SAFRAN SA

MODELLING THE ELECTROPOLISHING PROCESS AS AN AID TO INDUSTRIALISATION

BOUCHER Aurélien

PhD Student Safran SA – UTINAM

DOCHE M.-L., HIHN J.-Y. (UTINAM), EXBRAYAT L. (SAFRAN)

30 nov. / 1er déc. 2022

ESPACE AUGUSTE COLMAR

Journées Traitements et parachèvements de pièces issues de fabrication additive

ASSOCIATION FRANÇAISE DU TITANE
The French Titanium Association

A3TS

IRT M2P

SAFRAN

Sommaire

01 | Target

02 | Preliminary test

03 | Electropolishing process

04 | Methodology developped on AM 316L SS

05 | Transfer on AM Inconel 718

06 | Test case: blading part

Target : surface finishing of blading part

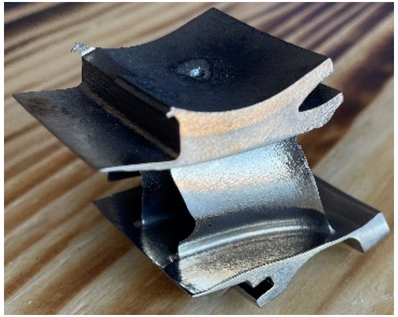
Specifications
Clean upper and lower parts
High roughness reduction of the inner parts

- **Demonstrator part**
  - Metallic additive manufacturing (AM) parts : Inconel 718 + Heat Treatment (HT)
    - AM → poor final surface finish
    - Inconel 718 + HT → alloy hard to mecanically polish

Electrochemical polishing: attractive solution if mastering the scale up of the process
Simulation can reduce the industrialization time by optimizing the treatment conditions and parameters

Preliminary test on the blading part

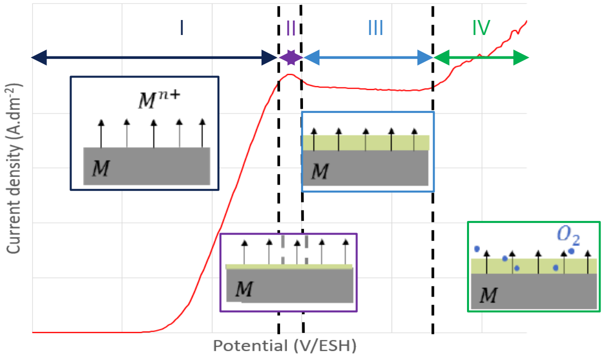
EP



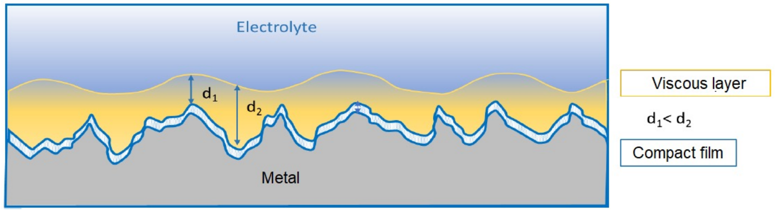
- **Test conditions:**
  - Demonstrator AM Inconel 718 + HT
  - UTINAM Electrolyte (mineral acids mix)
    - 50 °C – moderate directional agitation
    - Un-optimized polishing conditions→ proof of concept
  - Better roughness reduction and brightening with the internal cathode

Electropolishing is promising but subject to optimization
Simulation will allow to define the cathode designing strategy according to agitation and electrical parameters

Principle of electropolishing



Zone I: Active dissolution of metal
Zone II: Viscous layer formation
Zone III: Electropolishing plateau: controlled anodic dissolution
Zone IV: solvent oxidation



- **Mecanism:**
  - Controlled anodic dissolution
    - Levelling → « Macro-roughness » reduction
    - Brightening → « Micro-roughness » reduction
  - Absence of universal electrolyte
  - Main process parameters :
    - Hydrodynamic conditions
    - Potential (constant/pulsed, value)
    - Polishing time
    - Temperature

Principle of electropolishing simulation

- **Prediction of the current or potential distributions:**
  - Input parameters : tank geometry, anode/cathode sizes and positions, electrolyte/substrate data, agitation, etc…
  - Output values : local roughness decreases and dissolution rates

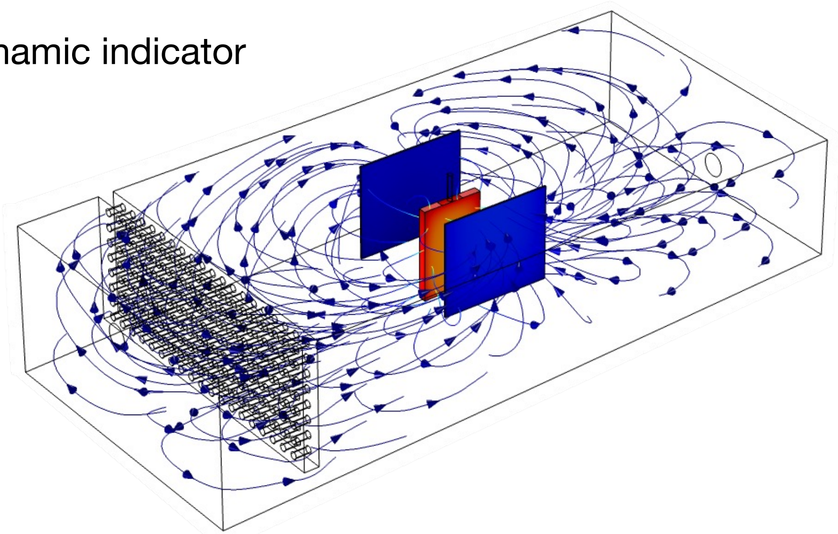
	Primary current distribution	Secondary current distribution	Tertiary current distribution
Characteristic	**No overpotential Potential at equilibrium**	**Overpotential Kinetic's laws**	**Nernst-Planck law: flux of species (diffusion, migration, convection)**
Data acquisition time	1 hour	1 day	1 month
Computation time	couple of seconds	few minutes	several tens of hours

The increase in model complexity leads to an exponential increase in the amount of input data needed and in input data acquisition as well as in computation times !

Methodology developped on AM 316L SS

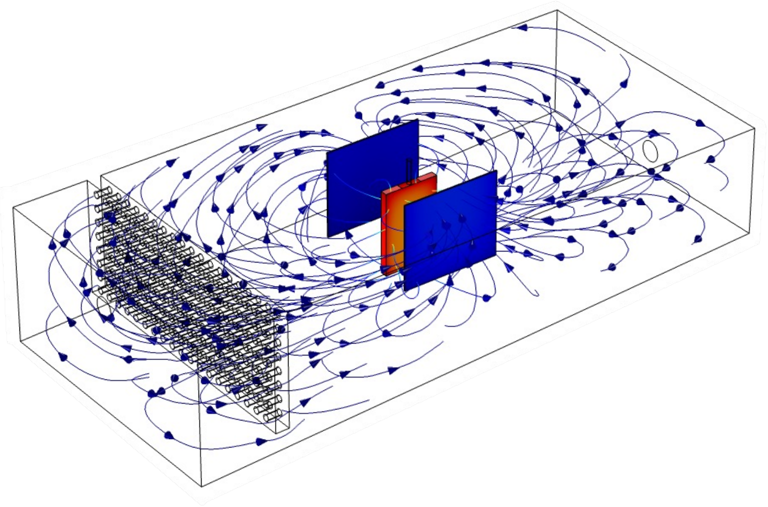
- **Methodology based on two independent simulations**
  - Secondary current distribution
  - Computational fluid dynamic
- **Input data are needed**
  - Data obtained at lab scale
    - Polarization curves (I-E) – dissolution yield – fluid dynamic indicator
    - Abac (dissolution rate and roughness reduction)

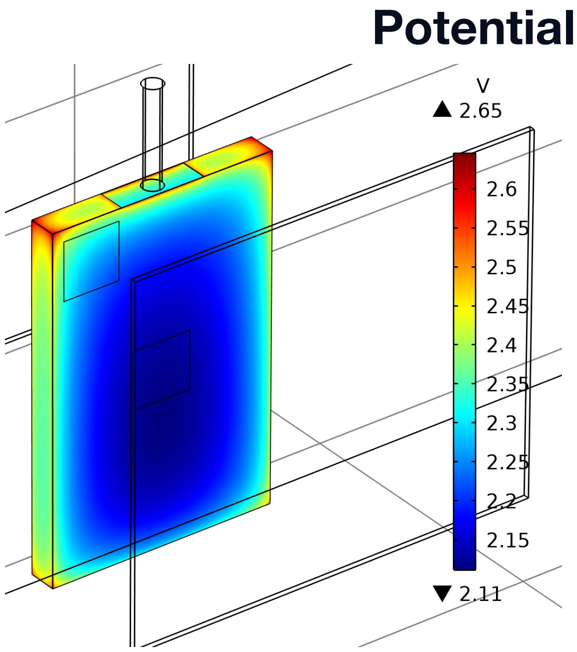
+



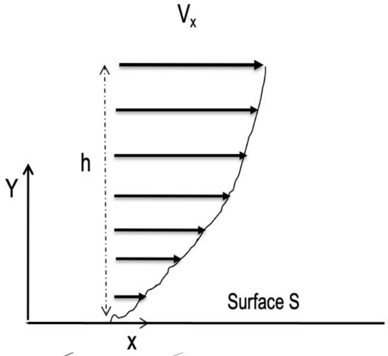
Methodology developped on AM 316L SS

- **Prediction of the secondary current distribution (SCD) resolution**
  - Current lines and current distribution
  - Potential distribution

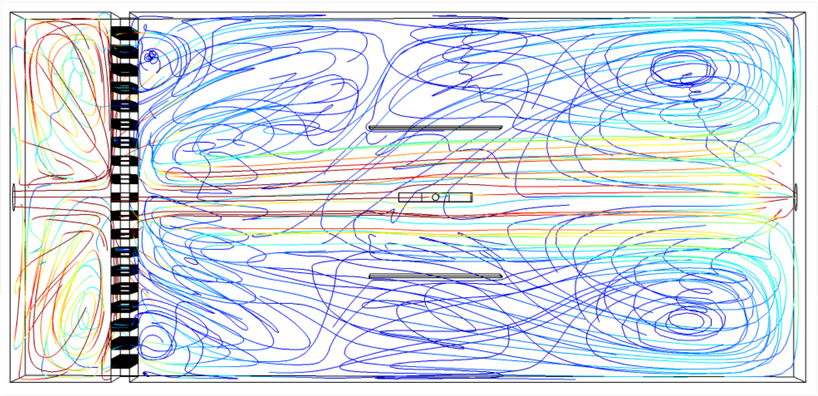


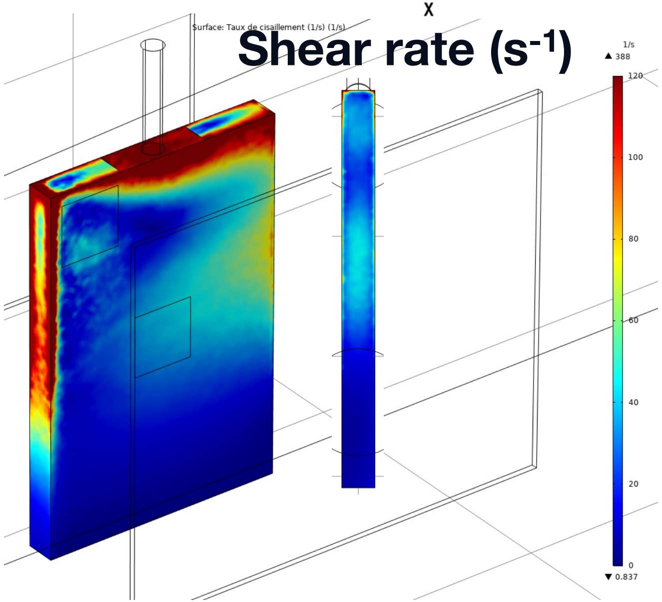


Methodology developped on AM 316L SS



- **Prediction of the computational fluid dynamics (CFD)**
  - Velocity vector field lines
  - Local distribution of shear rates (S_0)

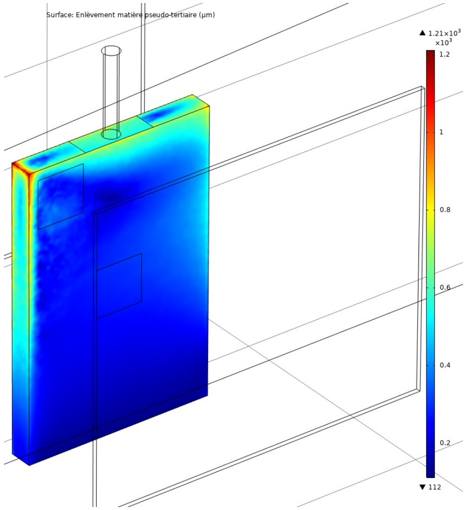




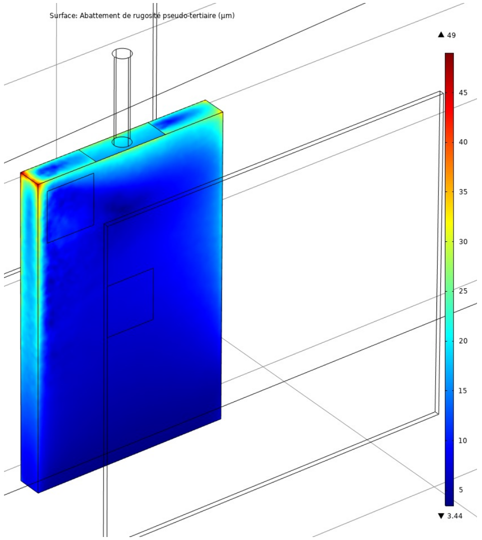
Methodology developped on AM 316L SS

- **Coupling both SCD and CFD gives simulation results for :**
  - Dissolution rate / material removal
  - Roughness reduction rate / roughness decrease
  - Predictability > 80 %

Material removal (µm)



Roughness reduction (µm)



Methodology developped on AM 316L SS

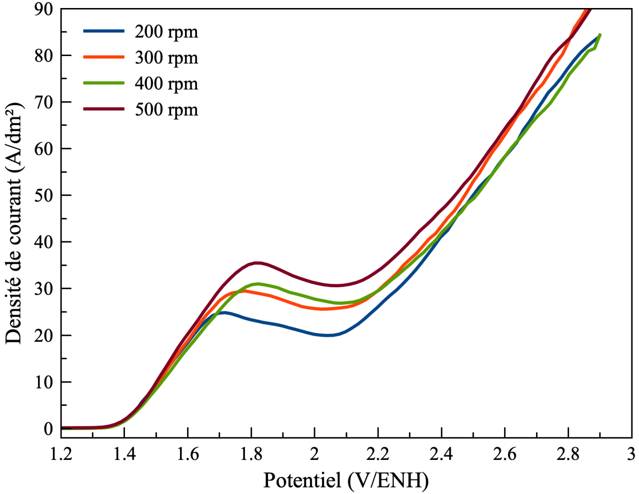
To be transferred on Inconel 718

Transfer on Inconel 718 : abac production

Input data production set-up

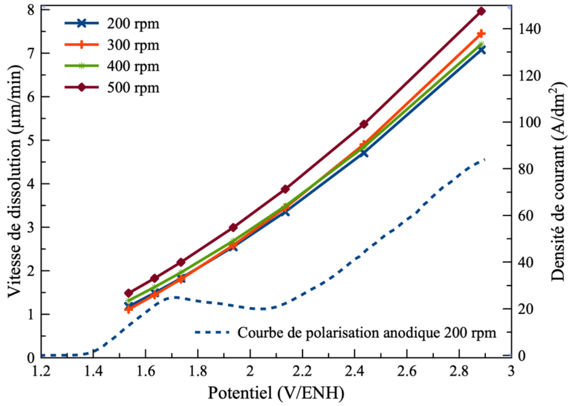
- RDE Ø 5mm (AM Inconel 718 + HT)
- CE: Pt-plated Ti grid
- REF $Hg/Hg_2SO_4/K_2SO_4$
- Mineral acids mix
- Rotating speed (200, 300, 400, 500 rpm)
- Linear sweep voltametry
- Chronocoulometry + Chronoamperometry (EP tests)

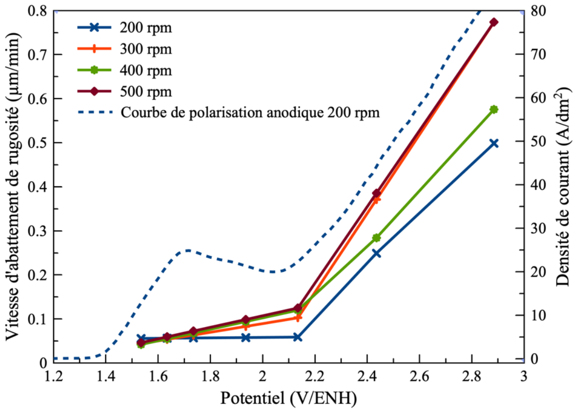
Transfer on Inconel 718 : behavioral law

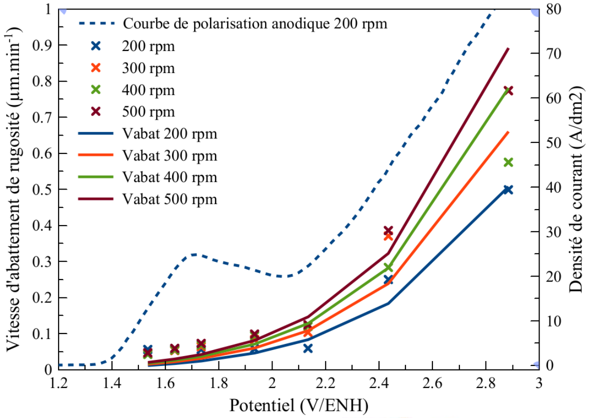


Determination of behavioral laws

- Previous abac
- Linearization as a function of potential
- Linarization according to shear rate
- Introducing temporality in the roughness reduction rate

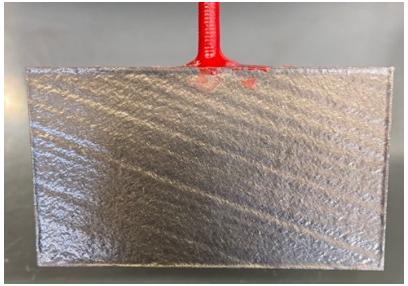


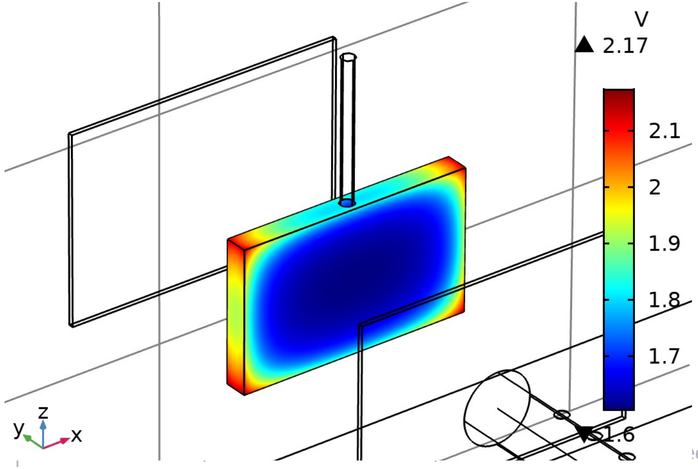




Model validation on AM Inconel 718 plates

- **Electropolishing of plates**
  - AM Inconel 718 plates + HT
  - CE 316L SS plates
  - REF $Hg/Hg_2SO_4/K_2SO_4$
  - Mineral acids mix





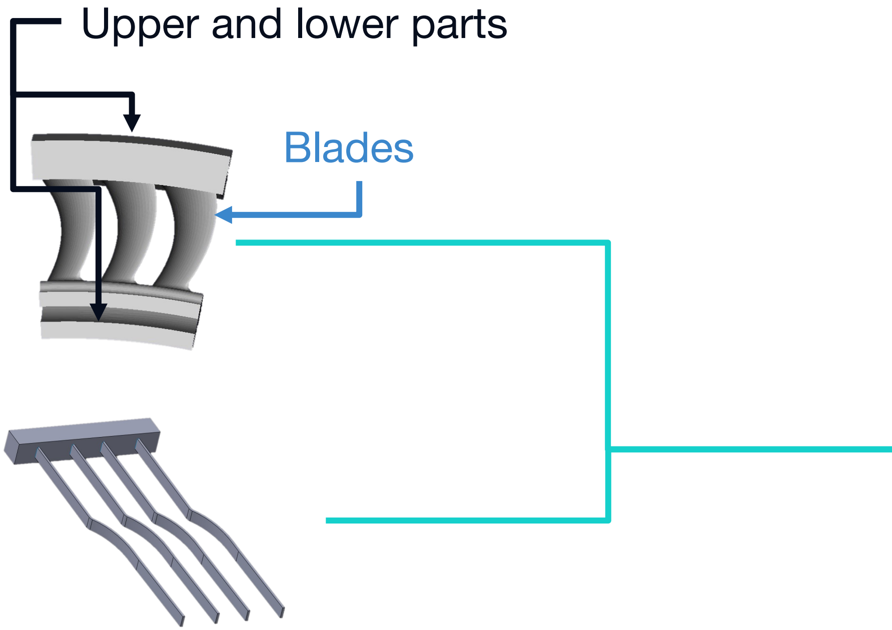
material removal (µm)	
experimental	*120*
predicted	*105*

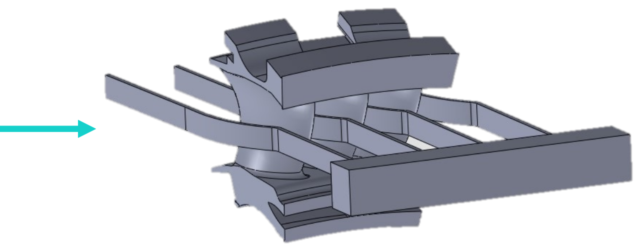
Roughness reduction (µm)	
experimental	*3,18*
predicted	*2,95*

Predictibility (%)	
material removal	*87,5*
roughness reduction	*92,8*

Electropolishing of blading part

Choice of process parameters based on simulation

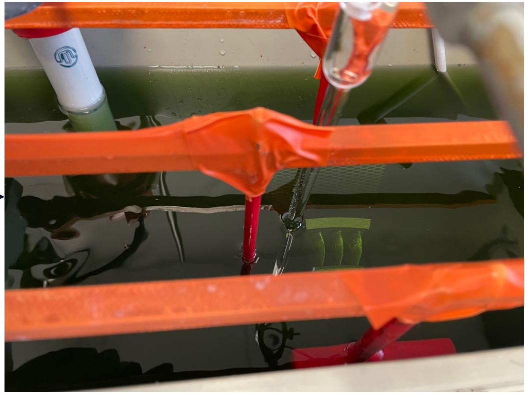


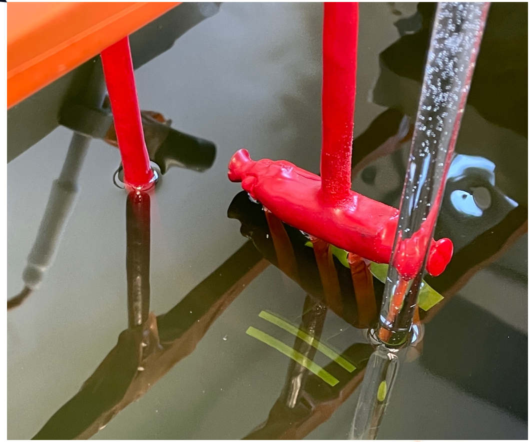


- **Simulation of different treatment configurations**
  - Different cathode shapes
  - Different anode / cathode distances
  - Different hydrodynamic and electrical conditions
- **Validation criteria**
  - Material removal and roughness reduction prediction
  - Polishing uniformity

Electropolishing of blading part

- **Two step polishing**
  - EP with Pt-plated Ti grid for the cleaning of the upper and lower parts of the demonstrator
  - EP with shaped cathode for the finishing of the blades of the demonstrator





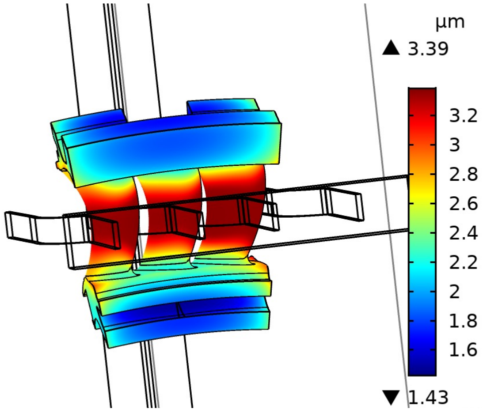
- **Simulation helped at designing the shaped cathode, specific to the blades**
  - Realization of the AM 316L SS shaped cathode

+

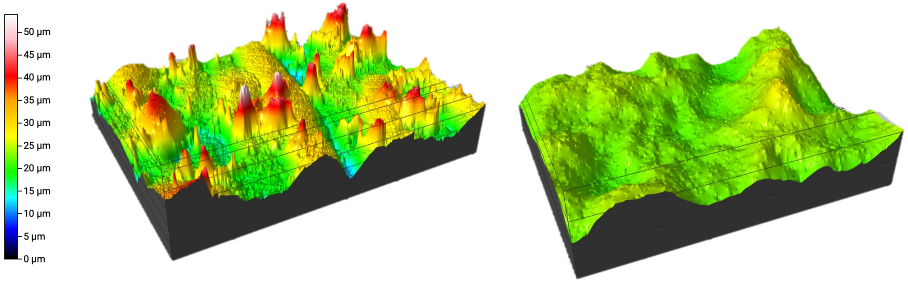
→

Electropolishing of blading part

- **Roughness reduction on the blades**
  - AM Inconel 718 + HT demonstrator part
  - Electropolishing under optimized conditions based on simulations
  - Predicted roughness reduction : 3,20 µm
  - Experimental roughness reduction : 3,19 µm



Profilometry	before EP	after EP
Optical (interferometry) Sa (µm)	4,56	1,367
Mechanical (cut-off 0,08mm) Ra (µm)	2,61	0,55



Conclusion

- **Model developpement on 316L SS :**
  - Coupling secondary current distribution and computational fluid dynamics allows the prediction of local dissolution rates and roughness reduction
- **Transfer on Inconel 718 :**
  - Thanks to the coupling strategy and experimental input data, based on electropolishing of AM RDE specimens, the predictability of the model is about 90 % when modeling the electropolishing of AM plates at a semi-industrial scale.
- **Electropolishing of blading part :**
  - Preliminary test : electropolishing is promizing but needs otpimization
  - A two step strategy was developped in order to fit the industrial specifications
  - The electropolished surfaces are in a good agreement with initial demands on roughness state
  - The modeling of the roughness reduction on the inner parts exhibit a high predictability

Do you have any questions ?

Thank you for your attention !

30 nov. / 1er déc. 2022

ESPACE AUGUSTE COLMAR

Journées Traitements et parachèvements de pièces issues de fabrication additive

ASSOCIATION FRANÇAISE DU TITANE The French Titanium Association

A3TS

IRT M2P Institut de Recherche Technologique Matériaux Métallurgie et Procédés

Institut UTINAM

SAFRAN