

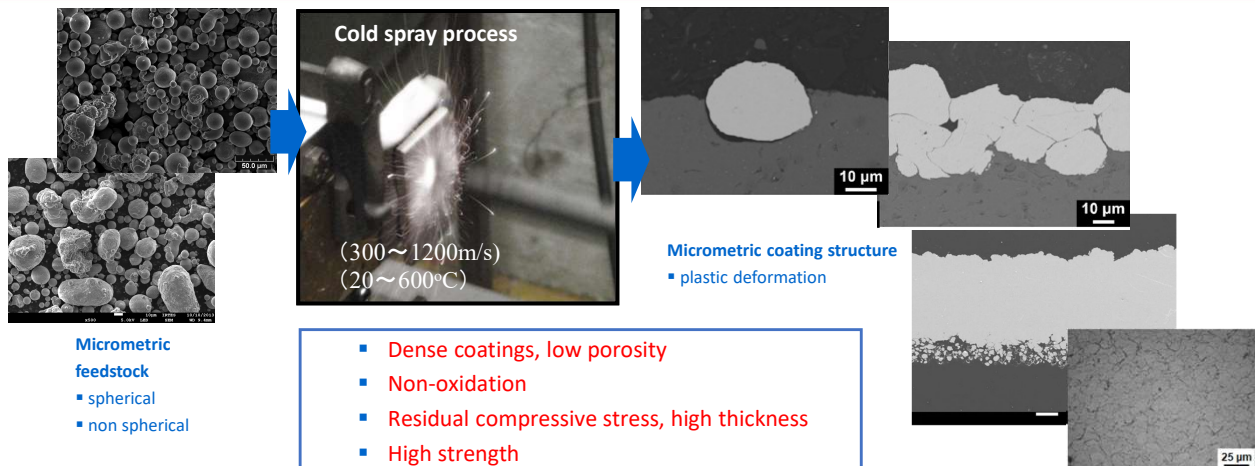
# New strategies using laser texturing for improving the adhesion in cold spraying

S. Costil, G. Darut, M.P. Planche, L. Vitu, R. Raelison, Ch. Verdy; H. Liao  
R. Kromer, A. Kusuran

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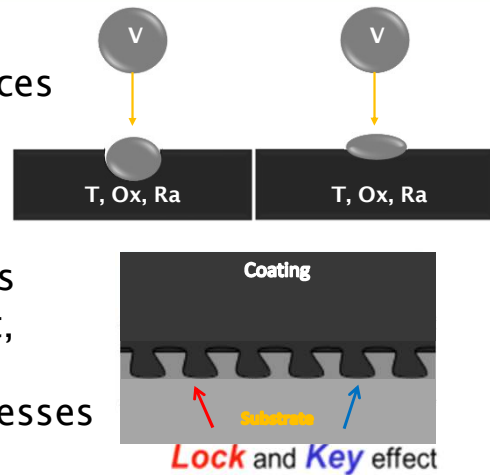
## Cold spraying



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## Cold sprayed coating

- Adhesion : the key features !
  - Mechanical and physico-chemical forces
  - Filler material spraying
  - Surface pre-treatments (required)
- Laser texturing
  - Technology as surface pre-treatments
  - Easy automation, localized treatment, flexibility
  - Diversity through materials and processes



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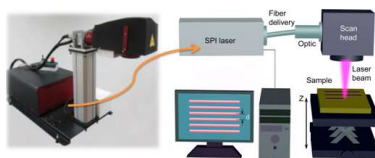


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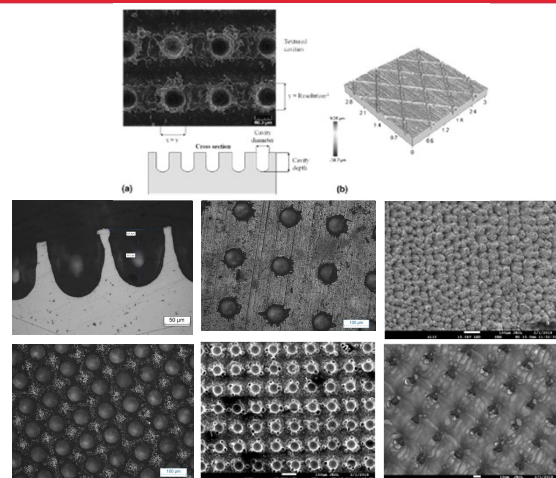
## Laser texturing

- different pattern morphologies
  - holes, lines, etc.
  - depth, diameter, angle
- $\pm$  dense spotted surfaces



- Nd-YAG
- $\tau = 120\text{ns}$
- $P < 20\text{W}$
- $F = 20\text{-}200\text{ kHz}$
- $1\text{J}/\text{cm}^2$

A. LAMRAOUI, Ph.D. thesis, University of Technology of Belfort-Montbéliard, 2011  
R. KROMER, PhD thesis University of Technology of Belfort-Montbéliard, 2016  
L. DESPRES, PhD thesis University of Technology of Belfort-Montbéliard, 2020  
A. KUSURAN, PhD thesis University of Technology of Belfort-Montbéliard, 2023



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# Experimental procedures

- Various processes
- High and low pressure
  - CGT Kinetics 3000 (compressed air, N<sub>2</sub>)
  - Metco
  - Helium recycled



- Several applications
  - Adhesion
  - Reparation
  - Conductivity
  - Assembly
- Several materials
  - Metals
  - Ceramics
  - Polymers

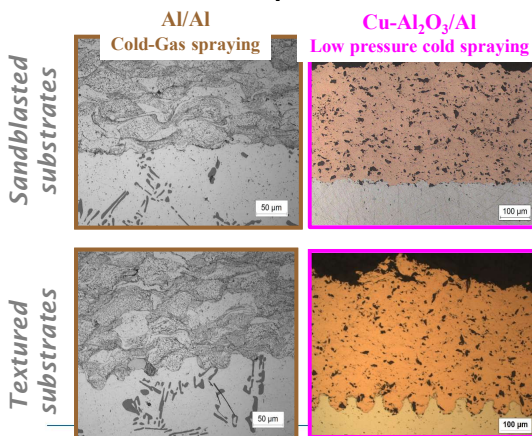


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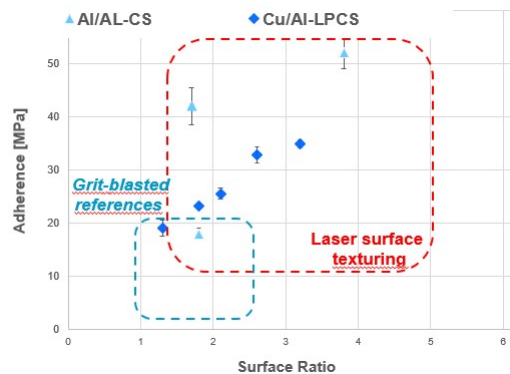


# Surface texturing for improving coating adhesion

- Via several processes



- Pull-off tests



R. KROMER, PhD thesis University of Technology of Belfort-Montbéliard, 2016

C633-79 - average of 5 tests

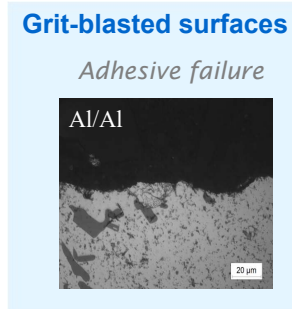


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# Surface texturing for improving the coating adhesion

- Mixed-mode failure – larger adhesion bond strength
- Cohesive toughness smaller than interface bond strength



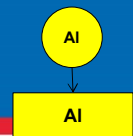
R. KROMER, PhD Thesis University of Technology of Belfort-Montbéliard, 2016



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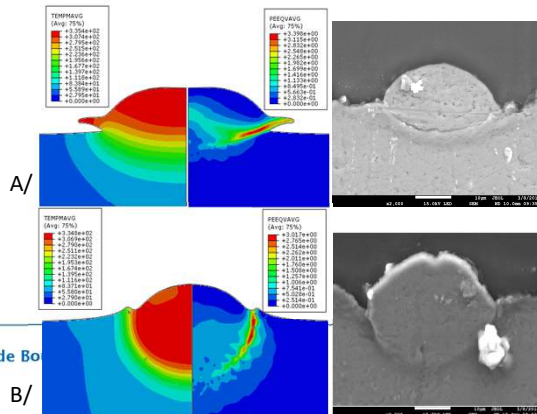
# Metal -to- Metal assembly



- Particle impact
  - Normal stress
  - Tangent flow
  - Elastic rebound



- Raw surface
  - Ejected matter
  - Lens shape
- Concave surface
  - Substrate strain > Particle strain
  - Interface temperature ↗



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# Metal -to- Metal assembly

- **Raw**
  - Shearing stress
- **Concave**
  - Shearing stress
  - Compressive stress
- **Adhesion bond strength**
  - LST > GB

Texture 1    Texture 2

Adhesion bond strength (MPa)

| Surface Treatment | Adhesion Bond Strength (MPa) |
|-------------------|------------------------------|
| Grit-blasting     | ~18                          |
| Texture1          | ~42                          |
| Texture2          | ~52                          |

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# Metal -to- Polymer assembly

- **Particle impact**
  - Elastic
  - Plastic
  - Elastic rebound
- **Raw surface**
  - Ejected matter
  - Particle rebound speed 25m/s
- **Concave surface**
  - Substrate deformation
  - Particle rebound speed 10m/s
  - Gripping zones

**Max. Principal Stress**

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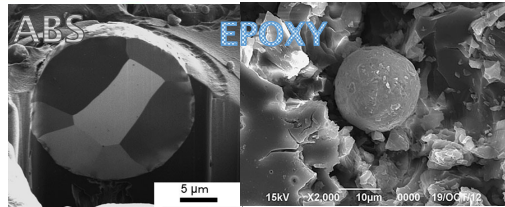
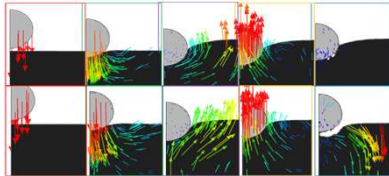
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# Metal - Polymer assembly

## Particle impact

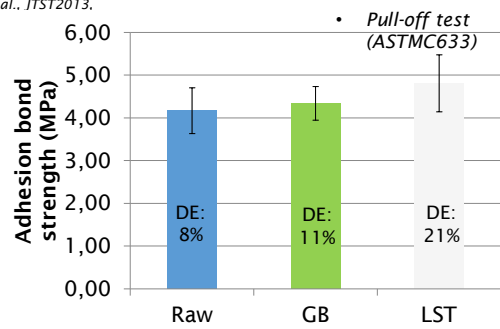
- Strain rate → Ductile-Brittle
- Window for deposition



A. Ganesan et al., JTST2013, 22:1275-

## Adhesion Bond strength

- Low mechanical properties
- Laser microstructure modification



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# Metal -to- Polymer assembly

## Bonding strength modeling and simulation

PEEK/Cu interface damage :

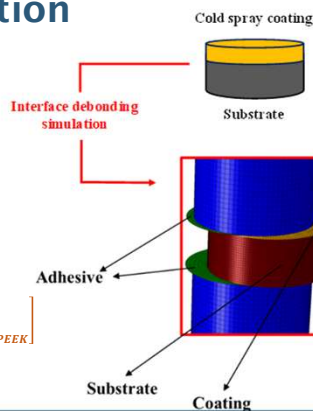
VCCT-based crack growth

Interface energy fracture :

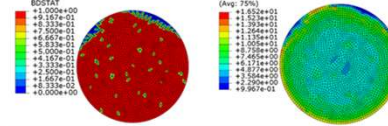
$$G_c = (\gamma_{PEEK} + \gamma_{Cu}) - \gamma_{Cu/PEEK}$$

Interface energy model :

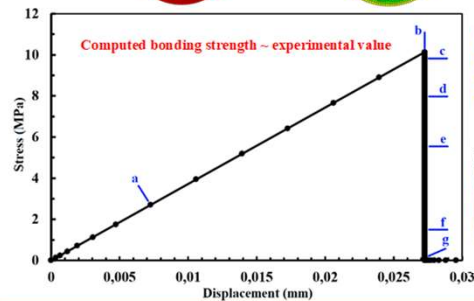
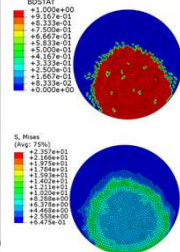
$$\gamma_{Cu/PEEK} = \frac{2}{3R} \left[ \frac{hS_v H}{V} \right]_{Cu} + \frac{hS_v H}{V} \Big|_{PEEK}$$



Failure initiation : point «c» on the computed curve



Failure propagation : point «e» on the computed curve



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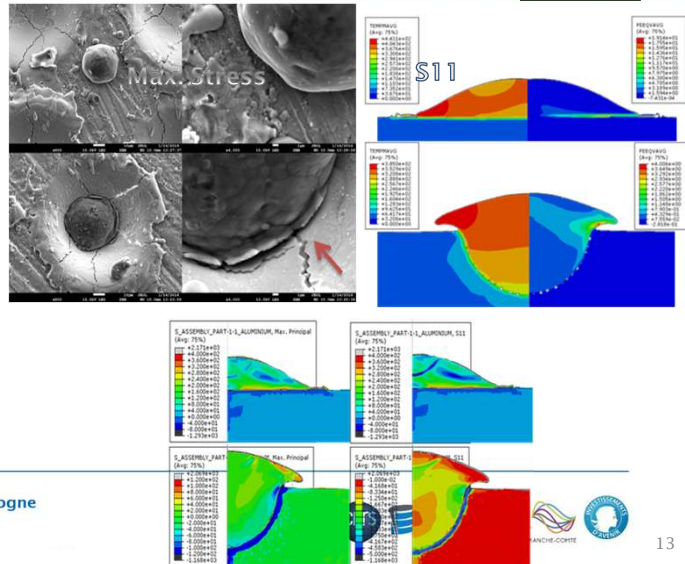


# Metal – Ceramic assembly

Al

Al<sub>2</sub>O<sub>3</sub>

- **Particle impact**
  - No substrate deformation
  - No shear instability
- **Raw surface**
  - Particle debonding on the edge
  - No residual stress for mechanical anchoring
- **Concave surface**
  - Particle locked in pattern
  - Compressive stress



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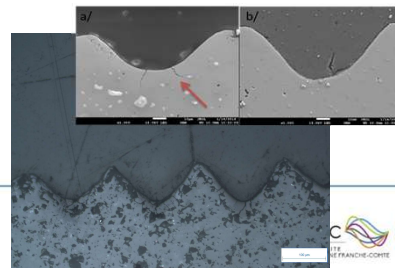
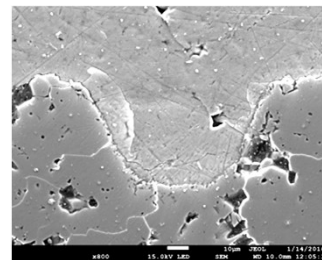
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# Metal – Ceramic assembly

Al

Al<sub>2</sub>O<sub>3</sub>

- **Raw surface**
  - Deposition difficult to obtain
  - Particle rebound
- **Concave surface**
  - Adhesion bond strength : 20MPa
  - Metallization of ceramic using cold spray
- **Laser surface texturing**
  - ns: heat affected zone – cracks ?
    - Optimized laser parameters
    - Shorter laser pulses ?



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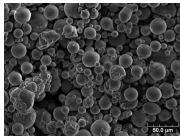
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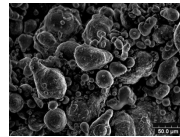
# Surface texturing for reparation

▪ Powders: 5056

5056-LERMPS

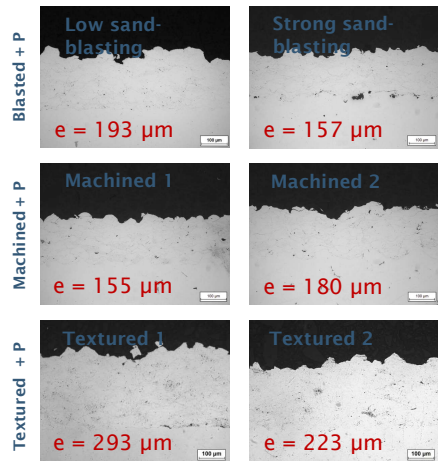


5056-ECKA

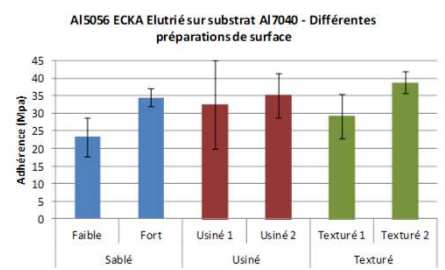


▪ Substrate: 7040

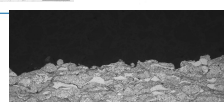
C-SAR Project – UTBM 2015



- Dense coatings
- Higher coating thickness after texturing
- Improved coating adhesion after a controlled (machined and textured) surface preparation

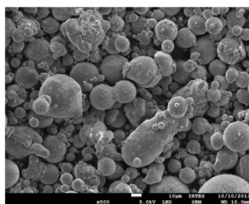


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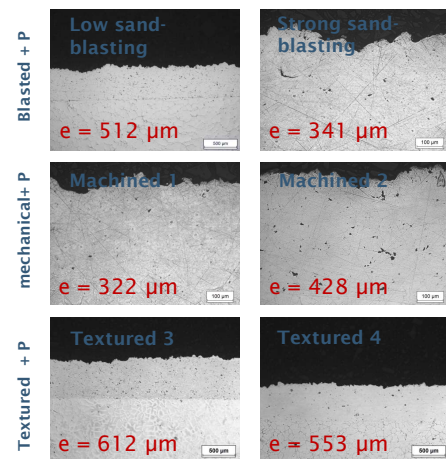
# Surface texturing for repairing surfaces

▪ Powders: RZ5

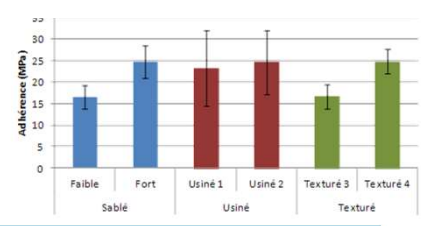


▪ Substrate: RZ5

C-SAR Project – UTBM 2015



- Dense coatings
- No adhesion comparison: systematic adhesive breakage
- Adhesion above the minimum value of 15MPa (approx. 25 MPa)



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# Surface texturing for multi-material assembly

Laser texturing

Cold Spray



New joining process patented:  
**LISI μ-MACH AP®**  
*(micro Mechanical Anchoring Cold Hybrid Assembly Process)*

→ Multi-material assembly: steel/aluminium alloy

A. KUSURAN, PhD Thesis University of Technology of Belfort-Montbéliard, 2023



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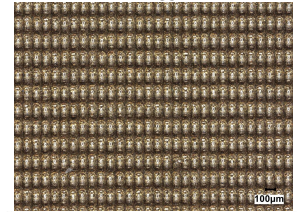
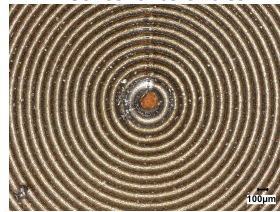
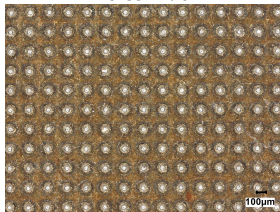
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# Surface texturing for multi-material assembly

Holes matrix

Concentrics circles

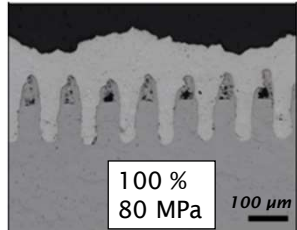
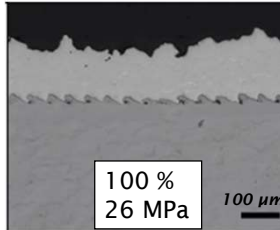
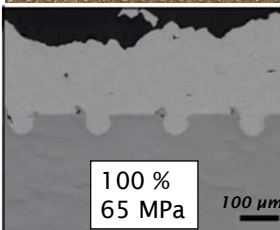
Lines



Aluminium alloy



Steel



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# Surface texturing for multi-material assembly

## Various potential patterns

**In L**

**Butt joint with double chamfer**

**Butt joint with chamfer**

**By hole covering**

## According to sollicitations

Tension

Tension

Tension

Shearing

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# Surface texturing for multi-material assembly


| Déplacement [mm] | F [N] |
|------------------|-------|
| 0.0              | 0     |
| 0.5              | 1000  |
| 1.0              | 3500  |
| 1.5              | 5500  |
| 1.8              | 6000  |
| 2.0              | 5000  |

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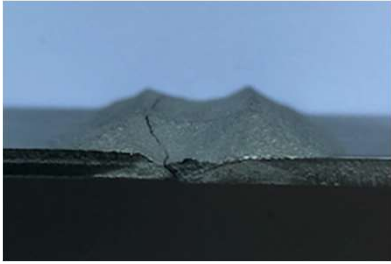
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# Surface texturing for multi-material assembly

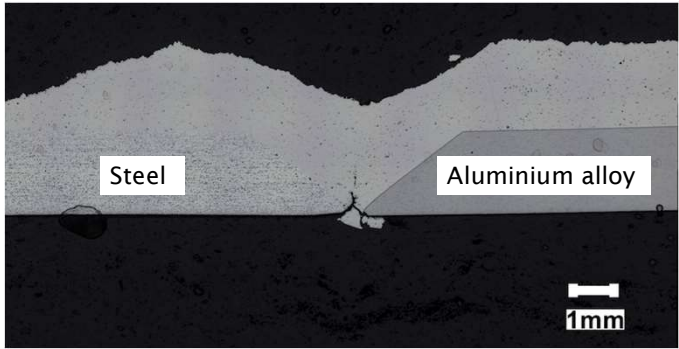


Steel      Aluminium alloy

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Ultimate strength: 80 MPa









Steel      Aluminium alloy

1mm



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# Surface texturing for multi-material assembly




Steel      Aluminium alloy


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*Steel*





*Aluminium alloy*




Aluminium alloy deposit


Steel






Aluminium alloy

100µm



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## Conclusion

- Laser texturing on various materials for any spray processes
- Substrate surface topography adapted to materials
- Coating adhesion improved after texturing
- Mechanical anchorage increased by hole morphology
  - Holes = obstacles for crack propagation

**Laser texturing : a promising tool for new material behaviors, new applications !**



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