MINES PARIS | PSL

Cold spray of metal-PEEK powder mixture onto short carbon reinforced polymer substrate

Speaker
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Under the supervision of
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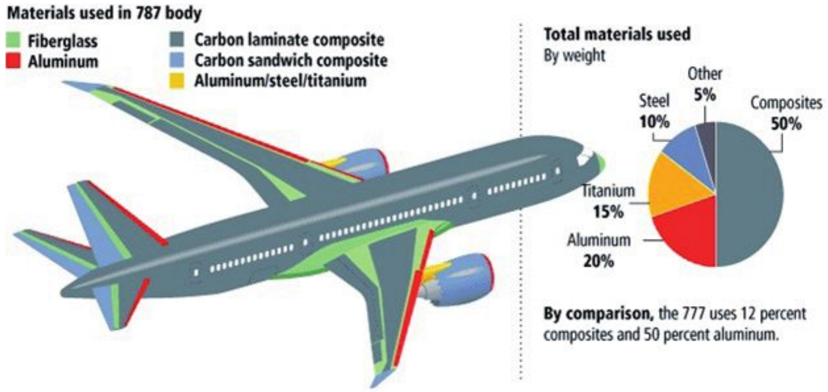
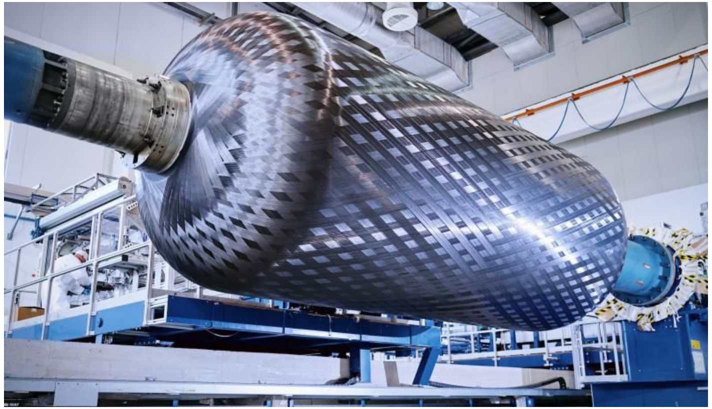
Cold Spray Club meeting HSU Hambourg, 20/10/2023

Institut Mines-Télécom · ARMINES · cnrs · LIEBHERR Aerospace · arca CRÉATIONS ET ÉBÉNISTERIE · INNOVATION PLASTURGIE COMPOSITES · RÉPUBLIQUE FRANÇAISE MINISTÈRE DES ARMÉES · AGENCE INNOVATION DÉFENSE · INSTITUT CARNOT M.I.N.E.S

Composite materials



Usage of various materials in the Boeing 787 Dreamliner (Katunin et al. 2017; Rosato 2013).



Composite case of Vega launcher made by filament winding process [credits avio.com].

Advantages:
- strength-to-weight ratio
- friction performance
- corrosion resistance

Disadvantages:
- low wear resistance
- low thermal conductivity
- low electrical conductivity

Outline

I. HPCS and LPCS pure aluminium coatings onto PEEK composite

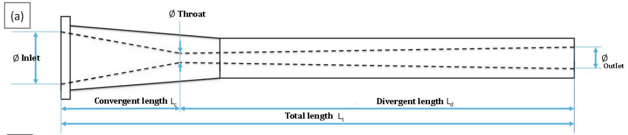
II. HPCS and LPCS mixed aluminium-polymer coatings onto PEEK composite

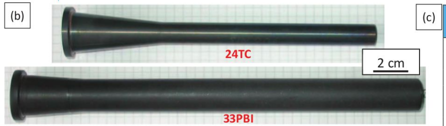
III. CFD analysis of cold spray process

IV. Particle impact simulation on composite substrate

Cold spray equipment

High pressure system
Cgt kinetic 3000

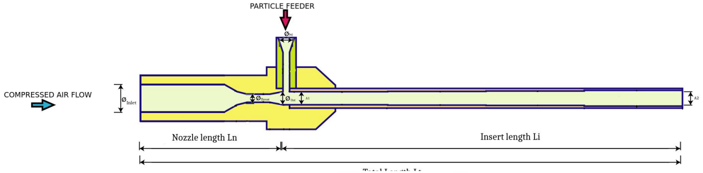




(c)

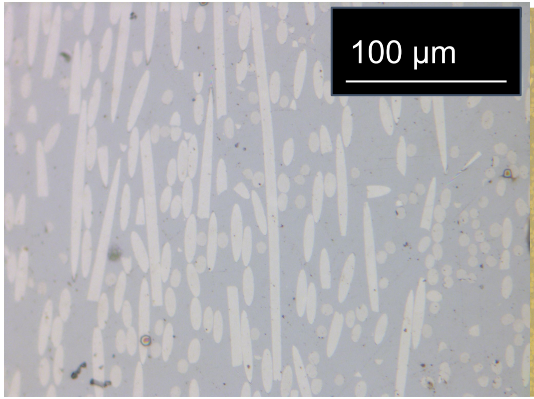
Dimensions (mm)	33PBI	24TC
L_c	40,0	40,0
L_d	182,4	132,4
L_t	222,4	172,4
$Ø_{Inlet}$	16,0	17,5
$Ø_{Throat}$	2,7	2,7
$Ø_{Outlet}$	10,1	6,5

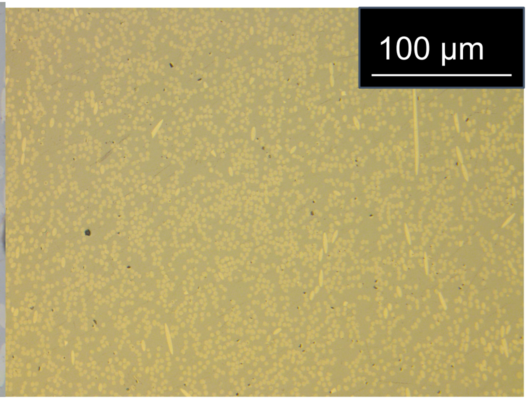
Low pressure system
Dymet 523



PEEK TM 90HMF40

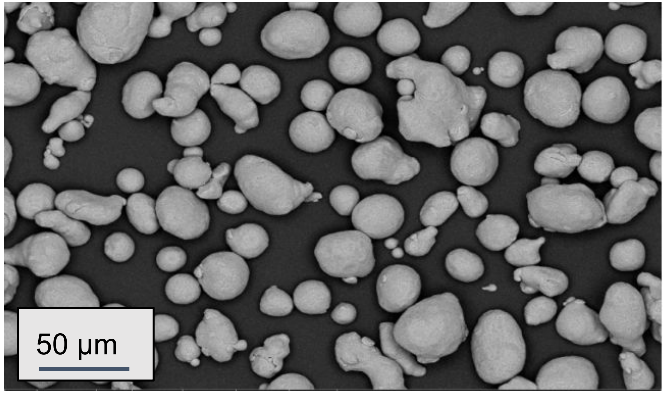
Short carbon reinforced PEEK substrate





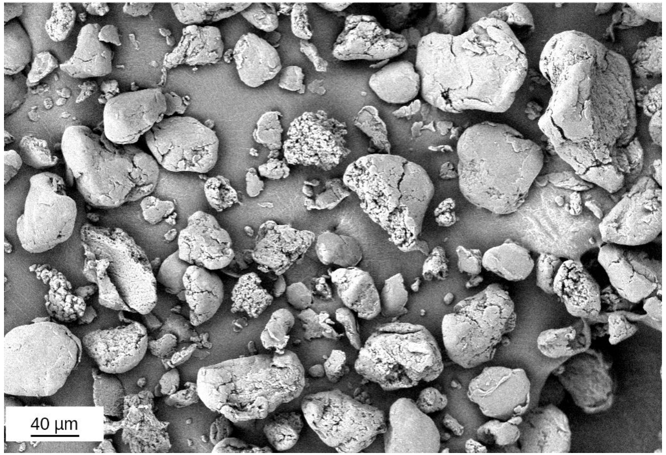
- High performance thermoplastic material
- 40% short carbon fibre reinforced
- Glass Transition Temperature (Tg) : 143°C
- Melting Temperature : 343 °C
- Diameter fibre 5 µm
- Length 80-100 µm

Metal & PEEK powders



Aluminium:

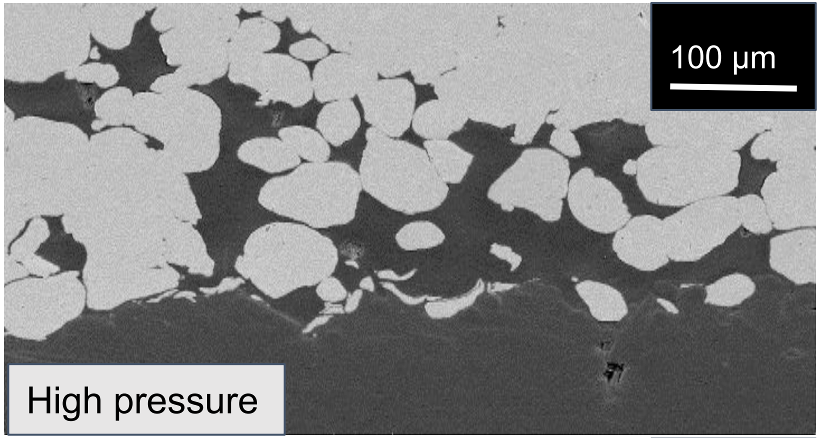
- Toyal 20-50 UPS
- Spherical
- 99.9 % purity
- D90 = 50 µm
- D50 = 30 µm

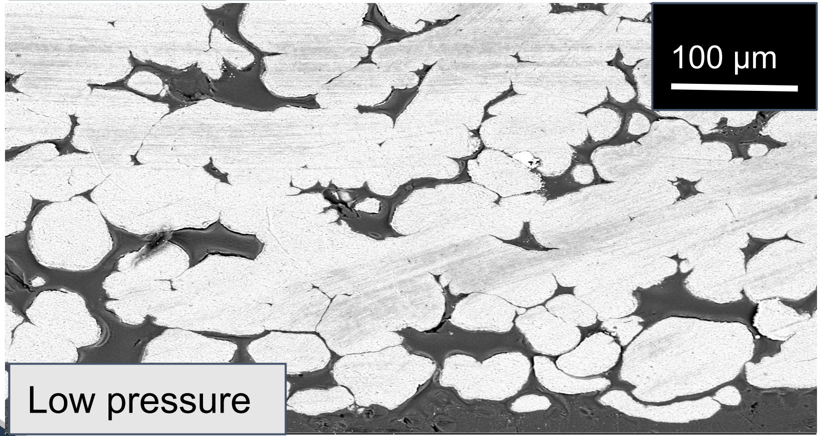


PEEK:

- Victrex Vicote 702
- Irregular
- D90 = 88 µm
- D50 = 53 µm

Cold spray test (pure aluminium)





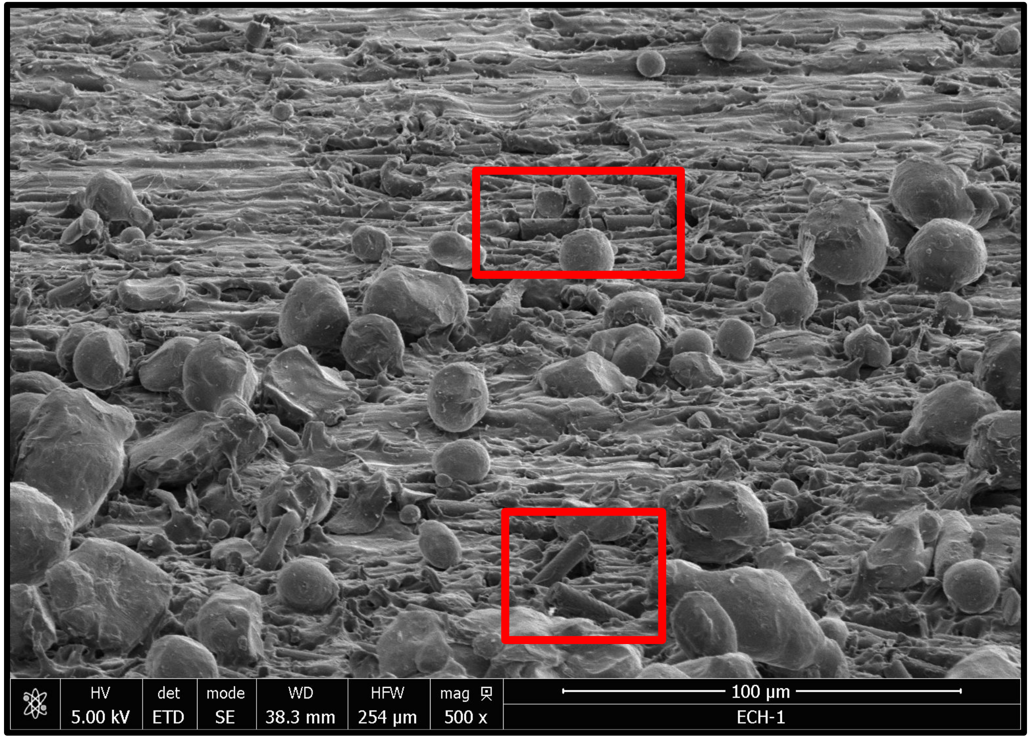
Similarities:

- Particles deformed at interface
- No mechanical anchoring
- Easy delamination

Differences:

- Higher porosity in the LPCS
- Lower deformation in the LPCS
- Higher erosion in the HPCS

HPCS splat test (aluminium)



Outline

I. HPCS and LPCS pure aluminium coatings onto PEEK composite

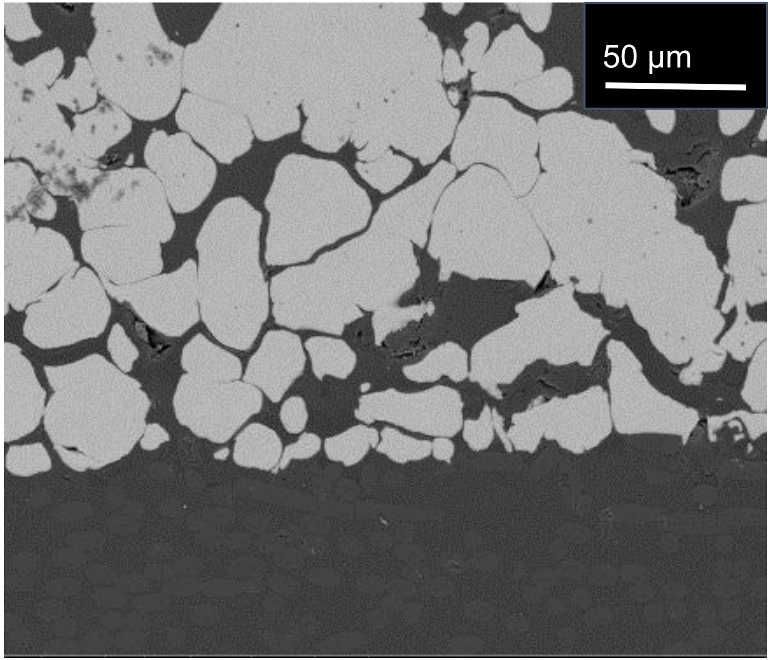
II. HPCS and LPCS mixed aluminium-polymer coatings onto PEEK composite

III. CFD analysis of cold spray process

IV. Particle impact simulation on composite substrate

High pressure cold spray

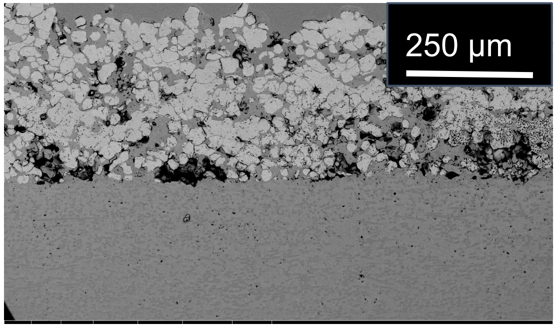
Mixture Al + 10%vol PEEK



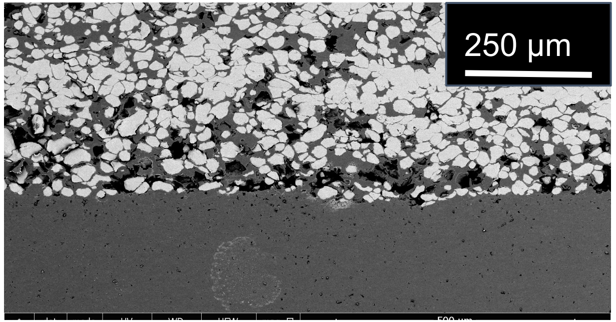
- Regular coatings
- Increased deposition efficiency
- Adhesion < 3 MPa
- Conductivity similar to pure aluminium coatings

Low pressure cold spray

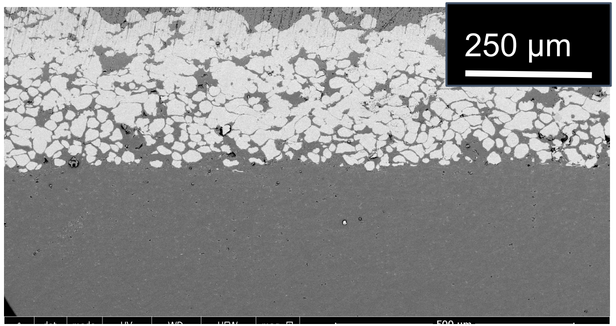
Mixture of Al and different PEEK content



20 % vol PEEK



10 % vol PEEK

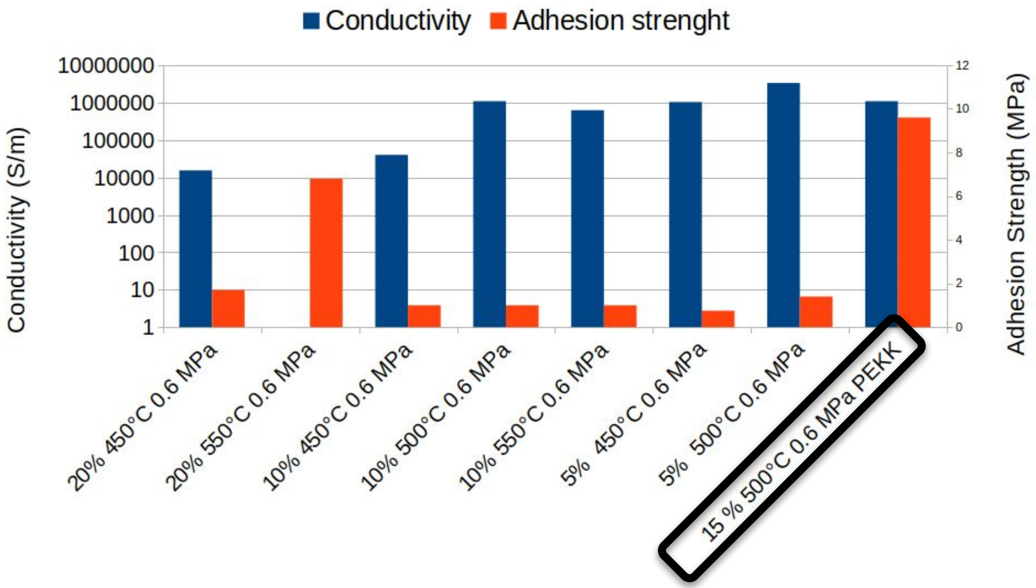


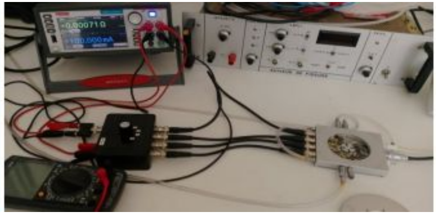
5 % vol PEEK

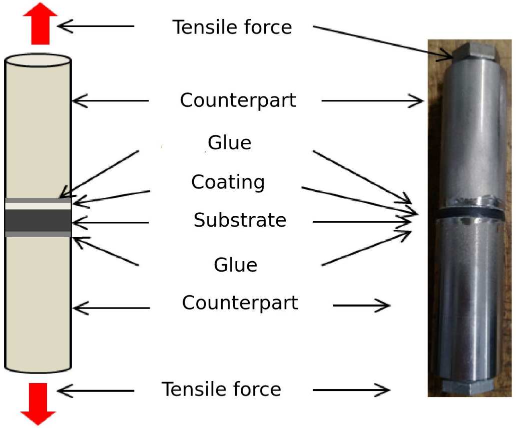
PEEK % ↑ Adhesion ↑ Conductivity ↓

PEEK % ↓ Adhesion ↓ Conductivity ↑

Adhesion vs Conductivity



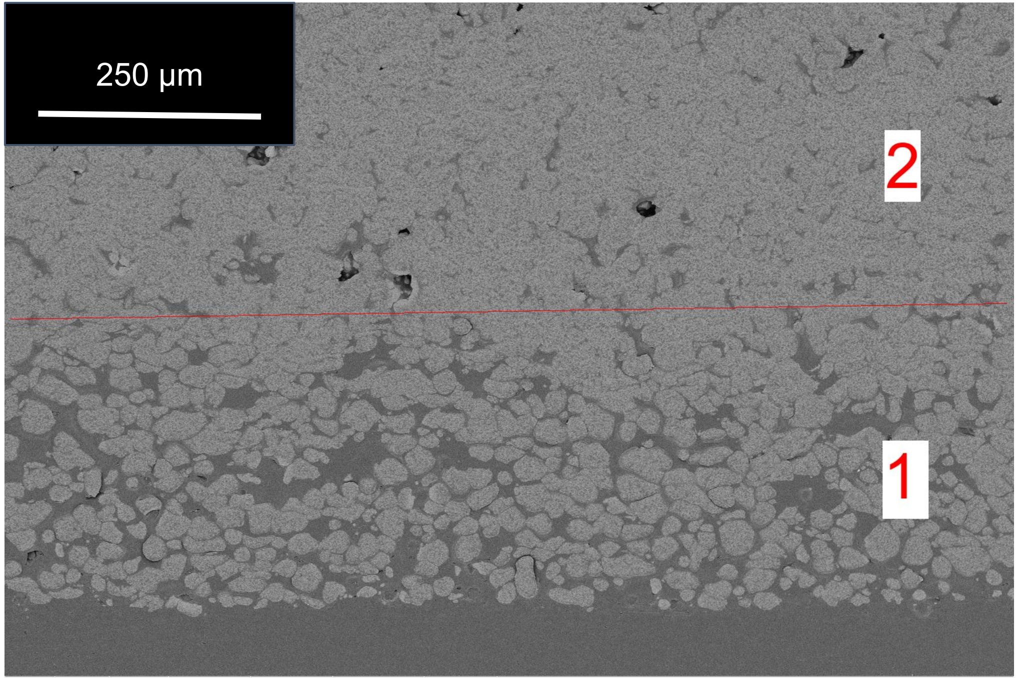




Best conductivity value for 5% of PEEK content

Best adhesion strength value for 20% of PEEK content

Low pressure cold spray
Sublayer strategy



- First layer: aluminium + 15% vol PEKK 8002
- Second layer: pure aluminium

Results:

- Cohesive failure between the layers **3 MPa**
- Conductivity $\mathbf{9 \cdot 10^6}$ **S/m**

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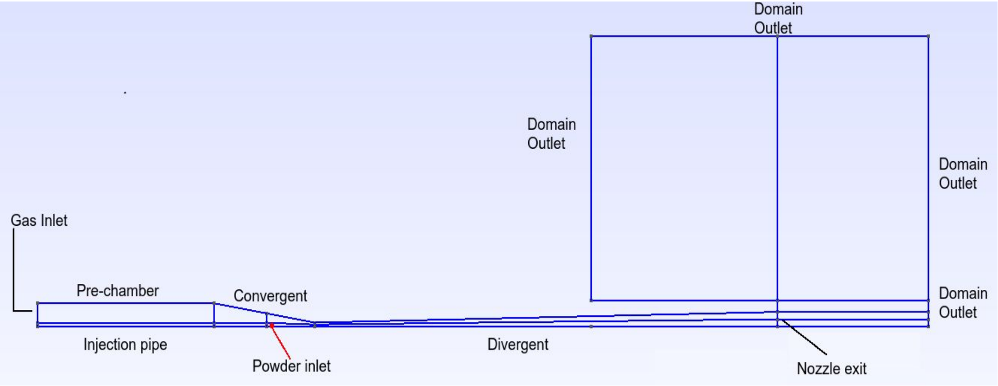
CFD analysis of HPCS & LPCS

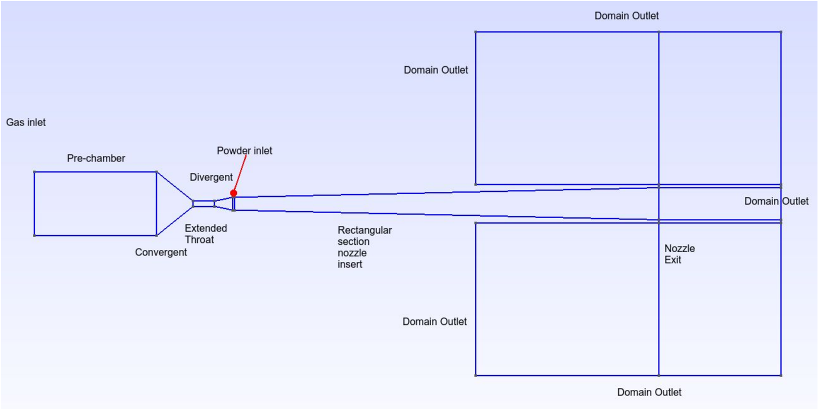
HPCS



33PBI round nozzle

- Axisymmetric geometry
- Axial injection
- No substrate
- Eulerian treatment of solid phase

LPCS

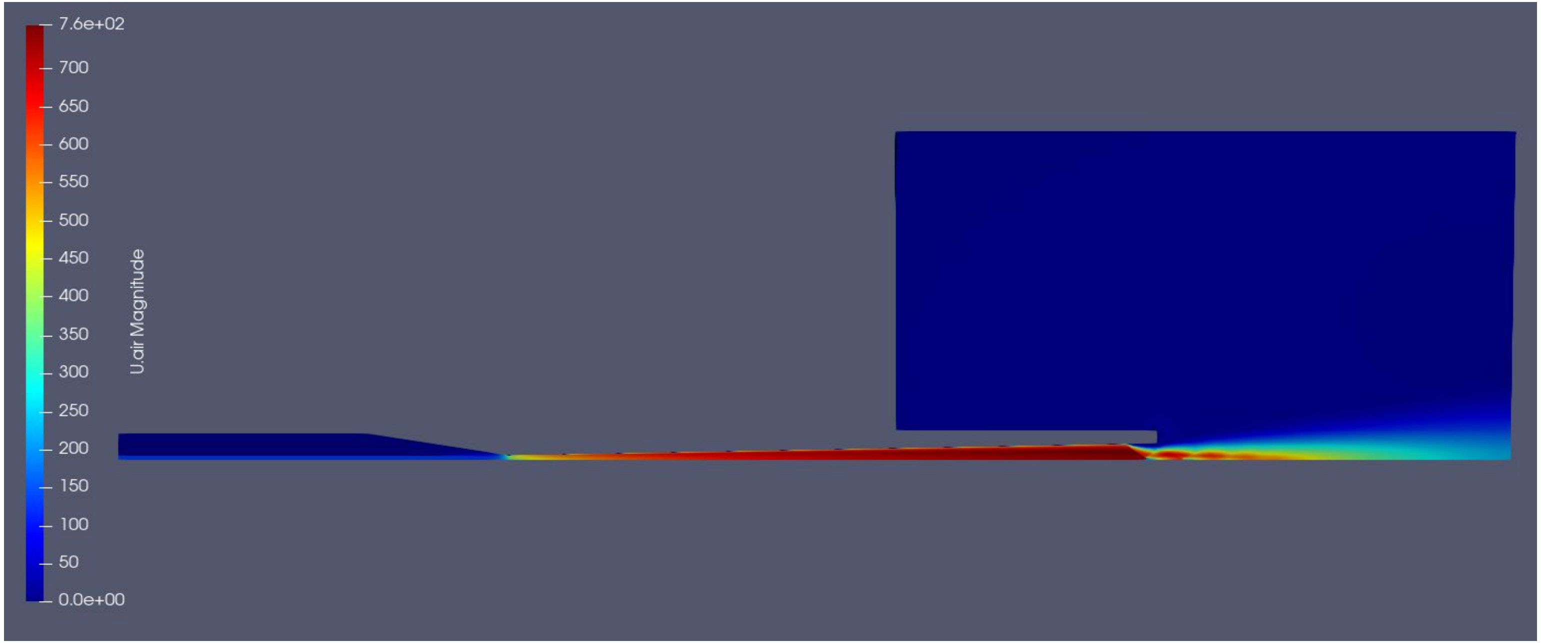


K7 flat nozzle + rectangular nozzle insert

- Full 3D geometry
- Radial injection
- Substrate
- Eulerian treatment of solid phase

CFD analysis of HPCS

Gas velocity

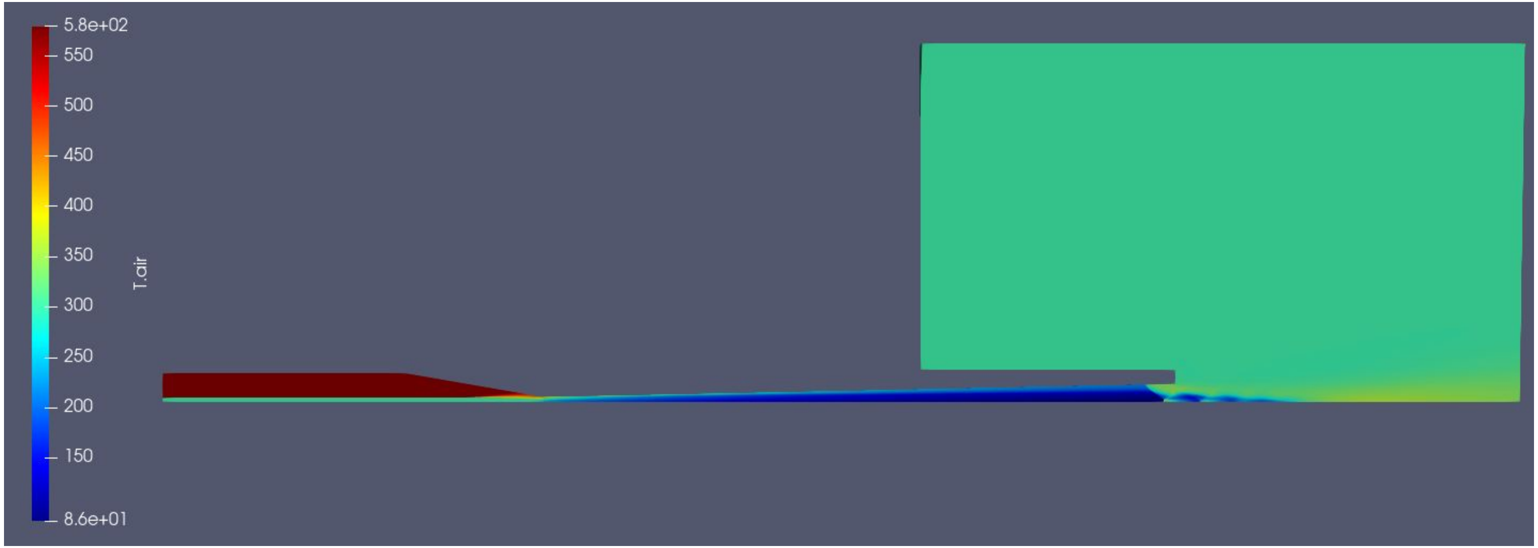


<u>Overexpanded flow</u>

<u>Series of oblique shocks at nozzle exit</u>

CFD analysis of HPCS

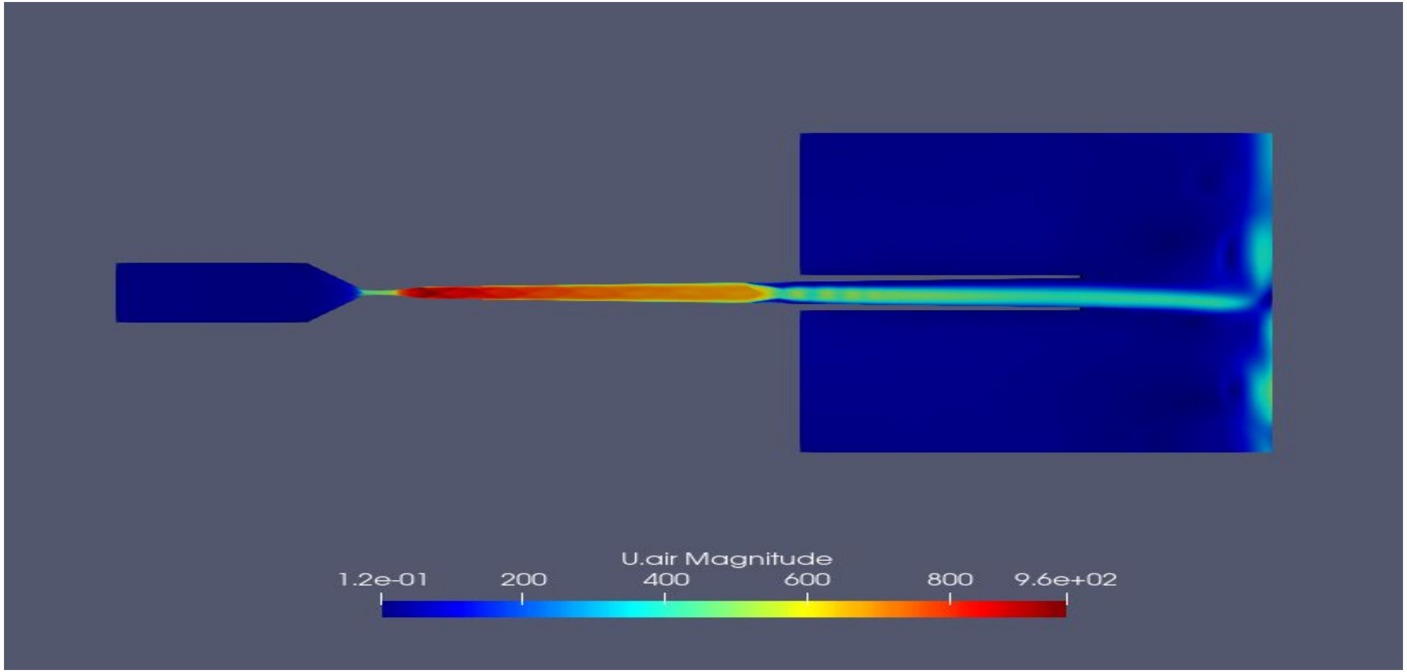
Gas temperature



<u>Low temperature along the nozzle</u>

CFD analysis of LPCS

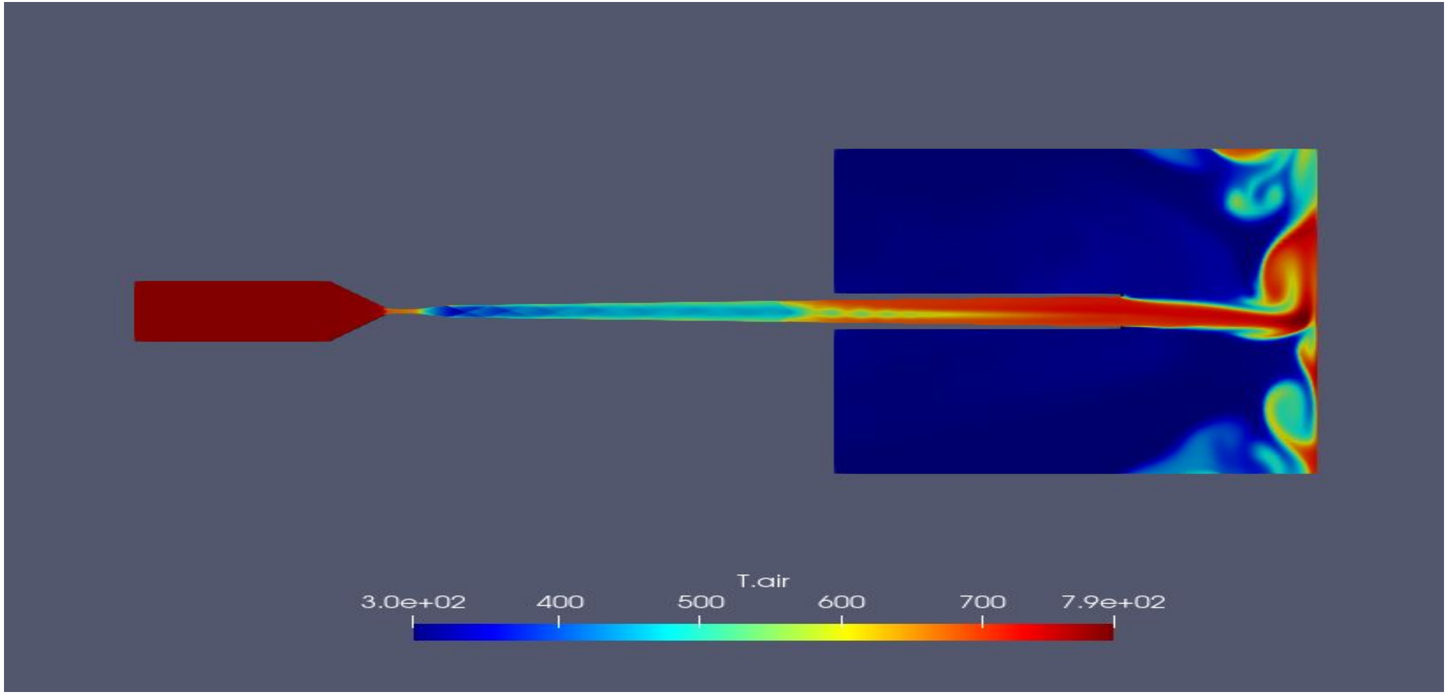
Gas velocity



<u>Sonic-subsonic flow after nozzle insert first half</u>

CFD analysis of LPCS

Gas fields

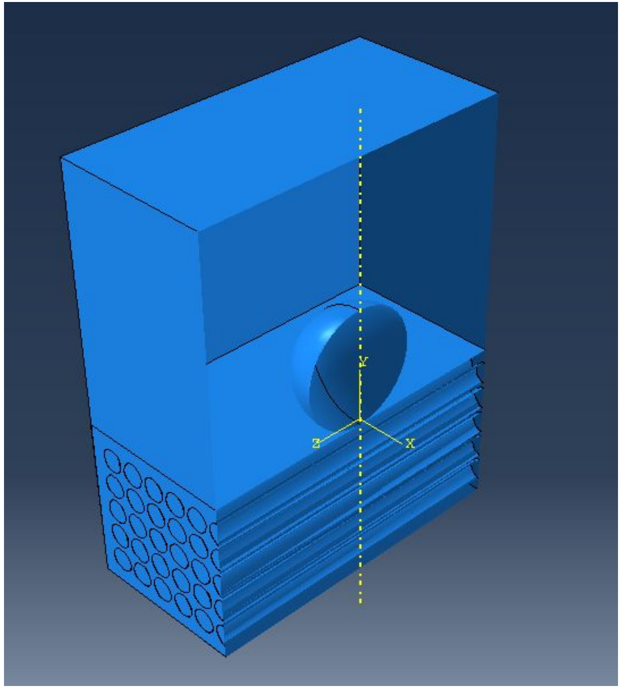


<u>High gas temperature at nozzle exit</u>

Outline

I. Cold spray a “not-so-thermal” process
II. Realization and optimization of cold spray metal coatings onto PEEK composite
III. CFD analysis of cold spray process
IV. Particle impact simulation on composite substrate
V. Extension to other substrates

CEL analysis of particle impact onto composite substrates



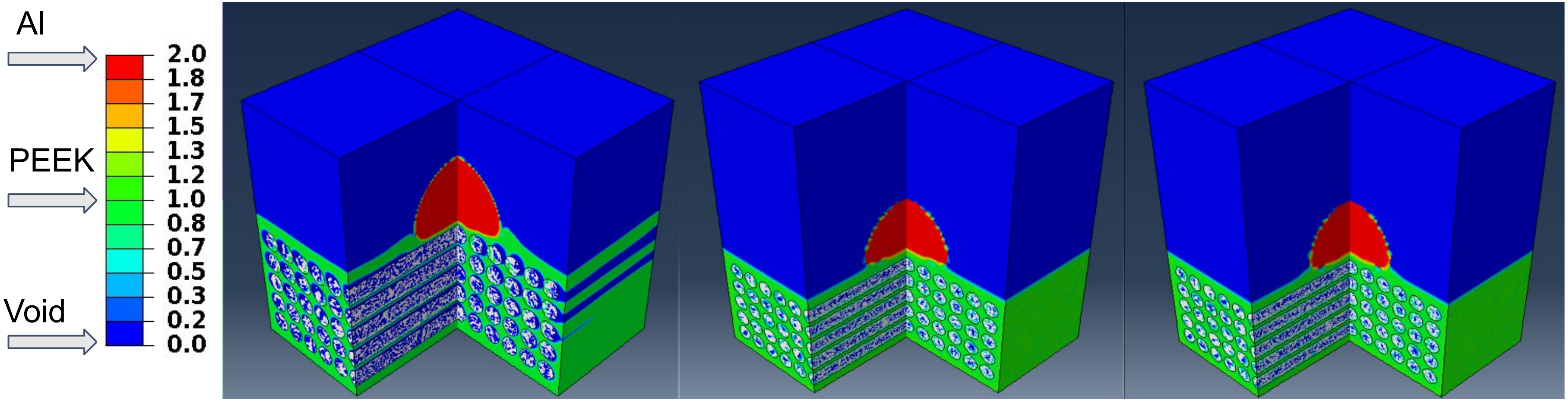
Eulerian part
Length = 70 μm
Width = 70 μm
Height = 35 μm

Particle instance
Diameter = 30 μm

PEEK matrix instance
Length = 70 μm
Width = 70 μm
Height = 35 μm

Short carbon fibers lagrangian part
Length = 70 μm
Diameter = 3 μm

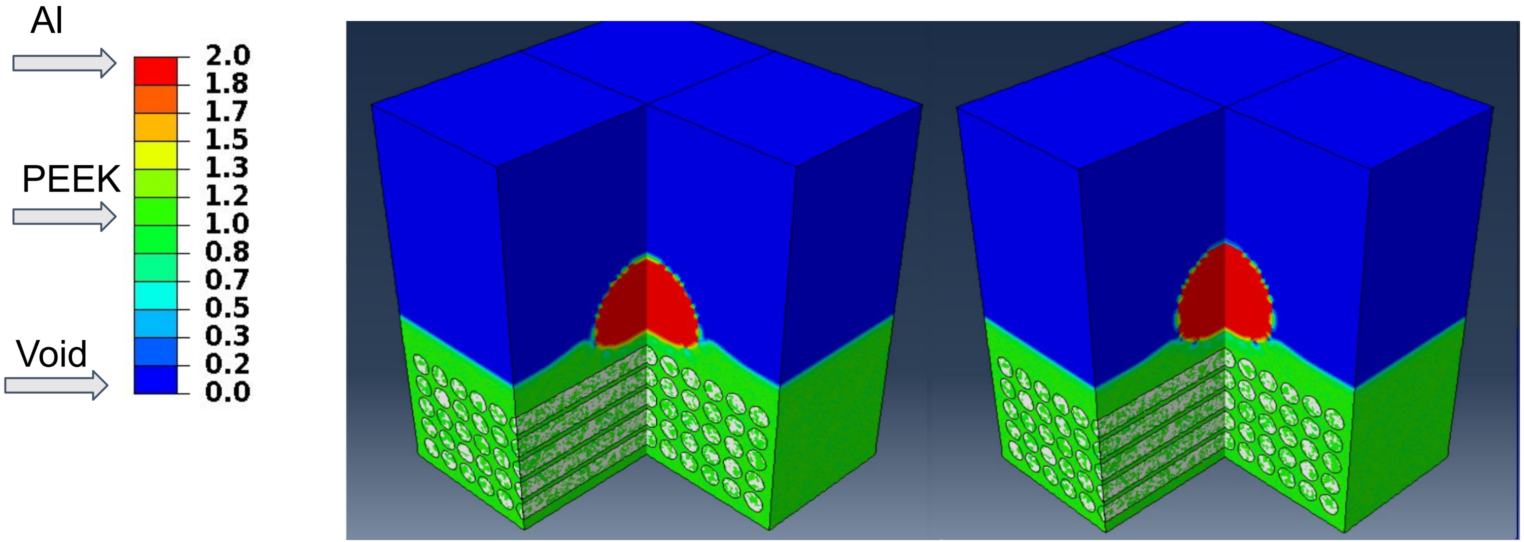
Single impact on PEEK composite
HPCS and LPCS differences



High pressure	Low pressure	Low pressure
V = 500 m/s	V =280 m/s	V =280 m/s
T = 300 K	T = 500 K	T = 600 K
Tsub= 300 K	Tsub= 300 K	Tsub= 450 K

Single impact on PEEK composite

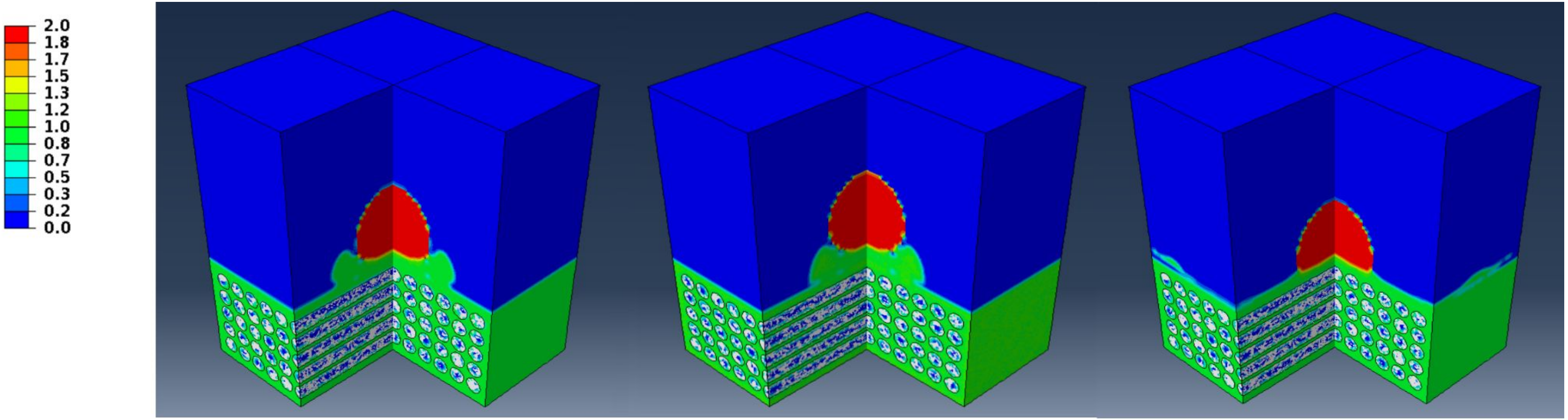
Thicker top layer strategy



High pressure
V = 500 m/s
T = 300 K
Tsub= 300 K

Low pressure
V =280 m/s
T = 500 K
Tsub= 300 K

PEEK-Aluminium mixture
Mattress effect

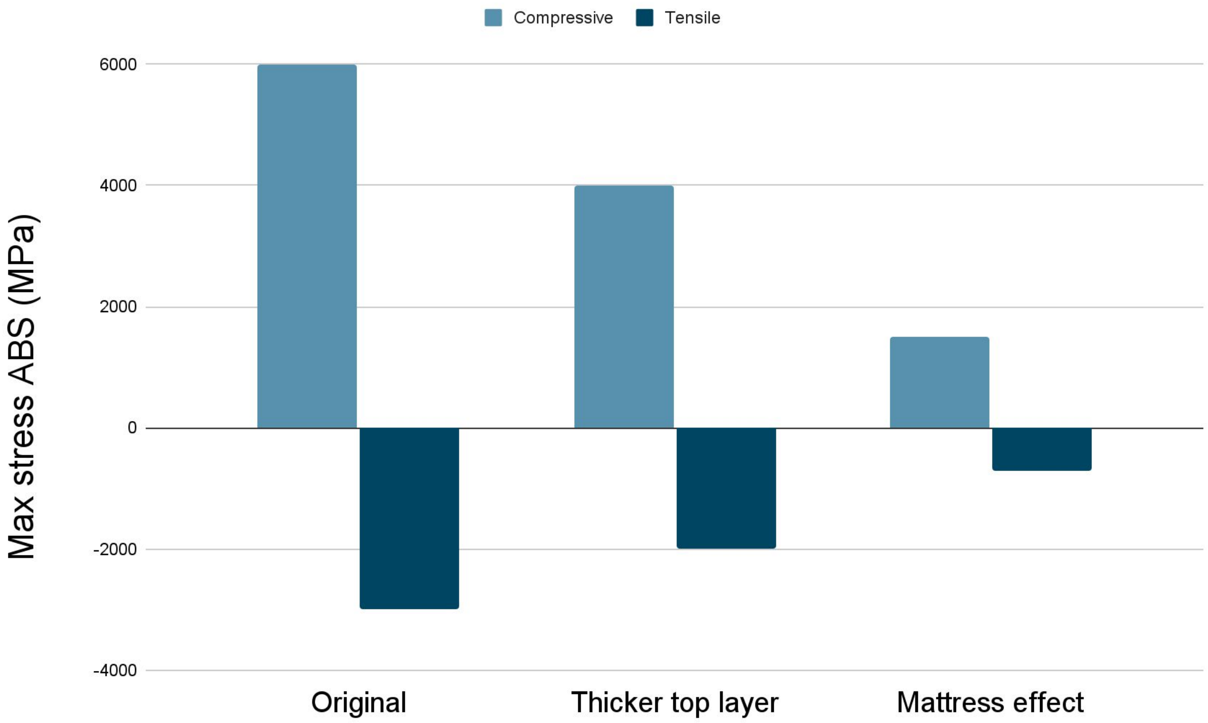


High pressure
$V = 500$ m/s
$T_{Al} = 300$ K
$T_{PEEK} = 300$ K
$T_{sub} = 300$ K

Low pressure
$V = 280$ m/s
$T_{Al} = 500$ K
$T_{PEEK} = 300$ K
$T_{sub} = 300$ K

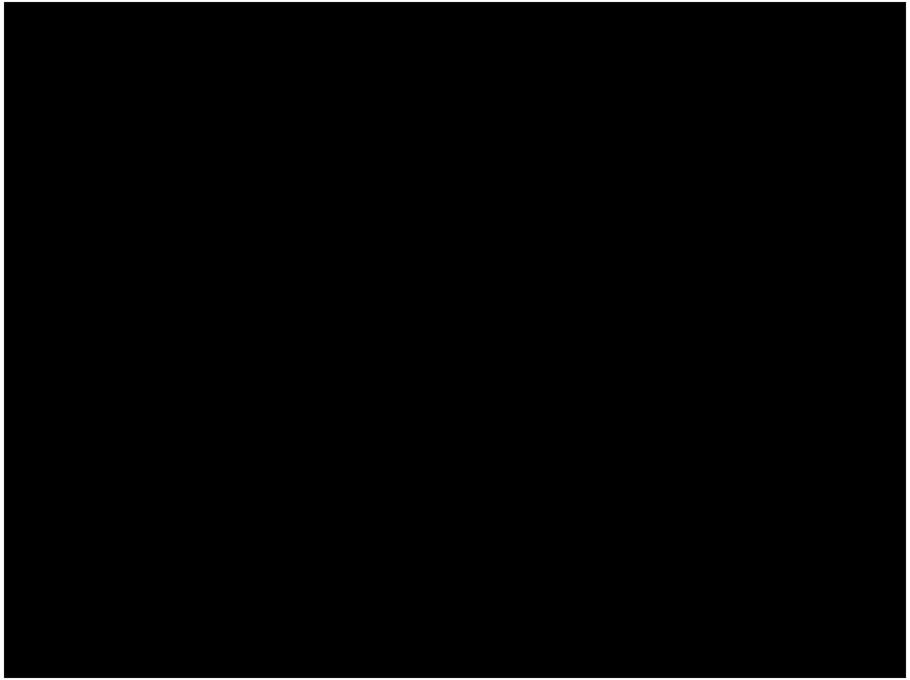
Low pressure
$V = 280$ m/s
$T_{Al} = 600$ K
$T_{PEEK} = 600$ K
$T_{sub} = 300$ K

Fiber stress induced by particle impact

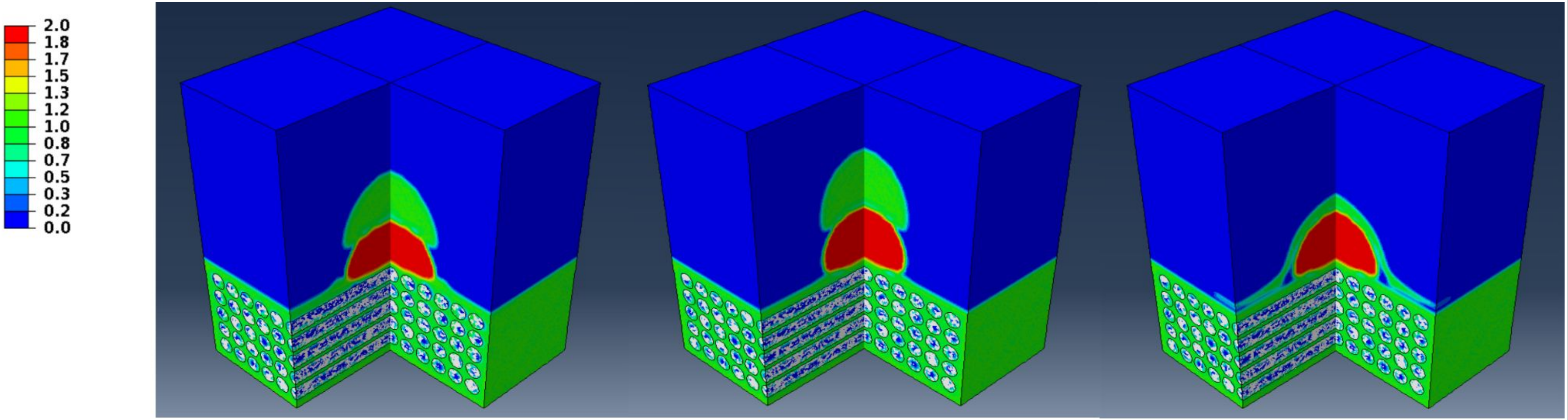


Modeling

Mattress effect simulation



PEEK-Aluminium mixture
"Spider man web" effect



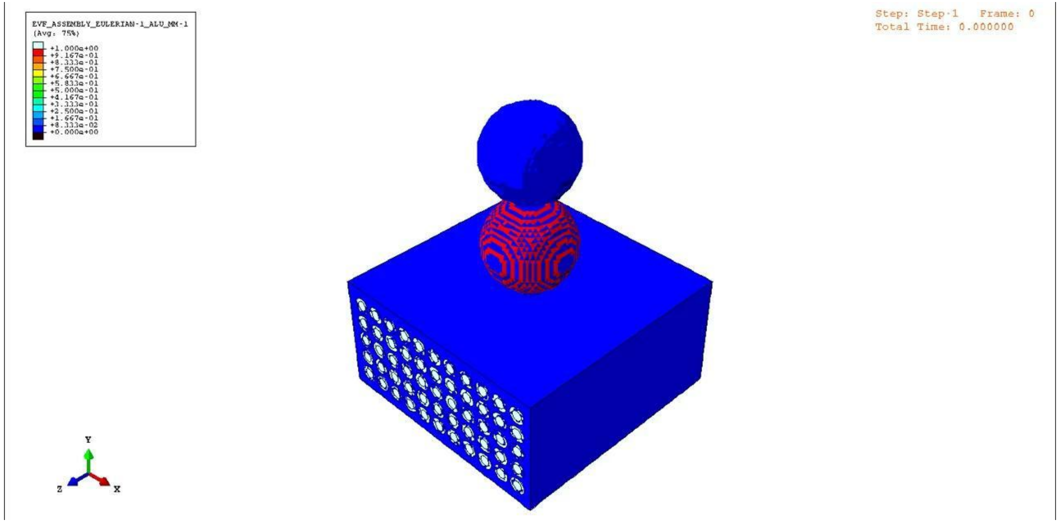
High pressure
V = 500 m/s
T_{Al} = 300 K
T_{PEEK} = 300 K
T_{sub}= 300 K

Low pressure
V =280 m/s
T_{Al} = 500 K
T_{PEEK} = 300 K
Tsub= 300 K

Low pressure
V =280 m/s
T_{Al} = 600 K
T_{PEEK} = 600 K
Tsub= 300 K

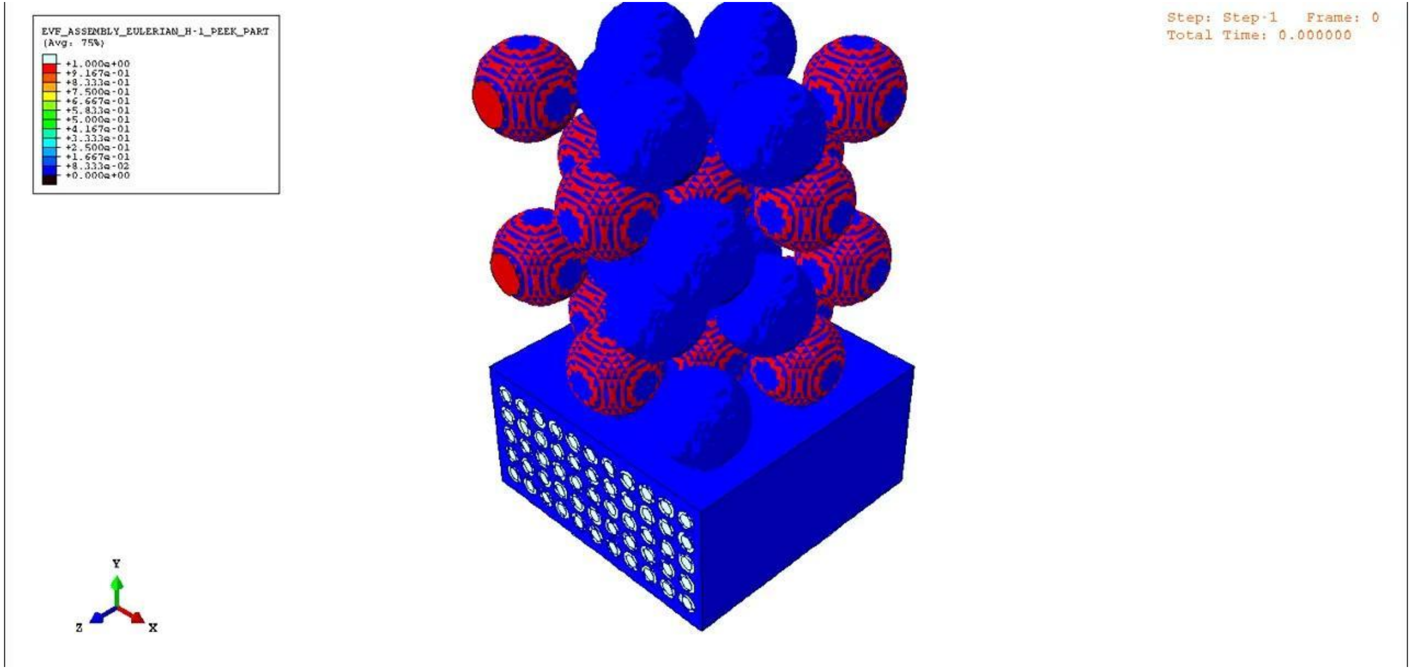
Modeling

Spiderman-web effect simulation



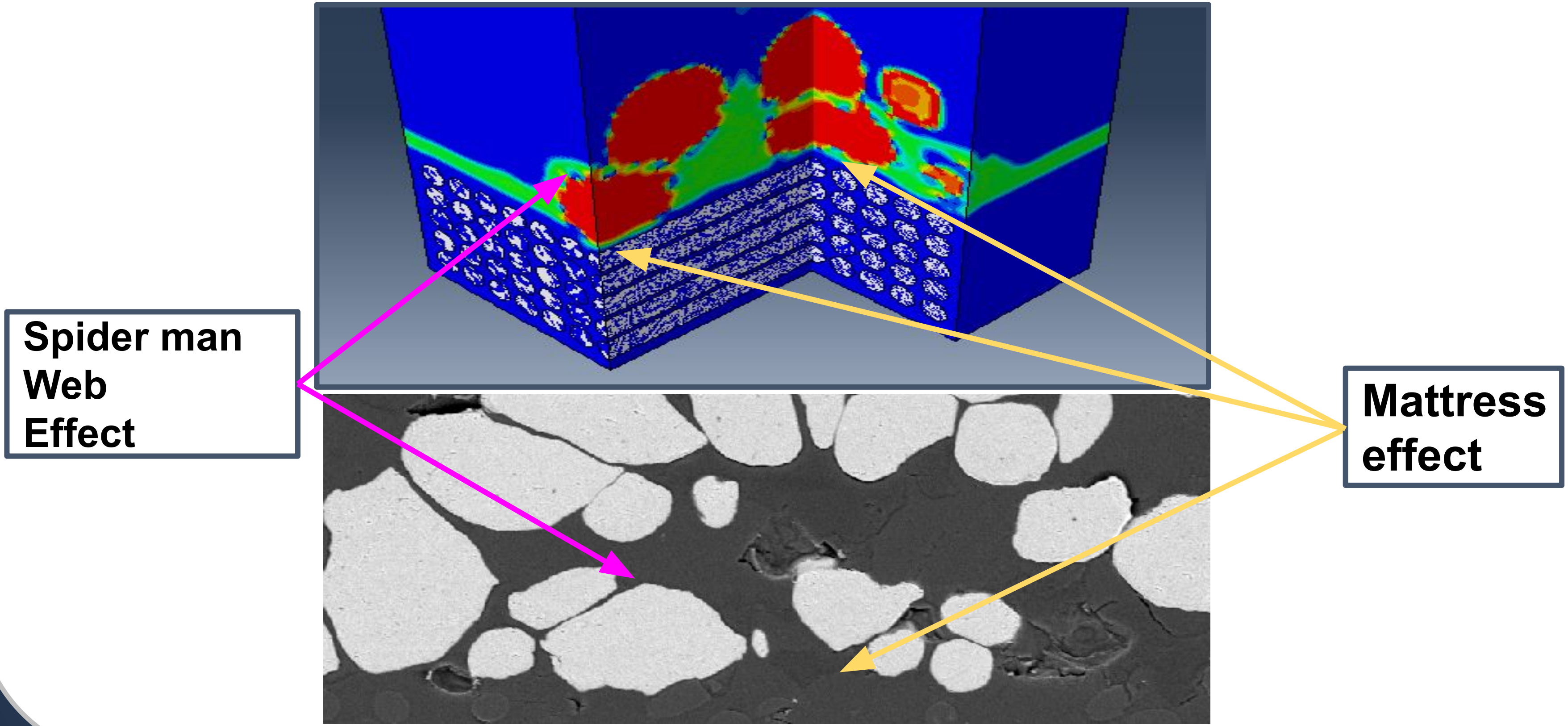
Modeling

Multiparticle impact simulation



Modeling

Multiparticle impact simulation



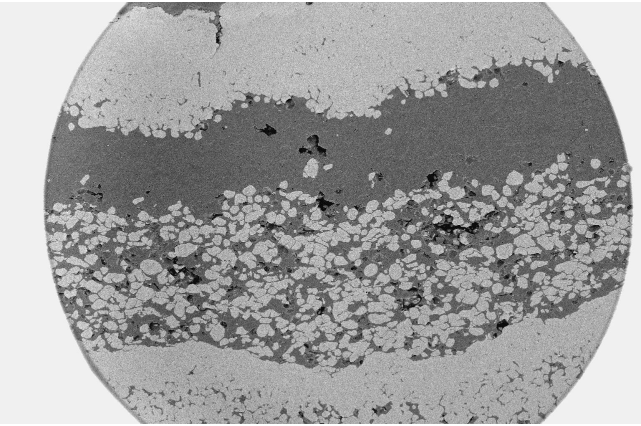
Conclusions

Conductive coatings onto short carbon reinforced PEEK

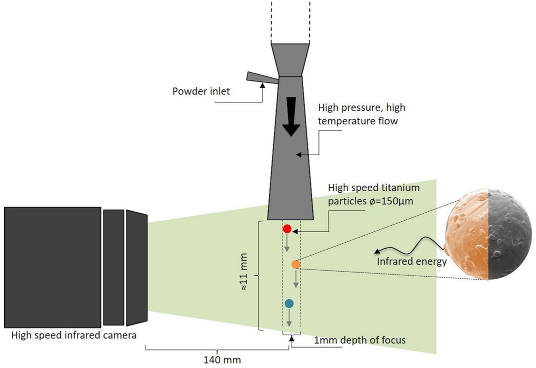
- Pure aluminium coatings with both low and high pressure CS gives very low adhesion
- A mixture of aluminium and a small percentage of polymer allows adherent and conductive coatings
- CFD analysis shows high temperature gas in the LPCS with flat nozzle exit
- FEM impact simulations revealed adhesion mechanisms in the case of mixed metal-polymer powders

Perspectives

Experimental:
- **Gradient coating**
- **Charged polymer powders**

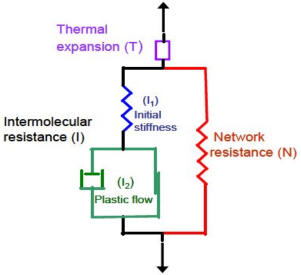


CFD:
- **Suitable heat exchange model**
- **Validation with particle temperature real data**
- **Nozzle optimization**



From Nastic, Jodoin

Impact simulation:
- **Increased particle number**
- **Fiber damage model**
- **Specific constitutive model for PEEK**



From Garcia-Gonzales