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Computational Simulation for Cold Sprayed Deposition

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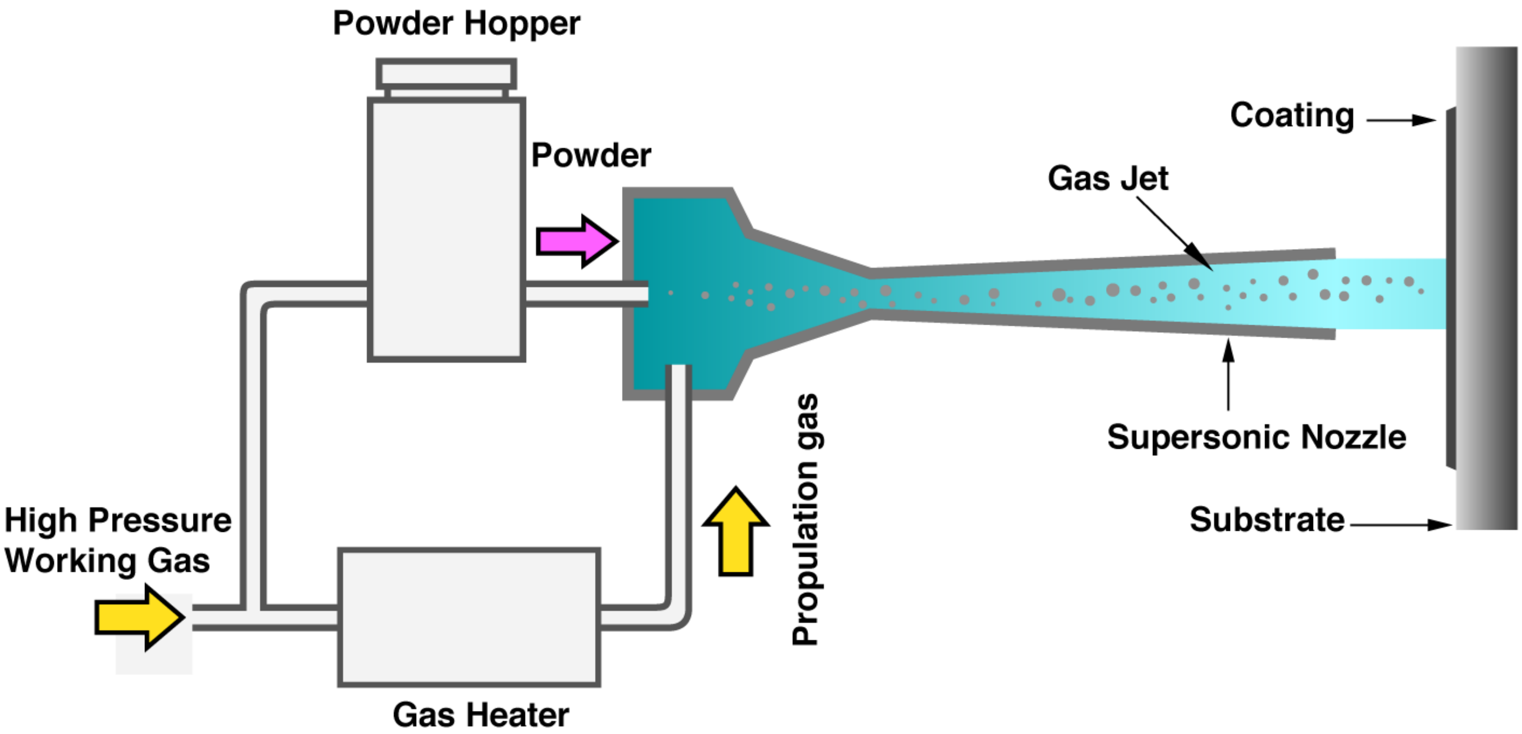
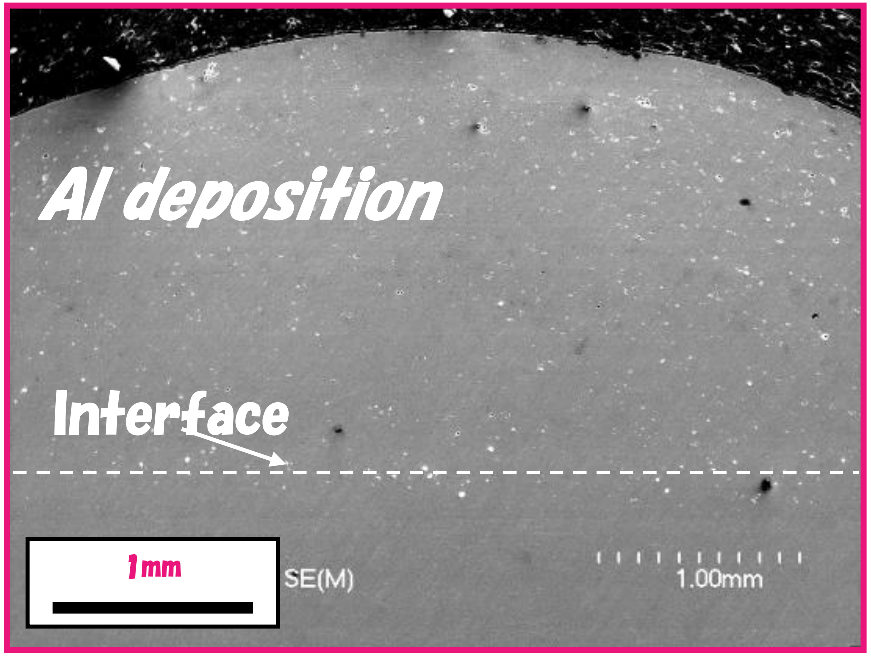
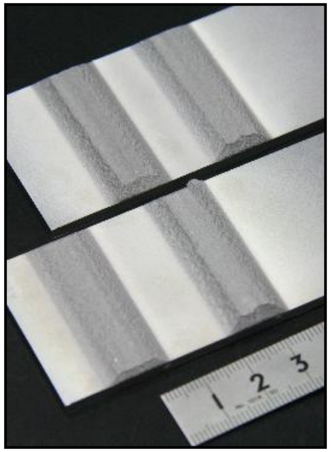
Cold spray



In conventional thermal spray technique, the coating material is heated to molten or semi-molten state. Therefore, thermal sprayed coatings have created some problems due to heating, i.e. high temperature oxidation and phase transformation. In the case of a cold spray technique, the particles are accelerated by the sonic/subsonic gas jet at the gas temperature, which is usually lower than melting temperature of powder materials.

From thin coating to thick deposition





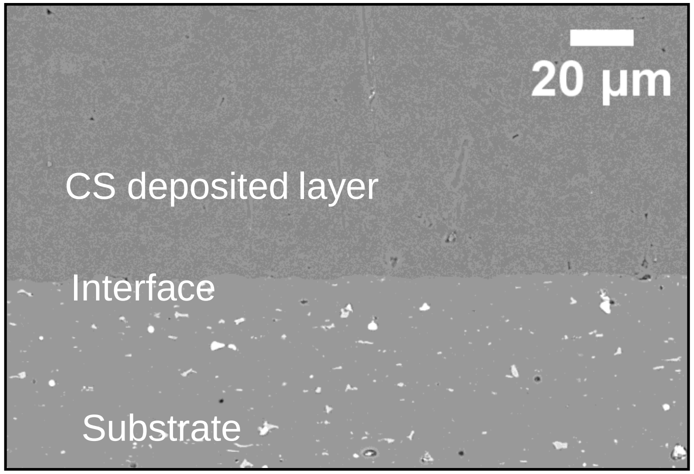

50-60mm thick deposition

Key issues

Optimization of spray conditions

Elucidation of deposition mechanisms

To obtain high quality coatings ….



Evaluation of adhesion strength

Development of new applications

Evaluation of several properties of the deposited layer

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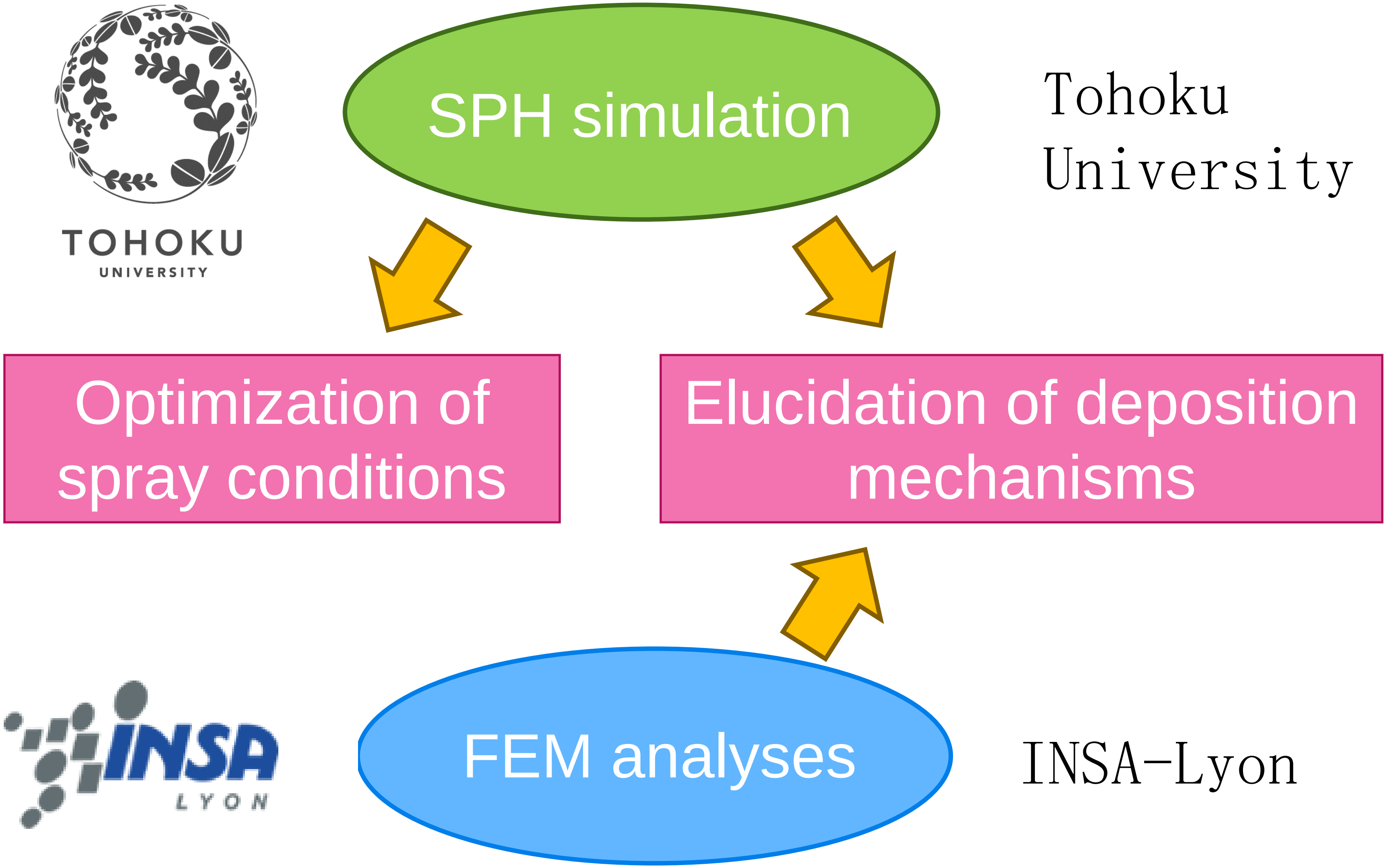

SPH simulation

Tohoku University

Optimization of spray conditions

Elucidation of deposition mechanisms

INSA LYON

FEM analyses

INSA-Lyon

Smoothed Particle Hydrodynamics (SPH) for Cold Sprayed Deposition

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  - Smoothed particle hydrodynamics (SPH)
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- Summary
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Lagrangian and Eulerian Mesh

Software packages used to perform CS analysis include

- CTH - coupled thermal mechanical hydrodynamic code
- ABAQUS and LS-DYNA – explicit FEA program

Lagrangian mesh

- Mesh is fixed to and moves with the material
- Remeshing is possible but expensive

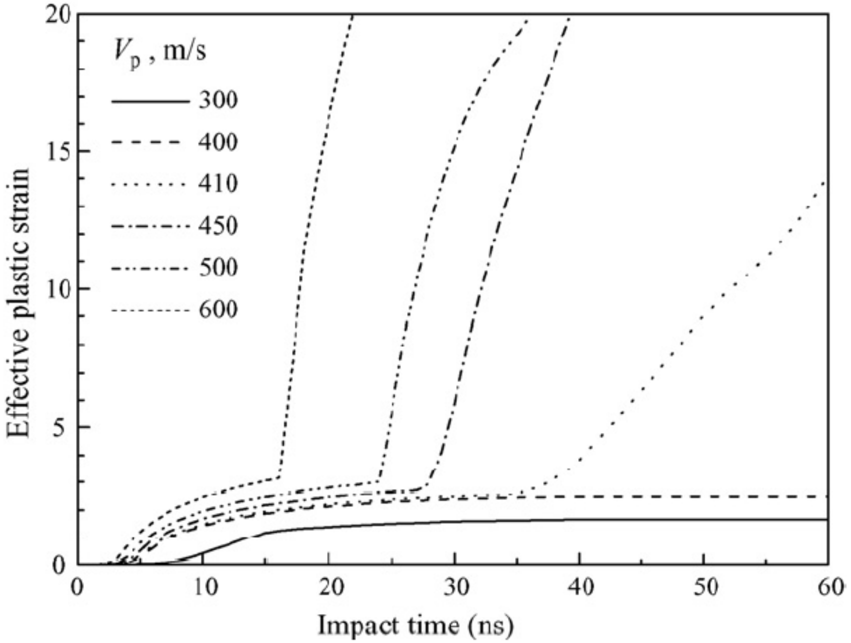
Eulerian mesh

- Mesh is fixed in space and materials pass through it
- Difficult to construct on complex geometries

Limitations in simulating high velocity impact

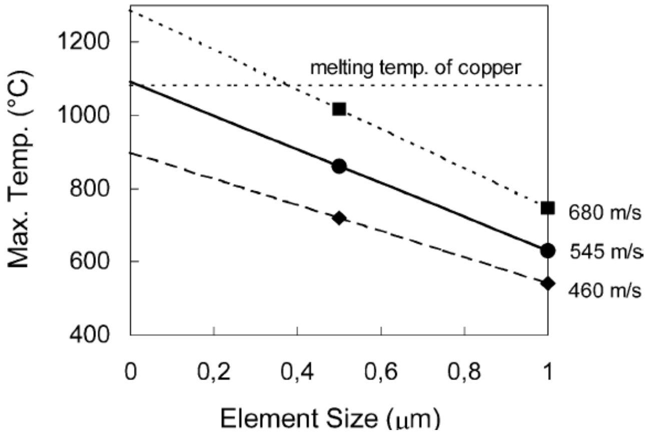
Limitations of the Mesh-based Methods

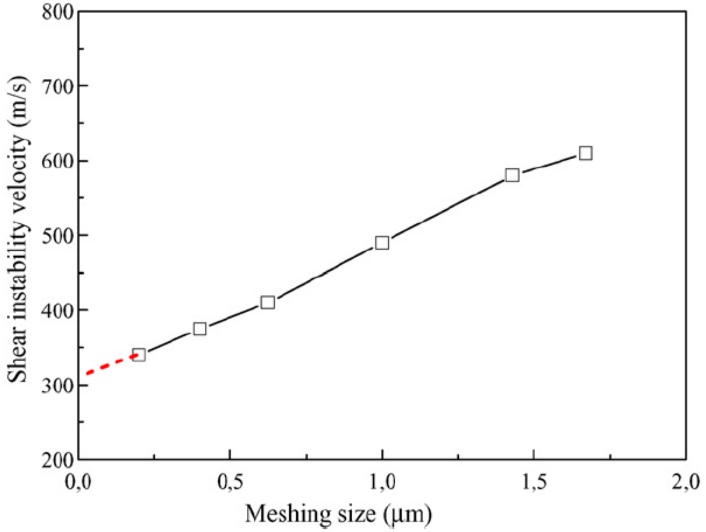
Assadi performed remeshing every 50 increments to overcome severe mesh distortion



A different approach is needed

Mesh size results in inaccuracies





Assadi H, Gartner F, Stoltenhoff T, Kreye H. Acta Mater 2003;51:4379

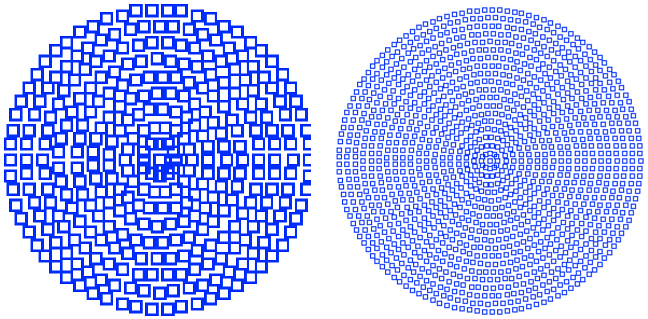
Li W-Y, Liao H, Li C-J, Li G, Coddet C, Wang X. Appl Surf Sci 2006;253:2852.

Smoothed Particle Hydrodynamics

Mesh free, adaptive, particle method

Advantage

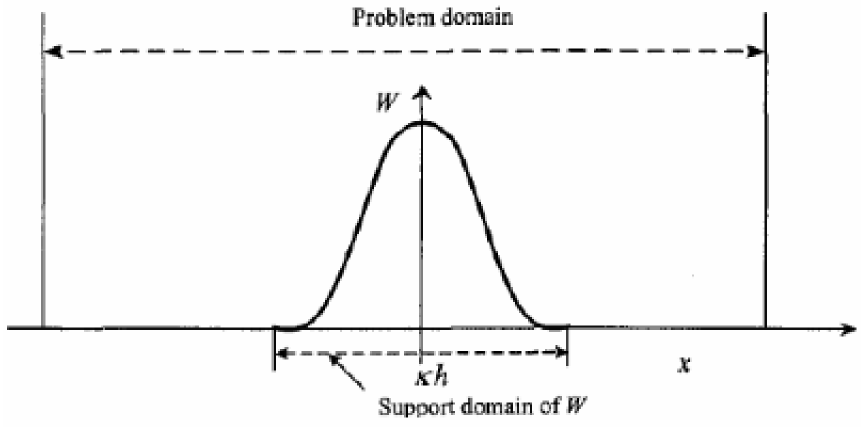
- Solving large deformation problems is easy
- Refinement of particles is easy
- Contact boundary condition can be ignored



SPH particles with 500 and 2000 particles

SPH formulation

- Integral representation method – kernel approximation



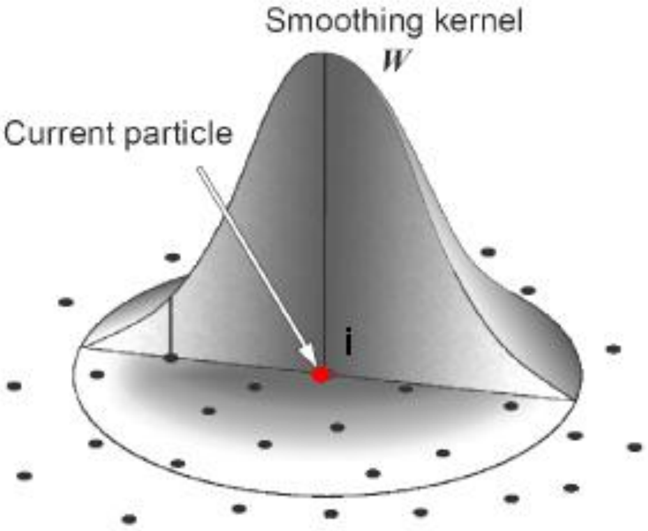
$$\langle f(x)\rangle = \int f(x')W\left(\frac{|x-x'|}{h}\right)dx'$$

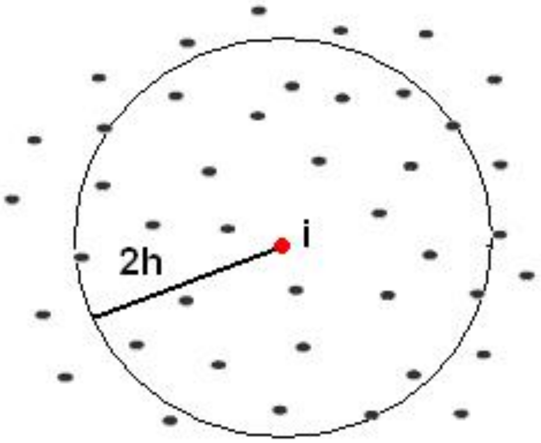
W = smoothing kernel
h = smoothing length

Smoothed Particle Hydrodynamics

SPH formulation

- Particle approximation





Particle approximation

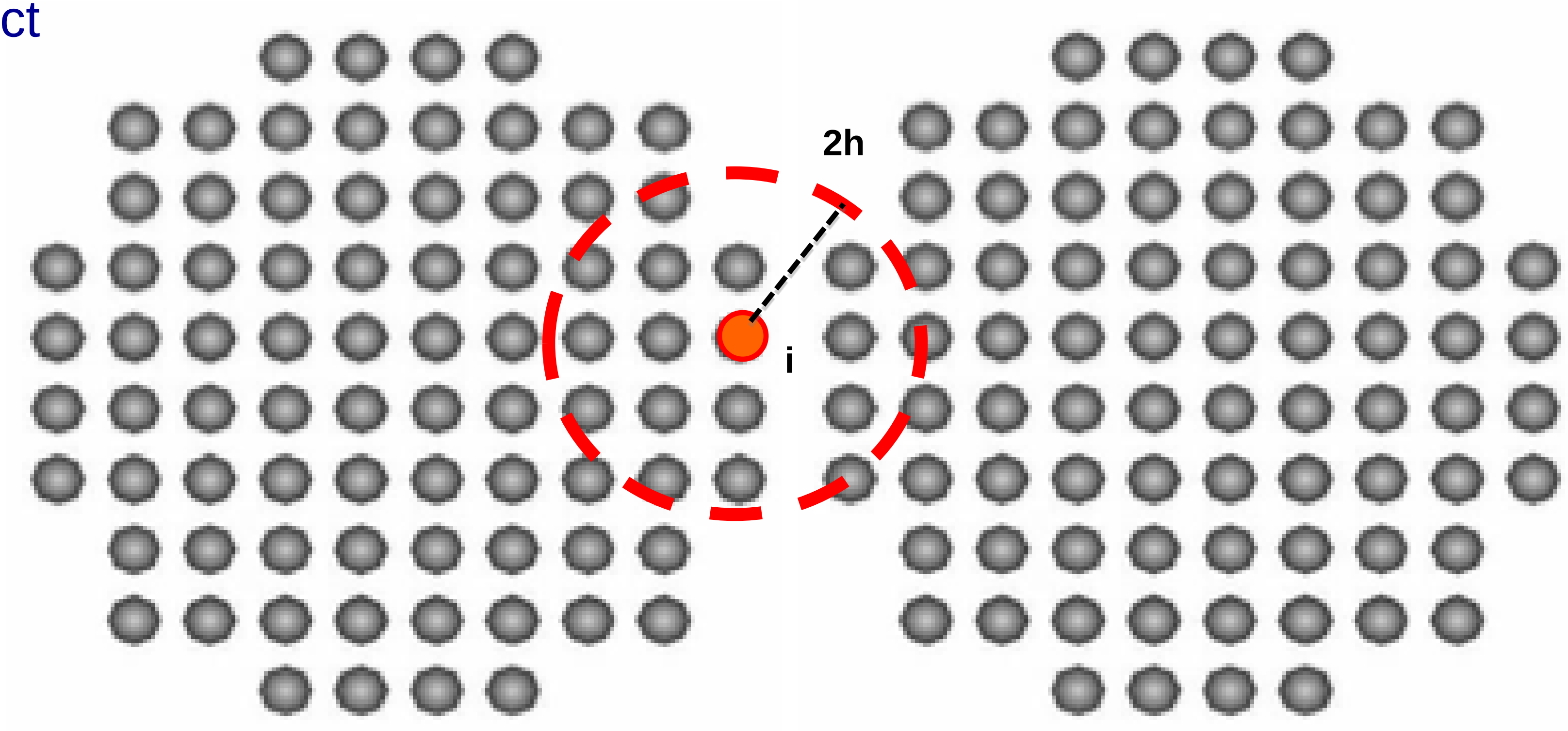
$$\langle f(x)\rangle \cong \sum_{i=1}^{N} m_i f_i W\left(\frac{|x-x'|}{h}\right)/p_i$$

Smoothing kernel is B-spline

$$W_4(v,h)=\frac{1}{\pi h^3}\begin{cases}\left(1-\frac{3}{2}v^2+\frac{3}{4}v^3\right) & 0<v<1\\ \frac{1}{4}(2-v)^3 & 1<v<2\\ 0 & \text{otherwise}\end{cases}$$

Smoothed Particle Hydrodynamics

Contact



Governing equations

Conservation of mass

$$\rho_i = \sum_j m_j W_{ij}$$

Conservation of momentum

$$\frac{dU_i}{dt} = -\sum_j \frac{m_j}{\rho_i \rho_j}(\sigma_j - \sigma_i).\nabla W_{ij}$$

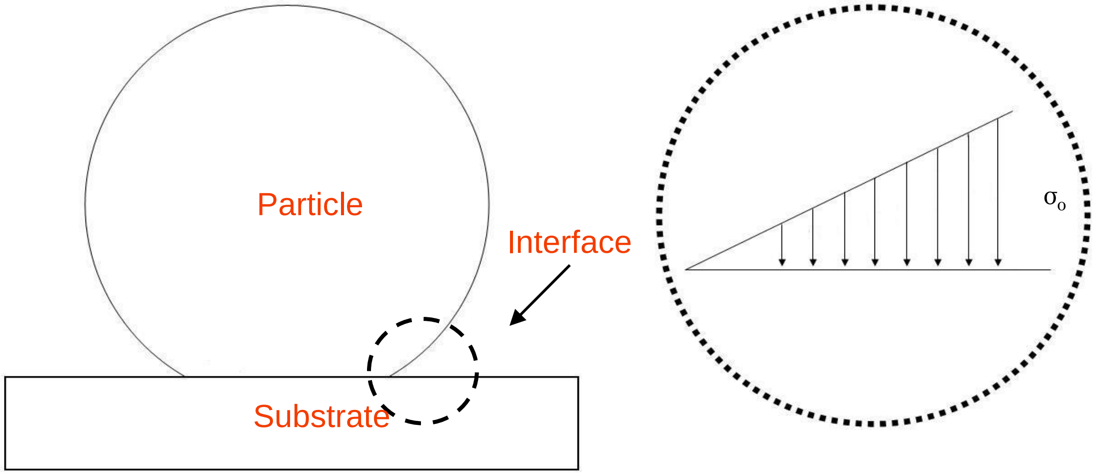
Conservation of energy

$$\frac{dE_i}{dt} = -\sum_j \frac{m_j}{\rho_i \rho_j}(U_j - U_i).\sigma_i.\nabla W_{ij}$$

Objective

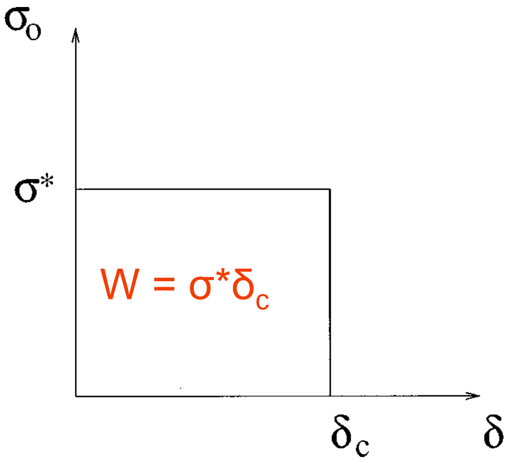
To demonstrate feasibility of the SPH method in simulating the cold spray process

Interface Reaction Model



Schematic diagram of adhesive interaction between powder particle and substrate due to interfacial traction

Dugdale-Barenblatt Cohesive Zone Model



$\sigma_o \sim 10^7$ N/m^2, $\delta_c \sim 10^{-8}$ m

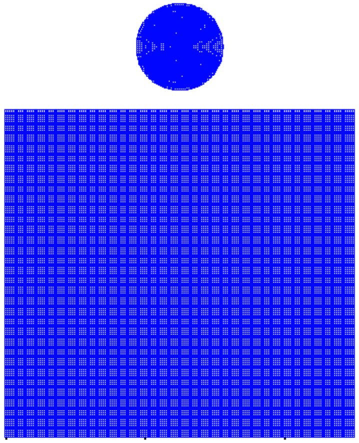
Huang R. EM 388F Lecture Notes 9: Nonlinear fracture mechanics II. In: http://imechanica.org/node/3110. 2008.

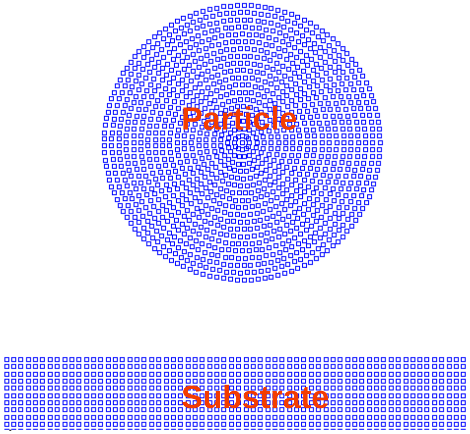
Model Criteria

1. Activated only upon contact
2. Limited to contact between different bodies

SPH Model

Schematic diagram

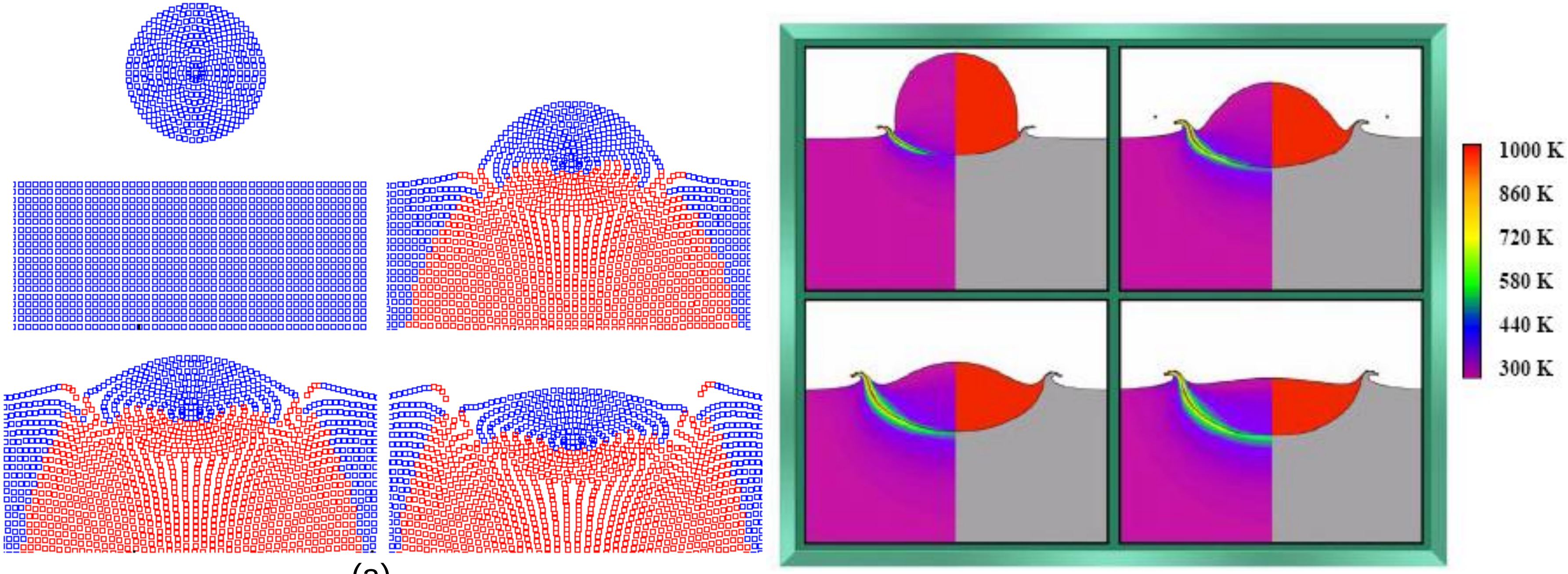




SPH particle input

		Analysis 1	Analysis 2	Analysis 3	Analysis 4
Material	Powder particle	Copper	Al-12Si	Aluminum	Aluminum
	Substrate	Steel	Mild steel	Aluminum	Aluminum
Size (μm)	Powder particle	25			
	Substrate	100			
Particle number	Powder particle	500			
	Substrate	5000			
Initial velocity (m/s)		700	500-1000	700, 780, 840	500-1000
Simulation time (ns)		250	50000	250	50000
Boundary condition		Fixed bottom plane			
Plastic model		Johnson Cook			

Analysis 1: Validation



(a)

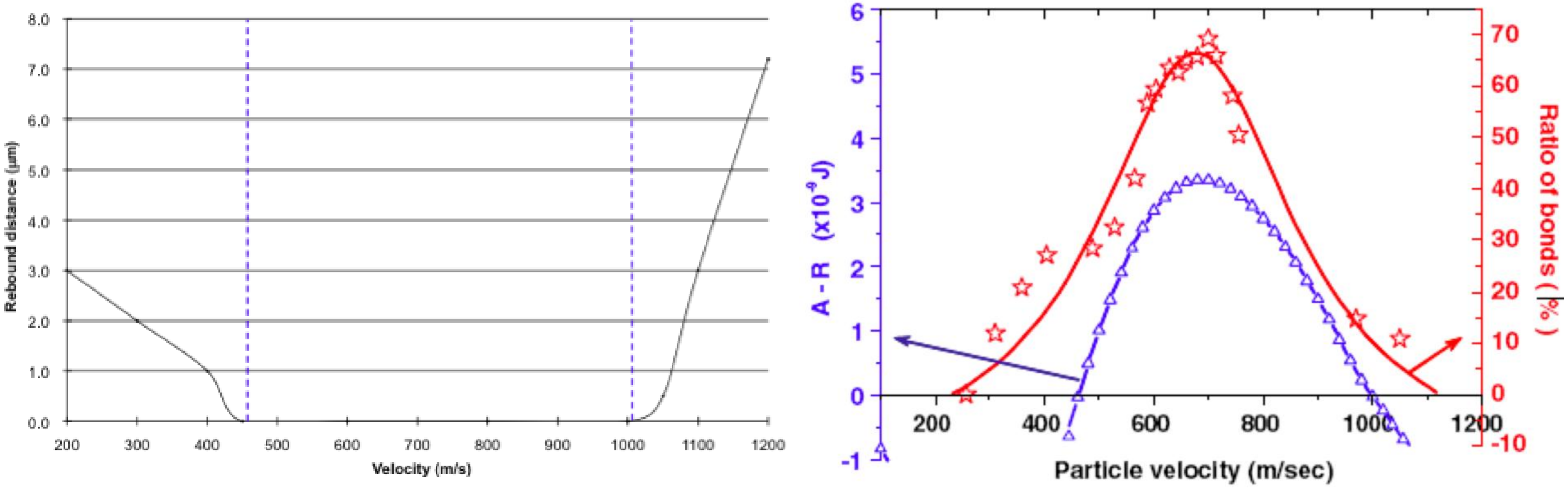
(b)

R.C. Dykhuizen, M.F. Smith, D.L. Gilmore, R.A. Neiser, X. Jiang, S. Sampath, J. Therm. Spray Technol. 8 (1999) 559–564.

Particle deformation upon impact at 700 m/s modeled using (a) SPH and (b) CTH (0 to 250 ns)

SPH method compares well with mesh-based method

Analysis 2: Validation



(a)

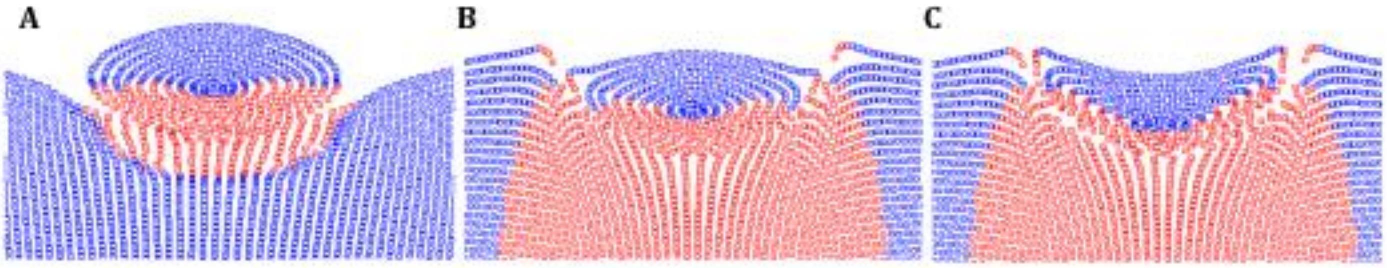
(b)

Wu J, Fang HY, Yoon SH, Kim HJ, Lee C. Scripta Mater 2006;54:665

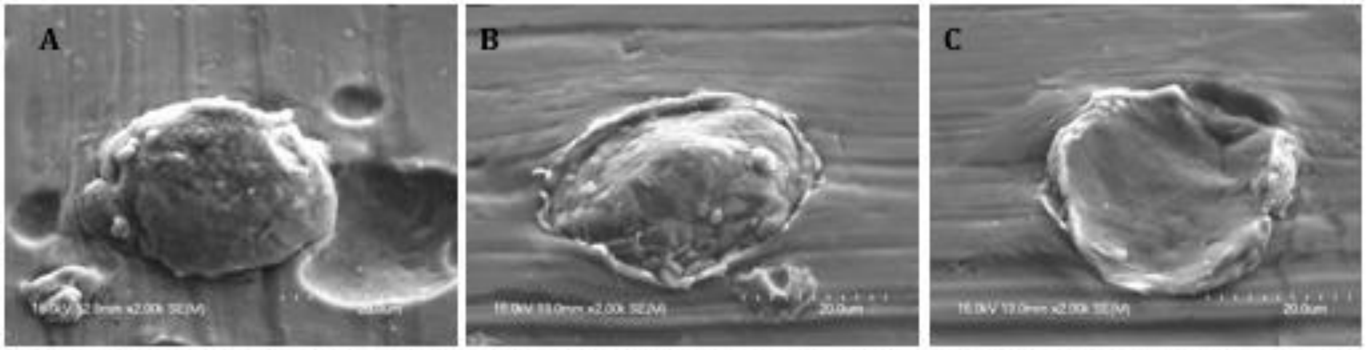
Calculated critical and maximum velocity via (a) SPH method and (b) adhesion and rebound energy equation

Interface reaction model implemented in SPH is justified

Analysis 3: Deformation Behavior



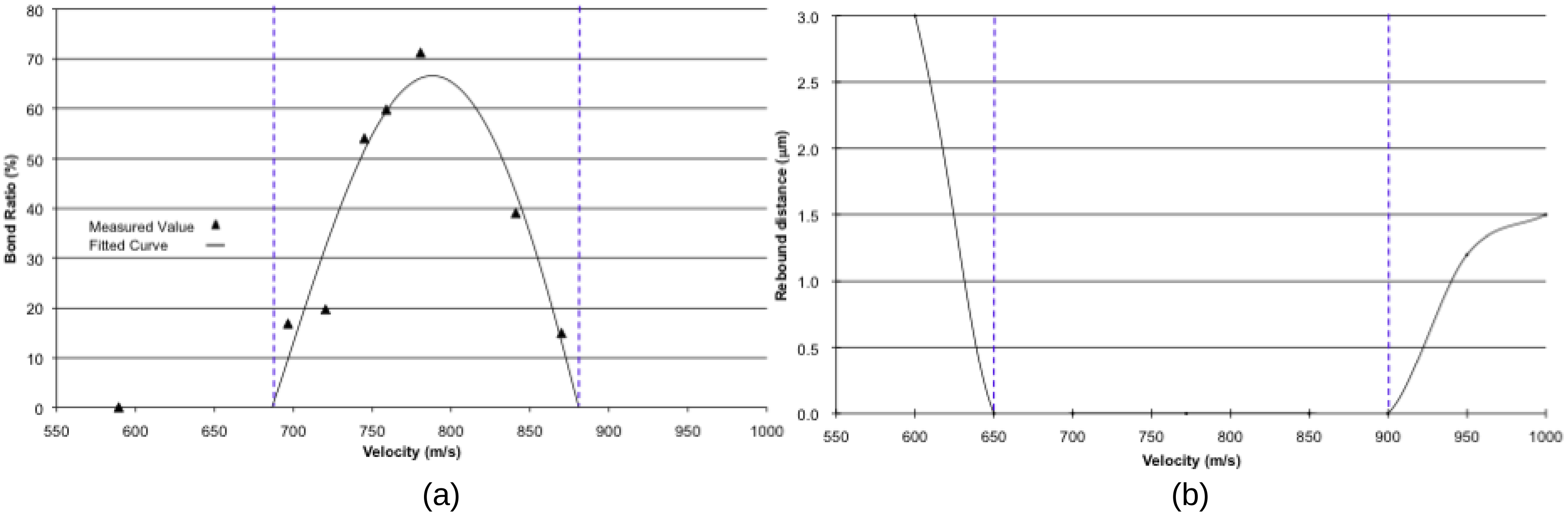
SPH SIMULATION OF DEFORMED ALUMINUM POWDER PARTICLES IMPACTED AT A) 700 M/S B) 780 M/S AND C) 840 M/S ON ALUMINUM SUBSTRATE



SEM IMAGES OF DEFORMED ALUMINUM POWDER PARTICLES (45° ANGLE TILTED VIEW) IMPACTED AT A) 700 M/S B) 780 M/S AND C) 840 M/S ON ALUMINUM SUBSTRATE

SPH simulation agrees with experiment

Analysis 4: Velocity Range



Calculated critical and maximum velocity via (a) bond ratio and (b) SPH method

SPH simulation agrees with experiment

Summary

The CS process was simulated by modeling the impact of spherical powder particles on a substrate using the SPH method

The adhesive interaction is modeled as intersurface traction using the Dugdale-Barenblatt cohesive zone model

SPH simulation compares fairly well with mesh-based method and experimental results

Further Work

SPH method will be implemented to model different spray parameters

Analysis number		1	2	3	4	5
Analysis type		Single impact	Multi impact		Single impact	
Shape	Powder particle	Irregular	Spherical	Irregular	Spherical	Irregular
	Substrate	Smooth				
Material	Powder particle	Aluminum			NiCoCrAlY	
	Substrate	Aluminum			Inconel 718	
Size (μm)	Powder particle	25			25 - 100	
	Substrate	100			6 times powder size	