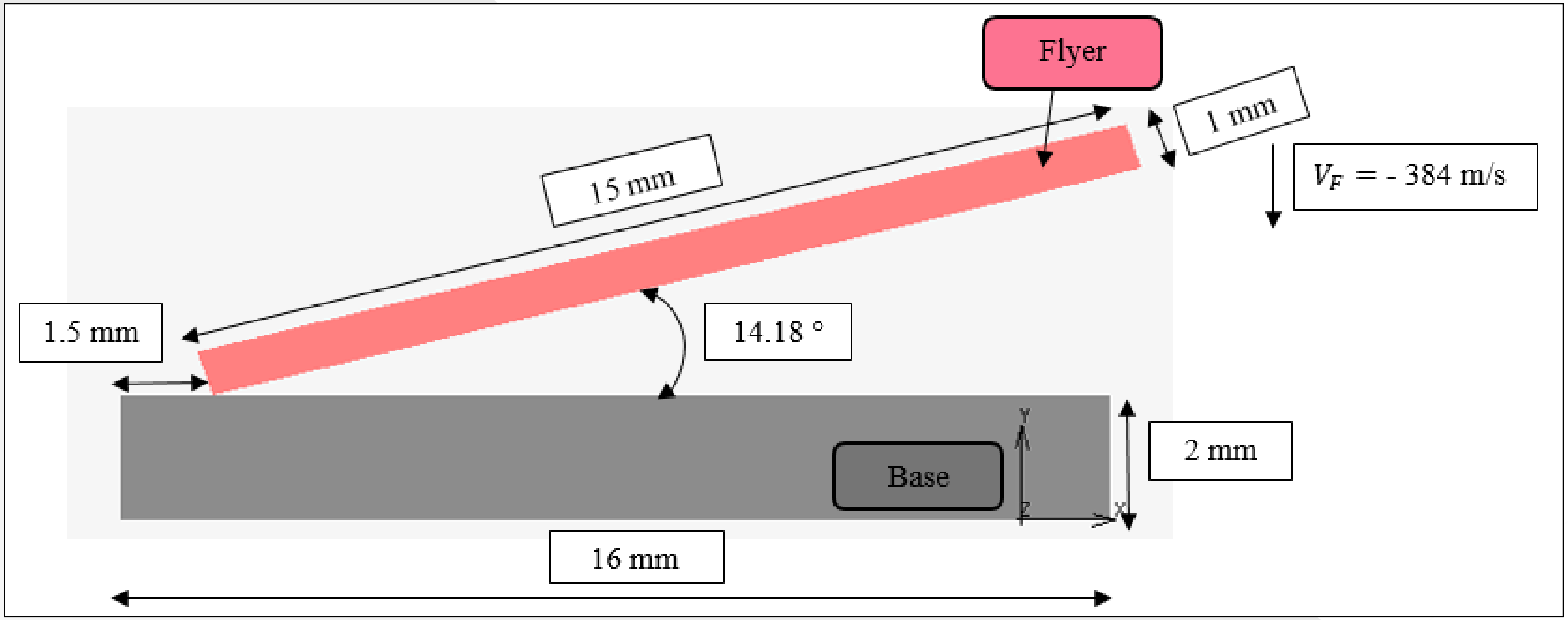
Experimental

Join'EM case study (V82)

- Configuration tested : flyer is in copper and the base is in aluminium



Join'EM case study (V82)

- 2D solid global remeshing.
- Johnson-Cook constitutive law.
- Process duration : 10 μs.
- Number of elements : 2227 => 4620.
- MEL : 45 μm .

Join'EM case study (V82)

- Initial conditions :

  -Structural :

  * a vertical velocity value of -384m /s imposed on the flyer.

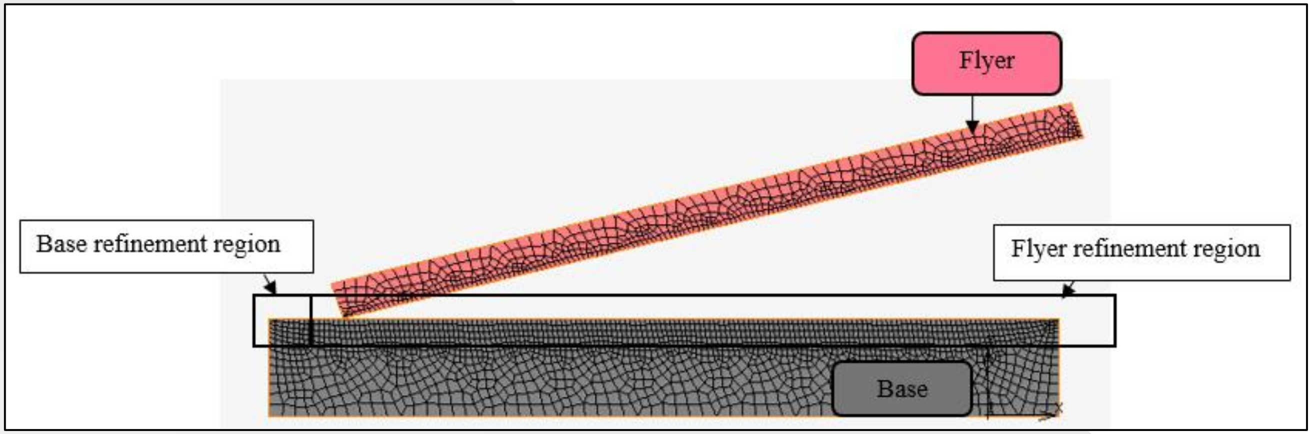
  -Thermal :

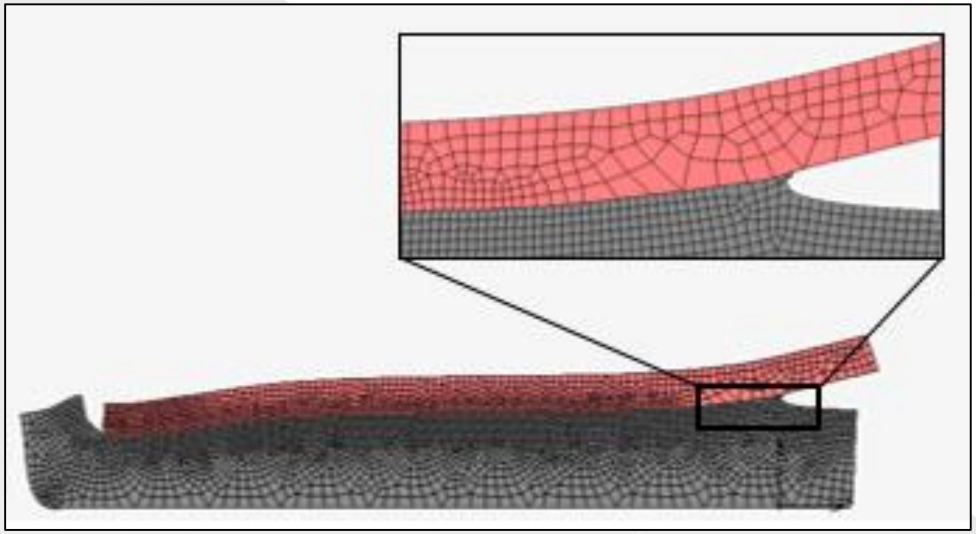
  * a room temperature of 296 K fixed for both the flyer and the base.

- Boundary condition : same as Nassiri's case.

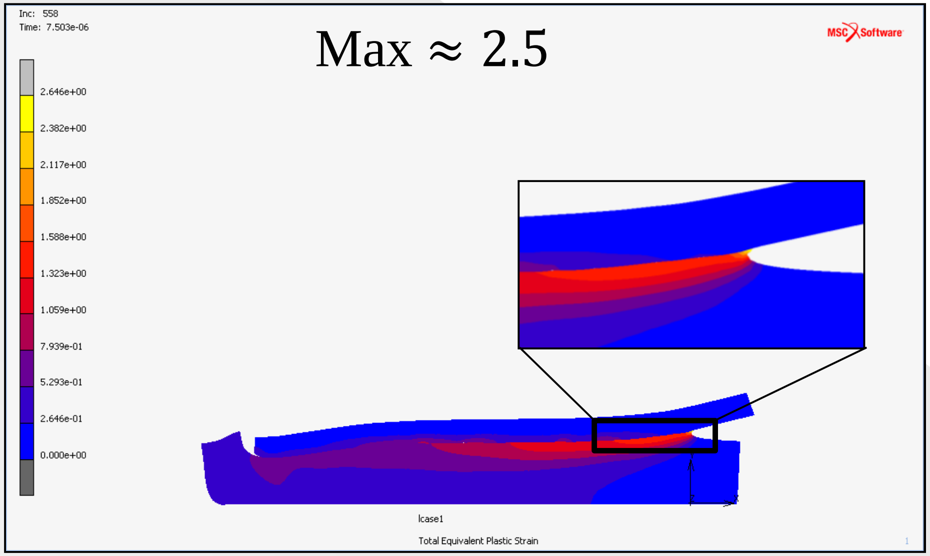
Join'EM case study (V82)

- Mesh evolution due to global remeshing

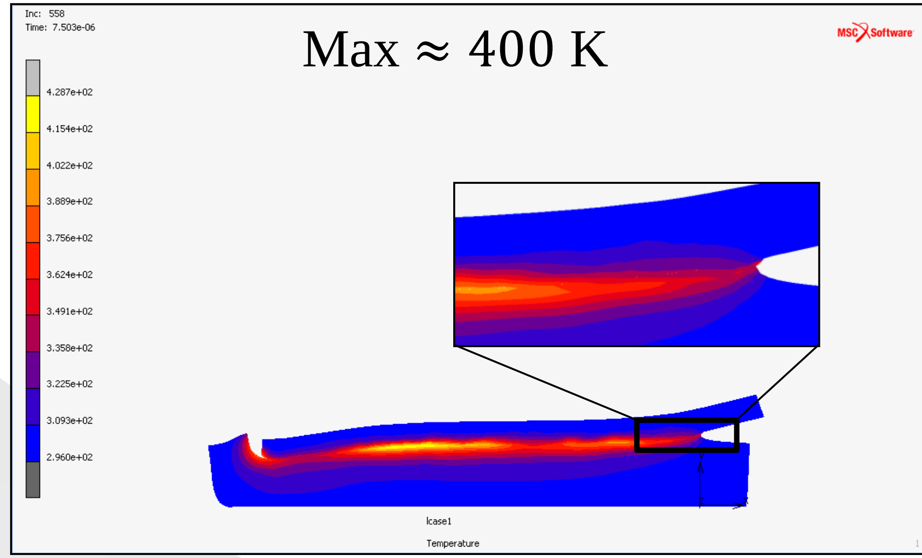




Join'EM case study (V82)



Total Equivalent Plastic Strain



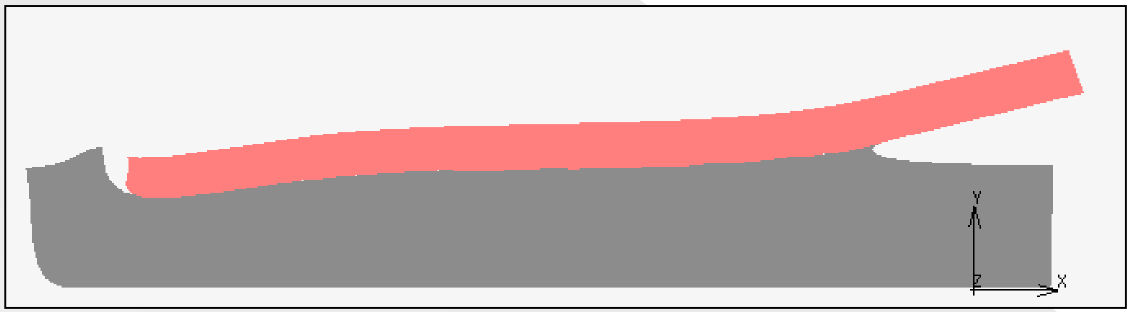
Temperature

- Elevation of temperature is due to plastic strain.
- The temperature of the interface is approximately 400K< T_{melt} = 926K

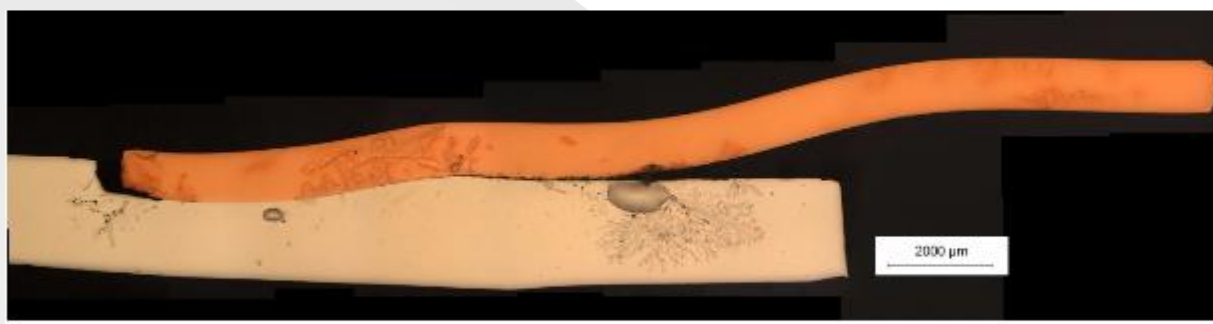
➔ Cold weld

Join'EM case study (V82)

- Experimental validation



Numerical



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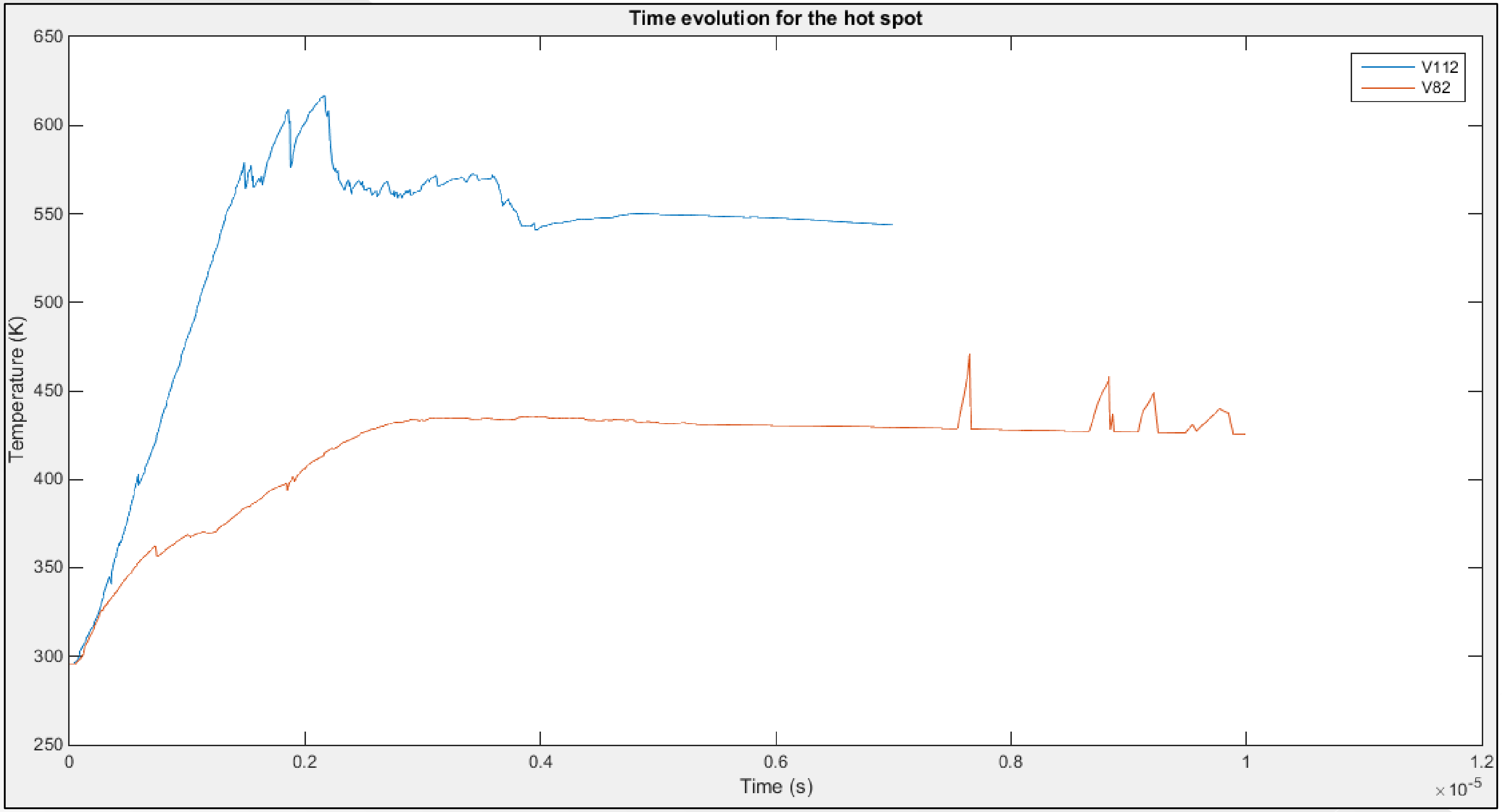
Experimental

Join'EM case study

- Time evolution for the hot spot (V112&V82).



Conclusion and Perspectives

- 2D simulation of Nassiri's case (Marc 2017 B) is closer to Nassiri's article (Abaqus /Explicit 6.13).

To Do:

- Improvement of contact management.
- 3D simulation.
- 2D axisymmetric simulation (Tube welding).
- Further experimental validations.
- Multiphysics simulation (Magneto-dynamic, Thermal, Structural).
- Mesoscale simulation (Eulerian modeling with MSC Nastran).

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