AMPTECH
Developing Advanced Manufacturing Process Technology Solutions

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

AMP SDSM&T

Gas Dynamics of Cold Spray & Control of Deposition

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SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY

Discovery and Technology Target

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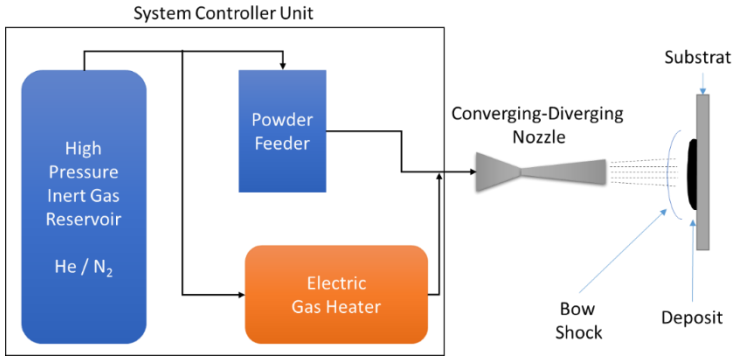
- Discovered in the 1980s at the Russian Academy of Sciences
- Line of sight process
- Coating thickness > 10 μm
- Extend expensive part life
  - Structural and geometrical surface repair
  - Crack growth prevention
- Coating of similar and dissimilar materials
  - Corrosion prevention
- Additive-subtractive manufacturing



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High Pressure Cold Spray System

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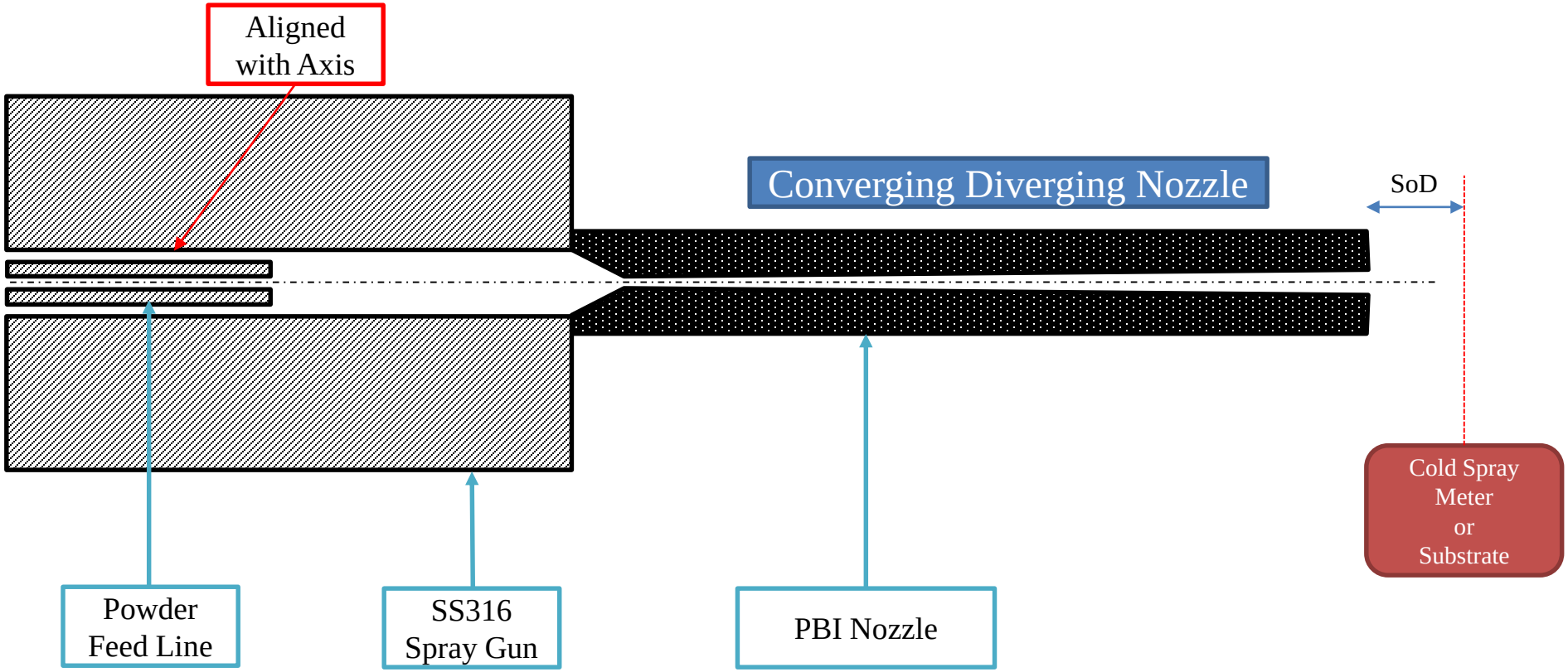

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Nozzle

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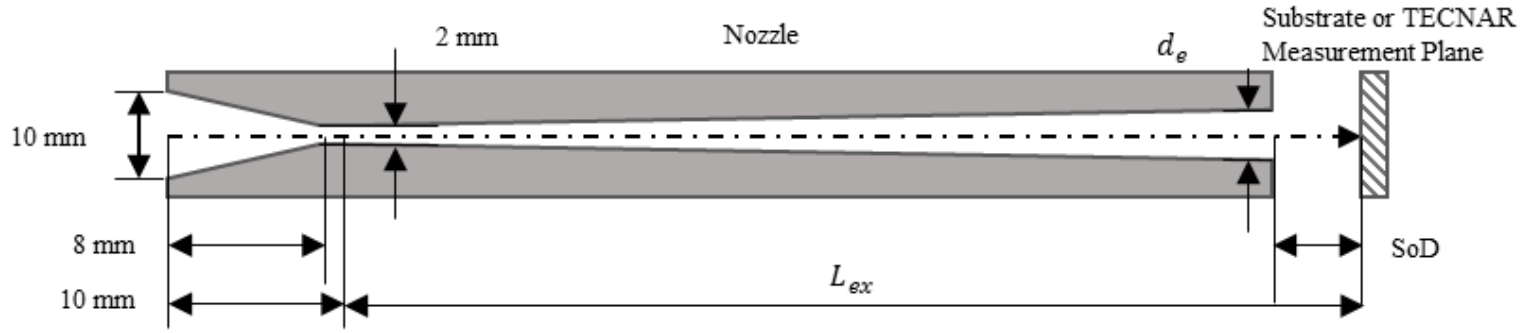
- Expansion ratio defines the Mach number of nozzle
  - $Expansion\ Ratio = \frac{(Nozzle\ exit\ diameter)^2}{(Nozzle\ throat\ diameter)^2}$
- Mach number changes throughout nozzle
  - $Mach = \frac{Gas\ Speed}{Speed\ of\ Sound} = \frac{V_{gas}}{\sqrt{\gamma RT}}$
- Gas velocity depends on gas inlet temperature



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Gas Behavior

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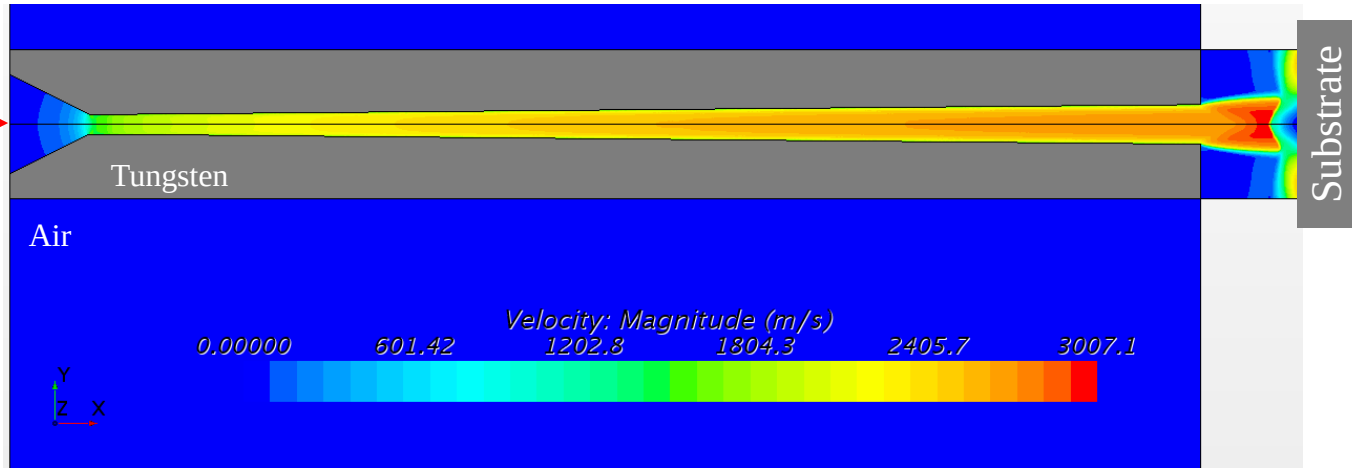
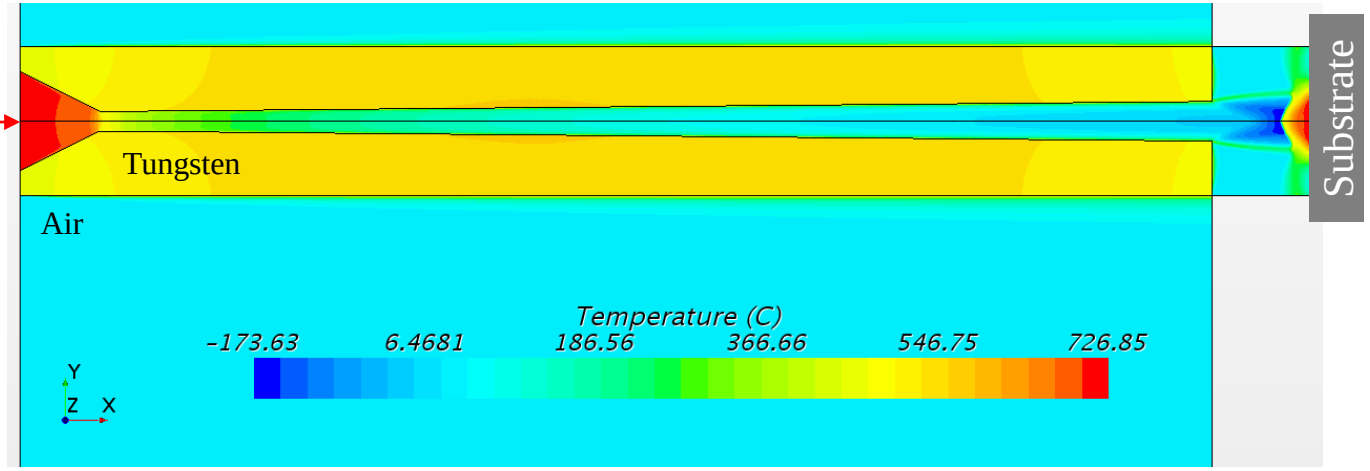
Helium
P = 900 psi
T = 700 C

Velocity Field



Helium
P = 900 psi
T = 700 C

Thermal Field



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Gas Impingement and Standoff Distance

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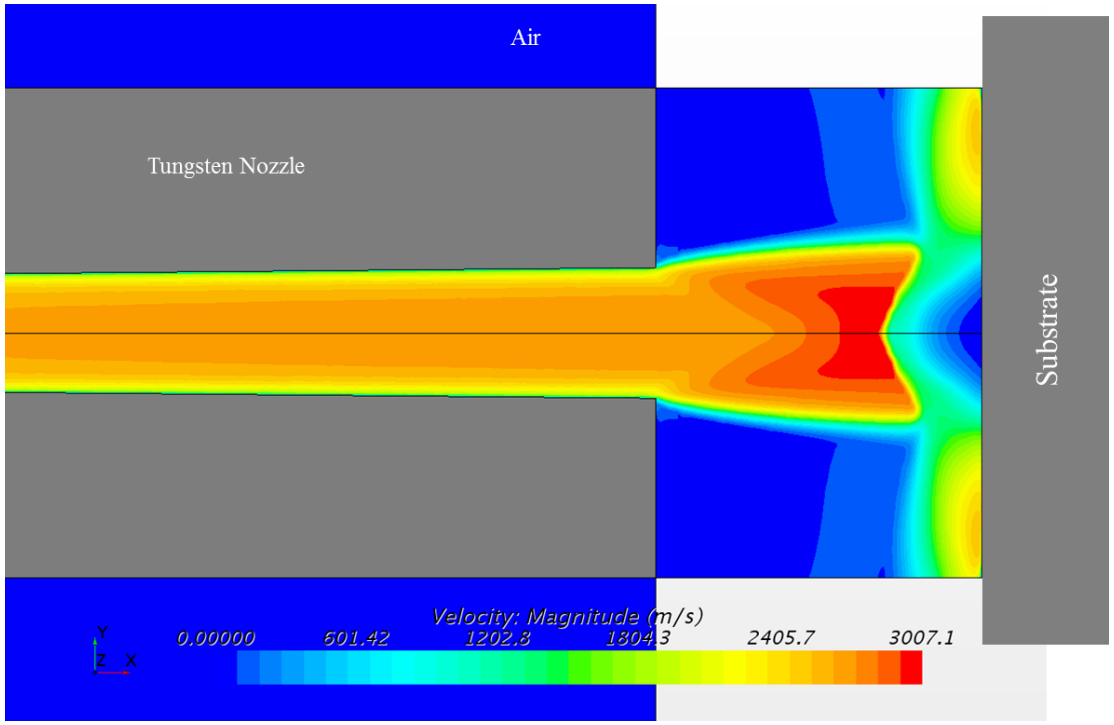
- Bow shock is stronger with lower standoff distances
- Increasing standoff distance causes falloff of particles
- Increased dispersion in the particle footprint



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Gas Impingement Velocity

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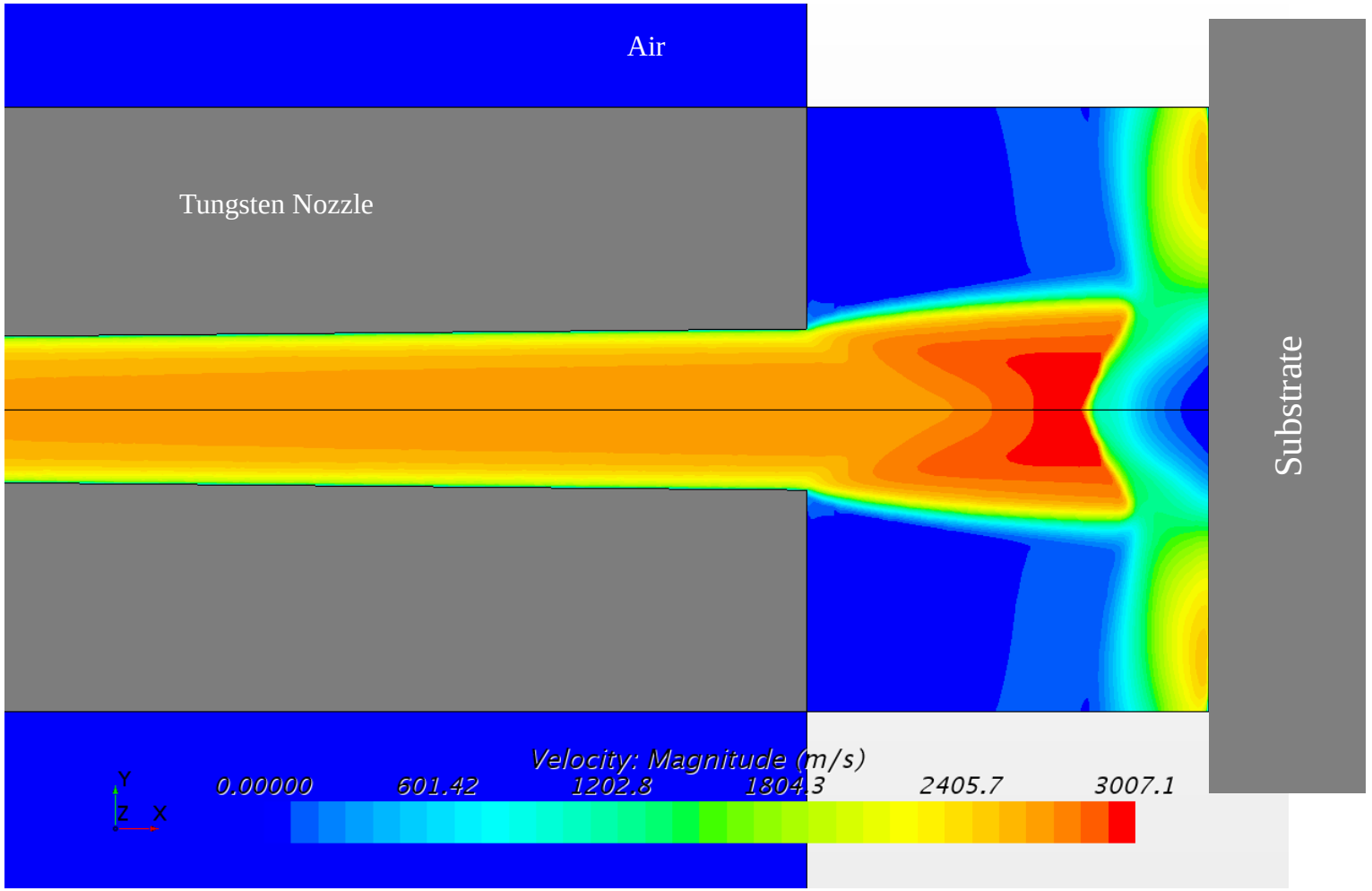

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Gas Impingement Temperature

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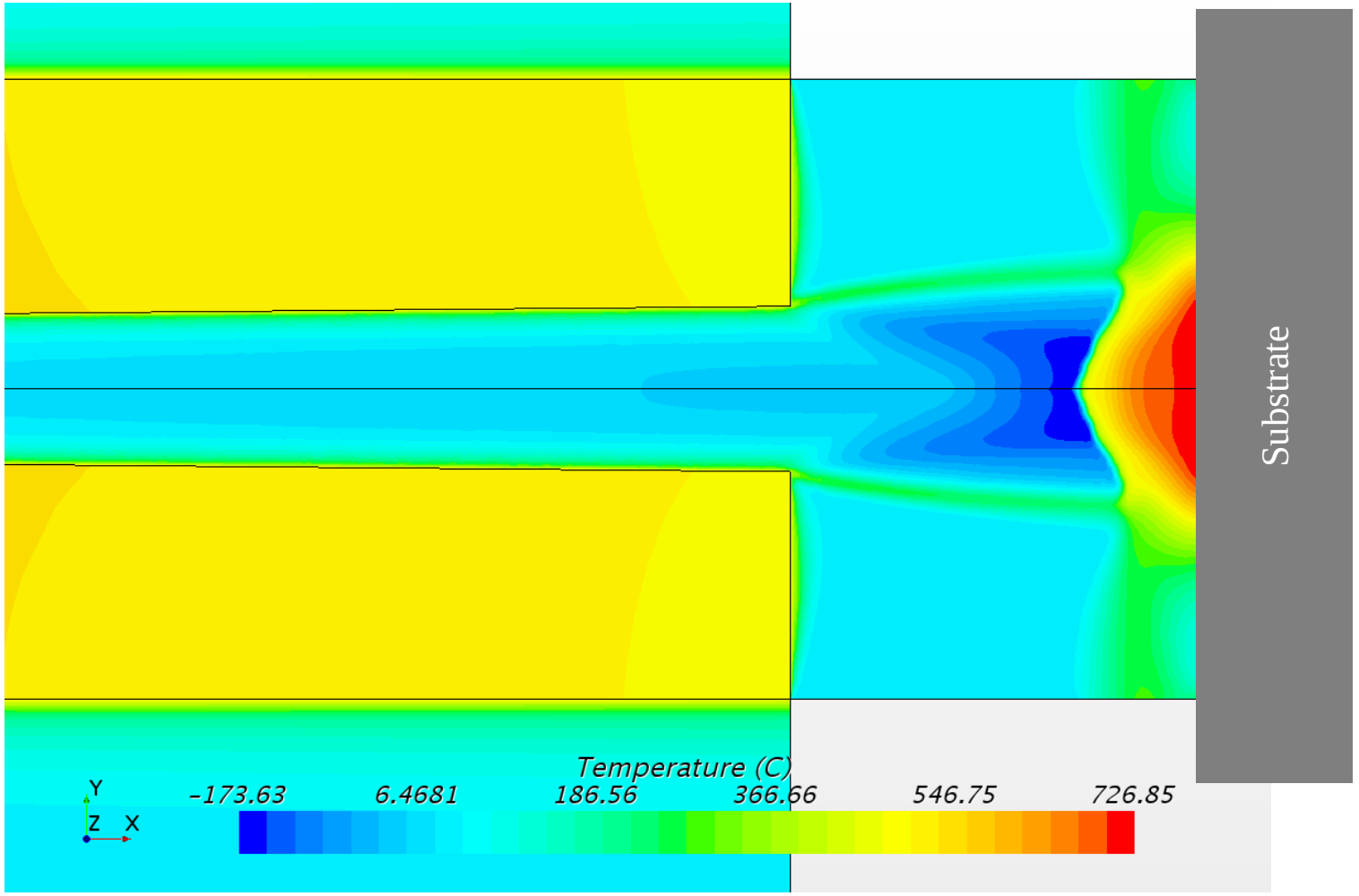
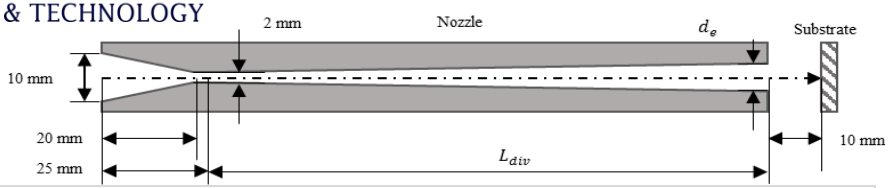
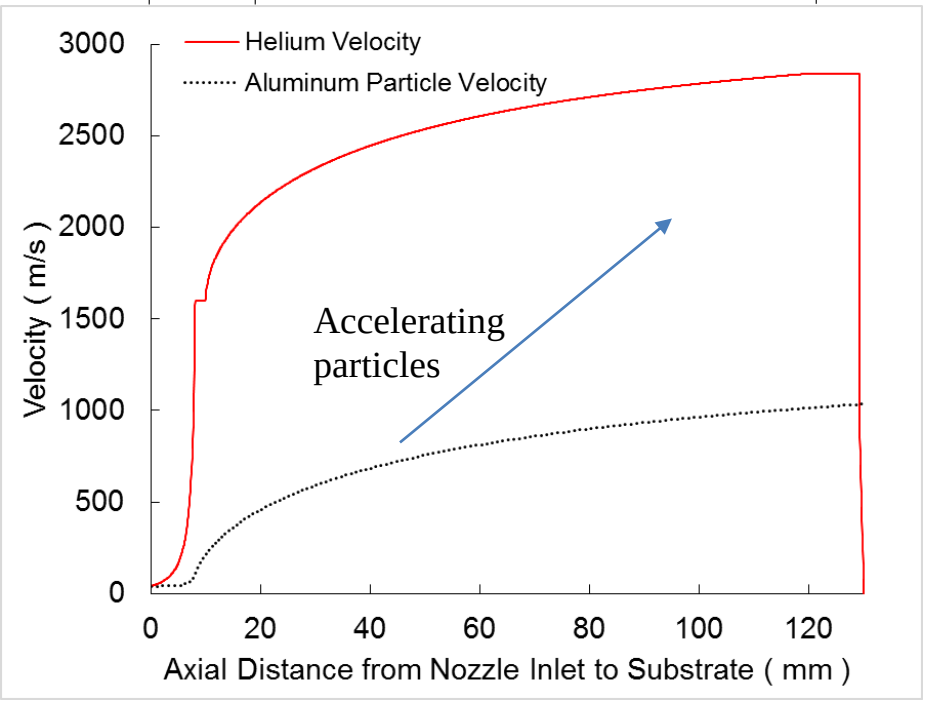


Particle Acceleration





Particle drag generated by gas-particle velocity difference

Gas Flow

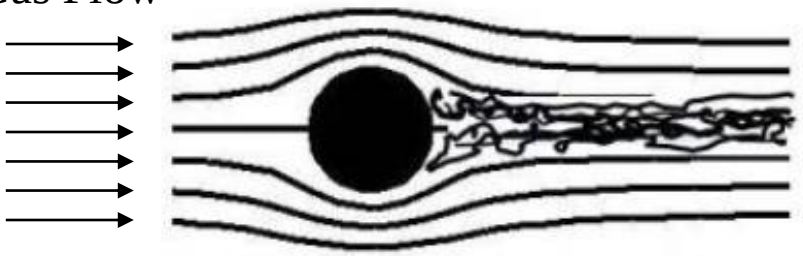


Image Source: https://www.grc.nasa.gov/www/k-12/airplane/dragsphere.html

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Particulate Flow

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Video 1: https://youtu.be/HGUVTPXgWNQ

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Bonding Criterion

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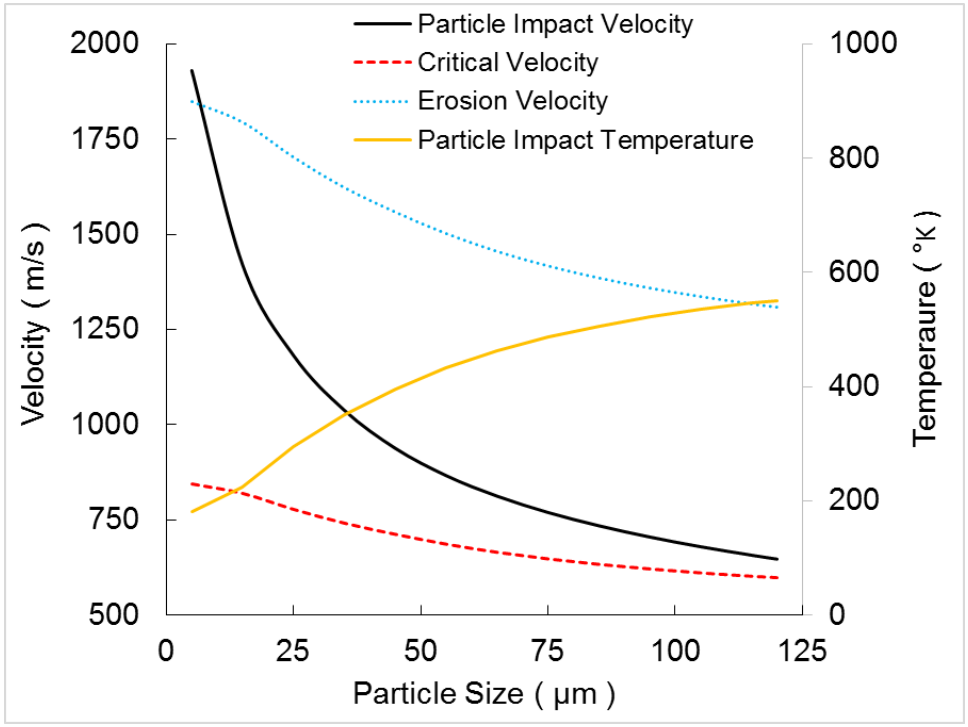
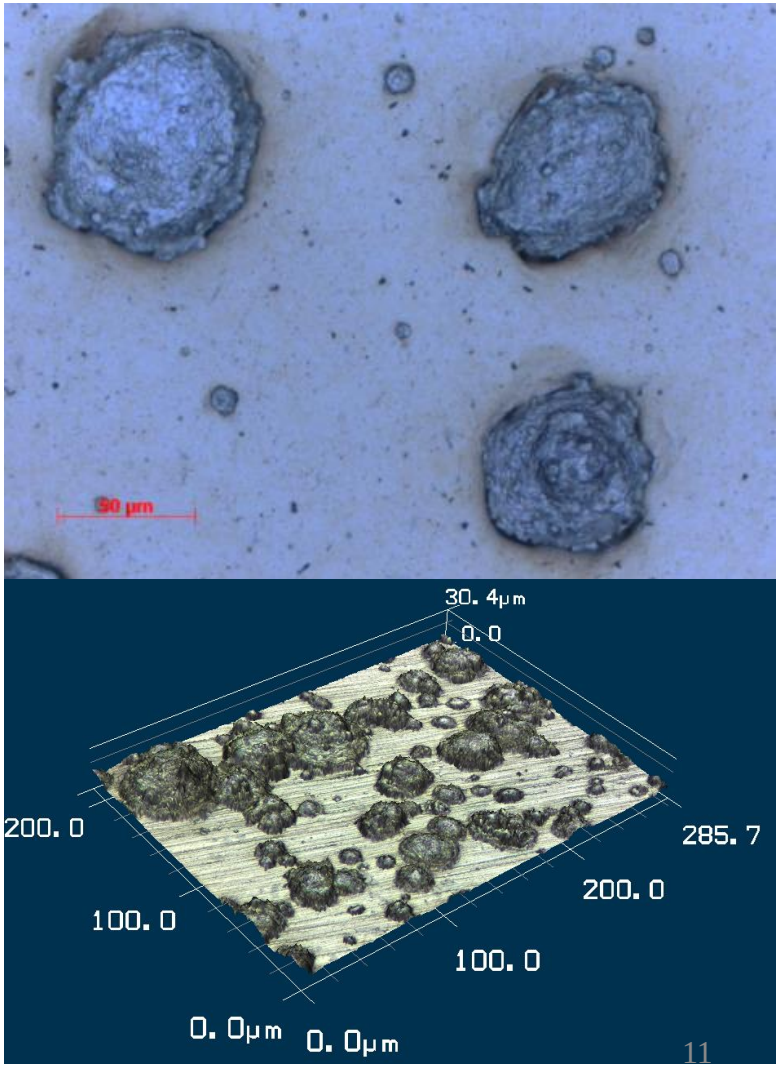
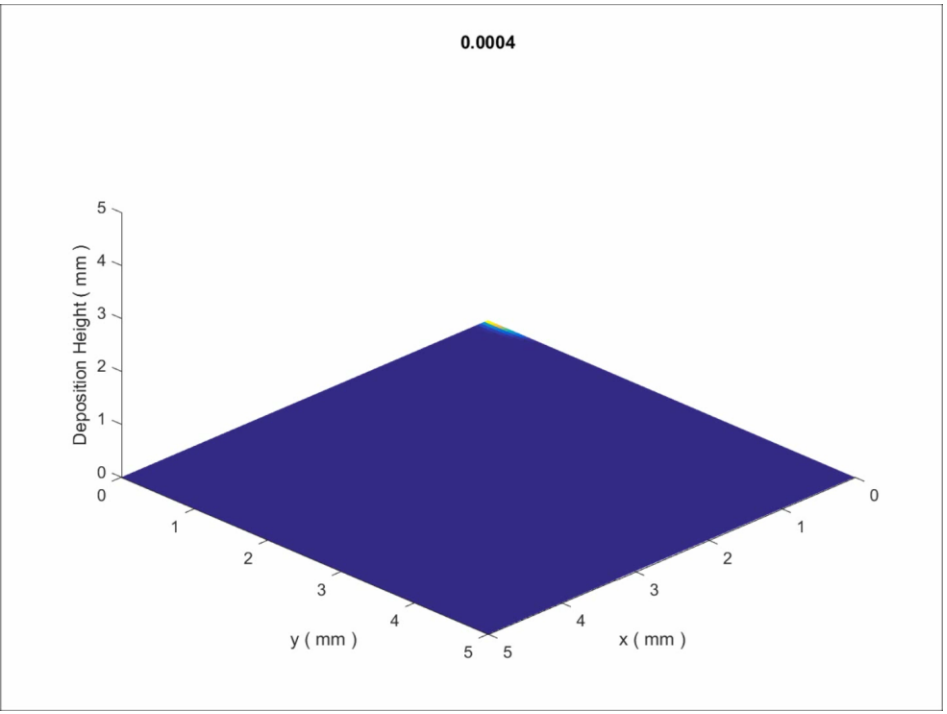
- What makes particles stick?
  - Particle impact velocity
  - Size dependence



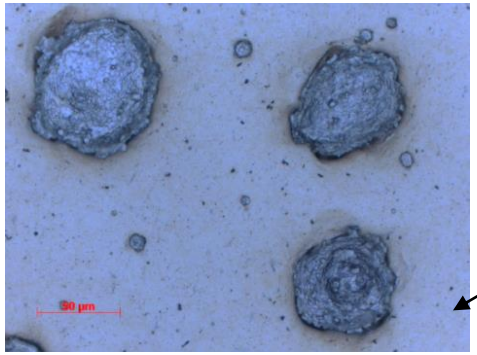


Deposition

Video 2 Link: https://youtu.be/Pu_zAsTnNKw

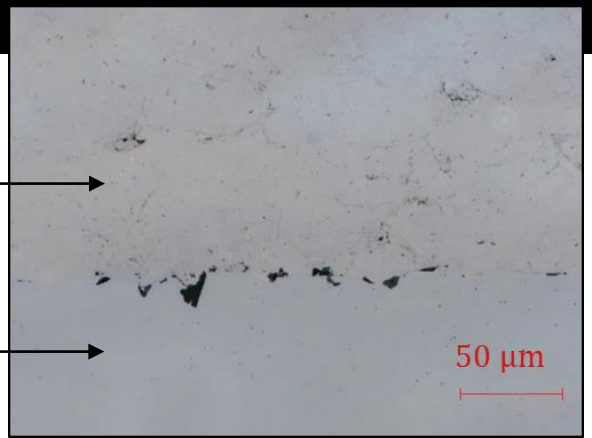


Video 3: https://youtu.be/UV80RfGWxlo



Dense Coating

Substrate



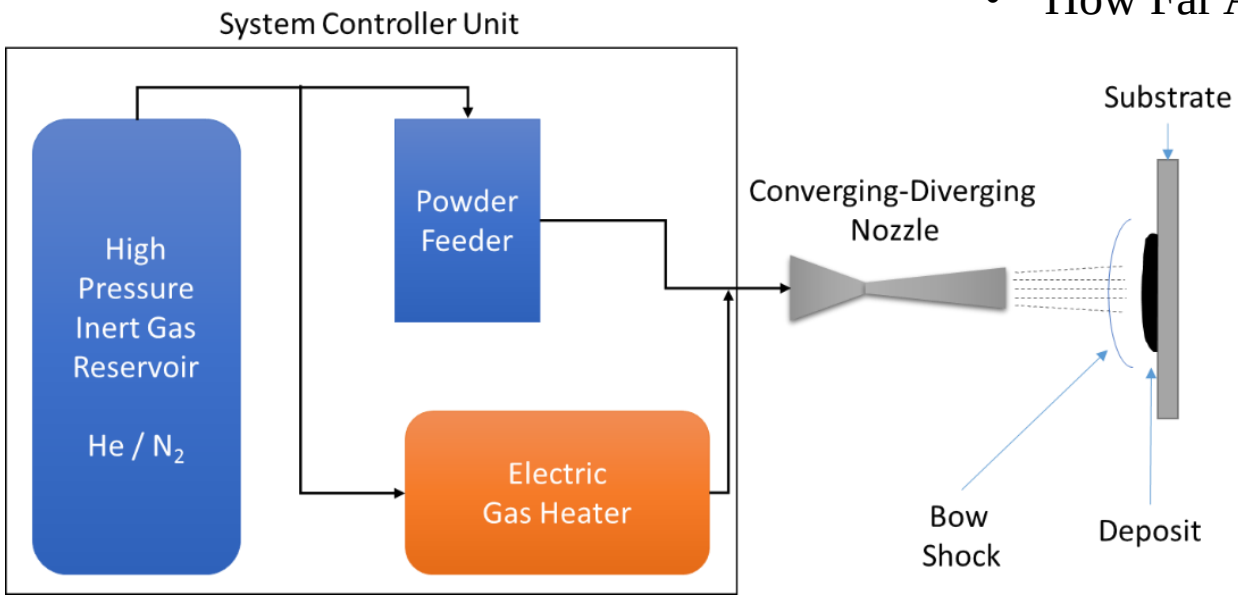
System & Equipment Control Effects on Quality

Gas Pressure

Powder
- Size
- Material
- Prep

Standoff Distance
- How Far Away?

Gas
- Air
- Nitrogen
- Helium
- Mixed Gas



Gas Temperature

Nozzle
- Material
- Geometry

Substrate
- Surface Roughness
- Shape

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Selecting Gas

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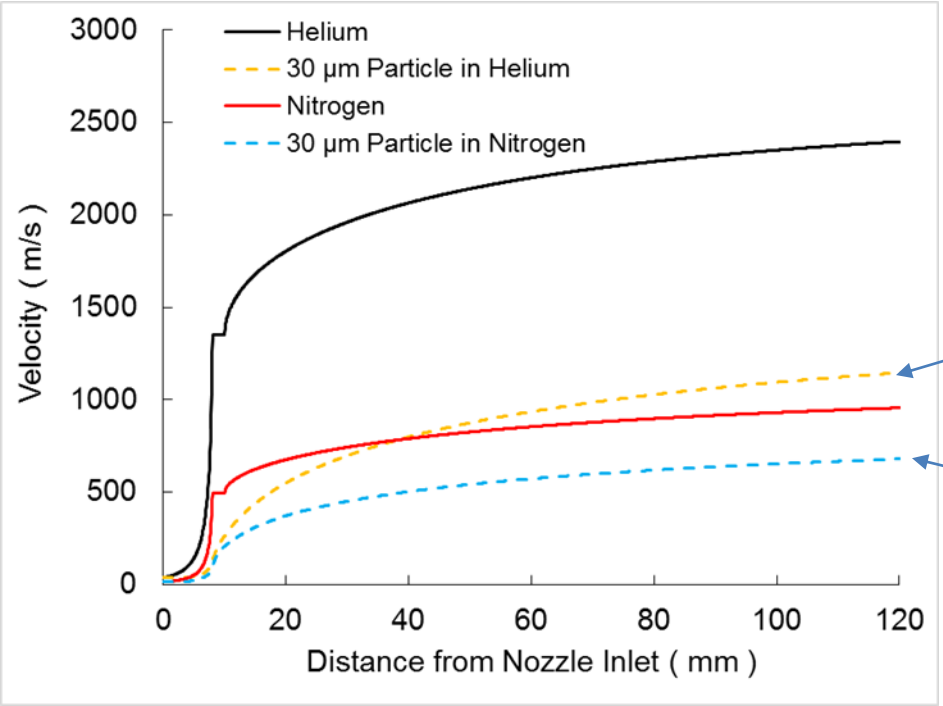
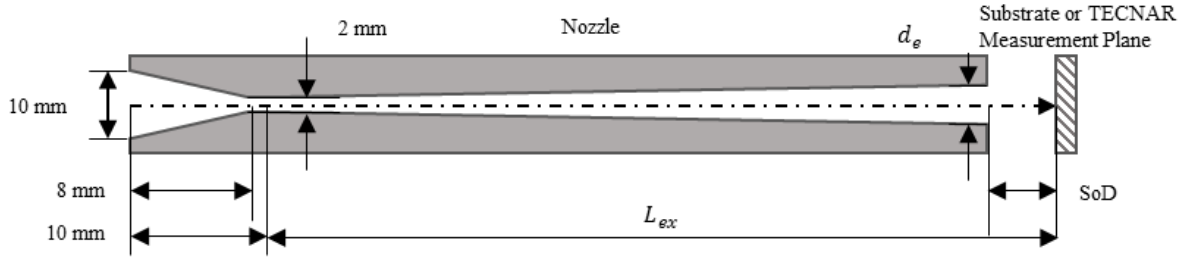


Impact Velocity = 1030 m/s

Impact Velocity = 685 m/s

cost of helium is 6 times that of nitrogen



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Particle Size

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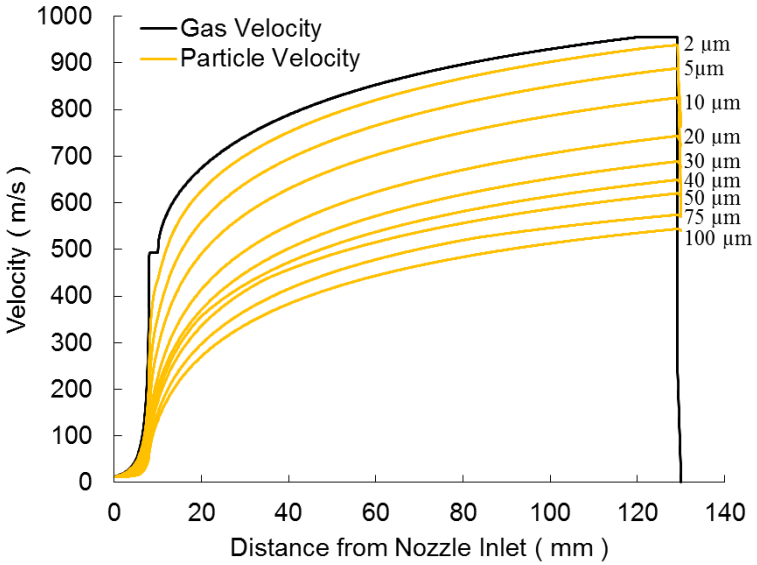
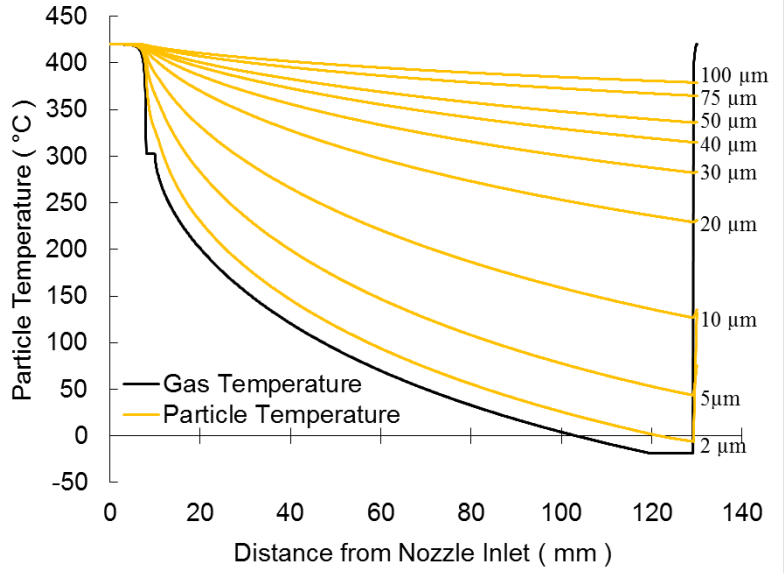
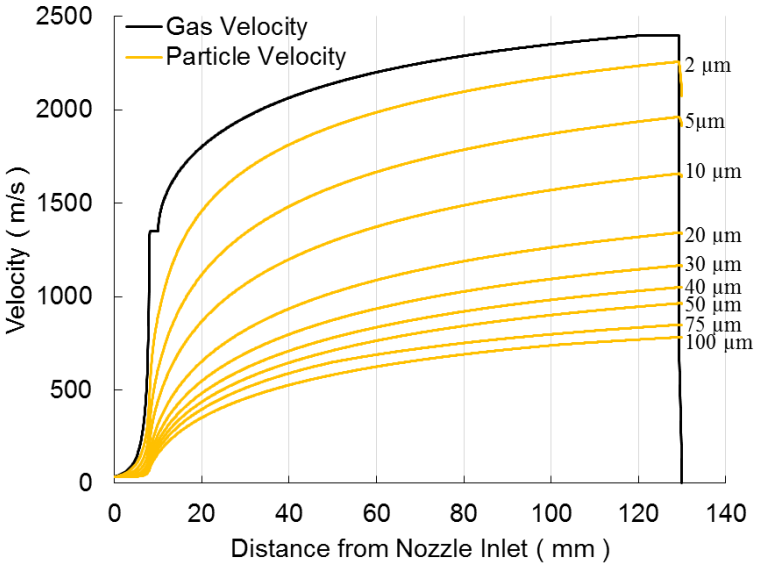
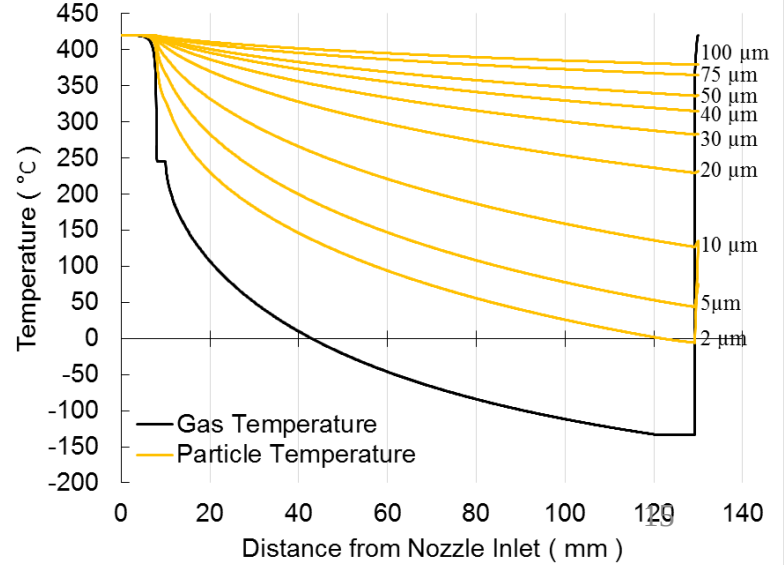
Nitrogen





Helium





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Powder Particle Size Selection

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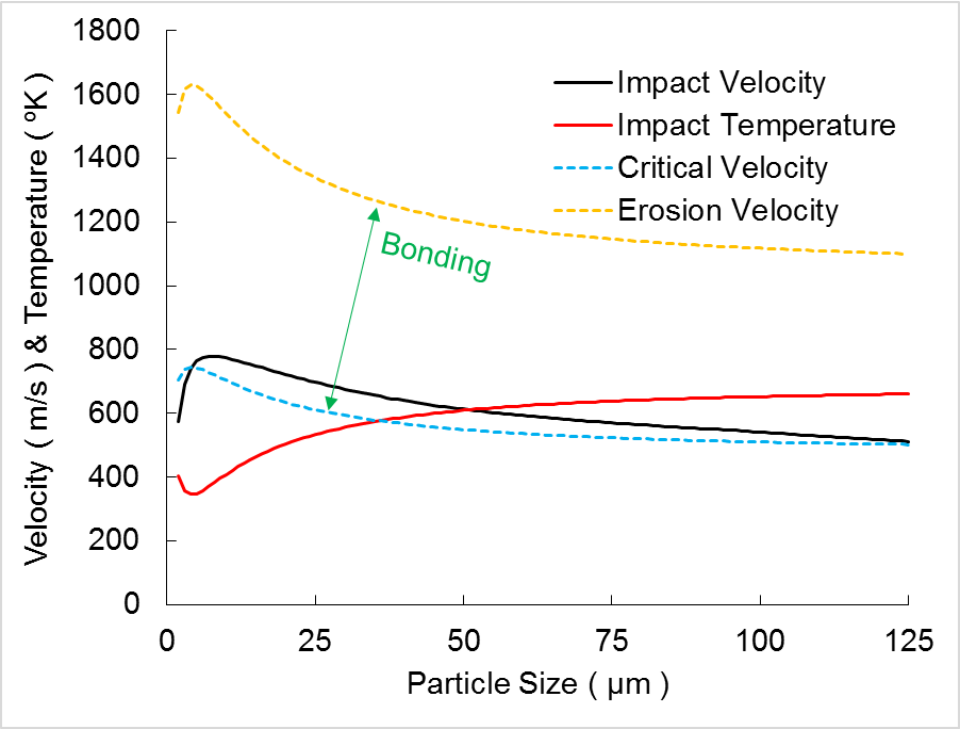
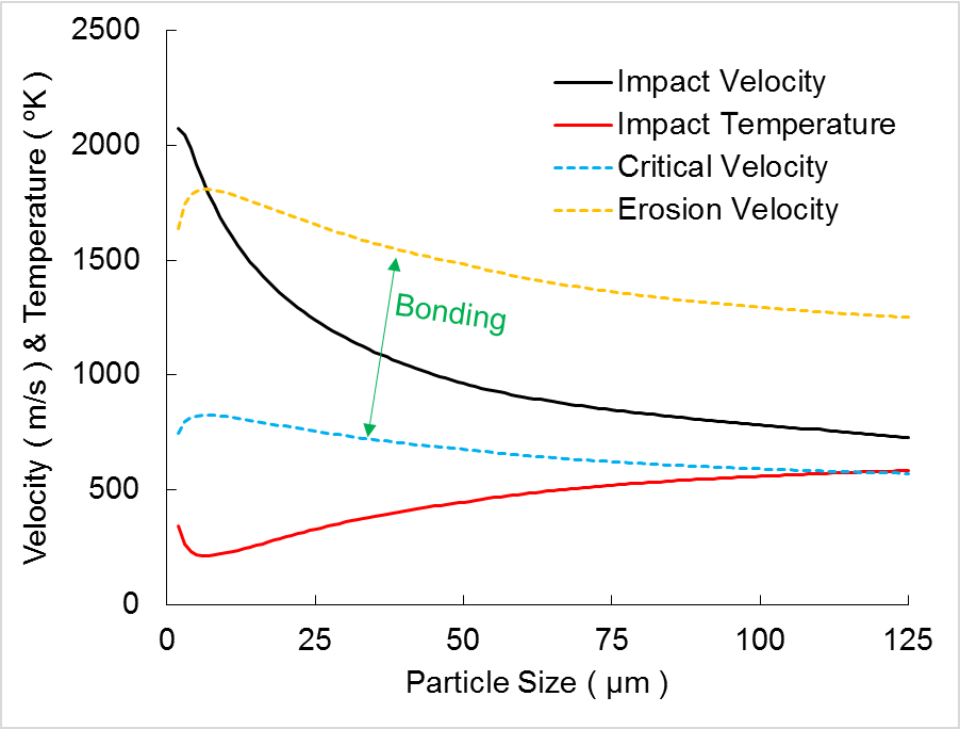
Nitrogen



Helium



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Changing Gas Pressure Nozzle Conditions

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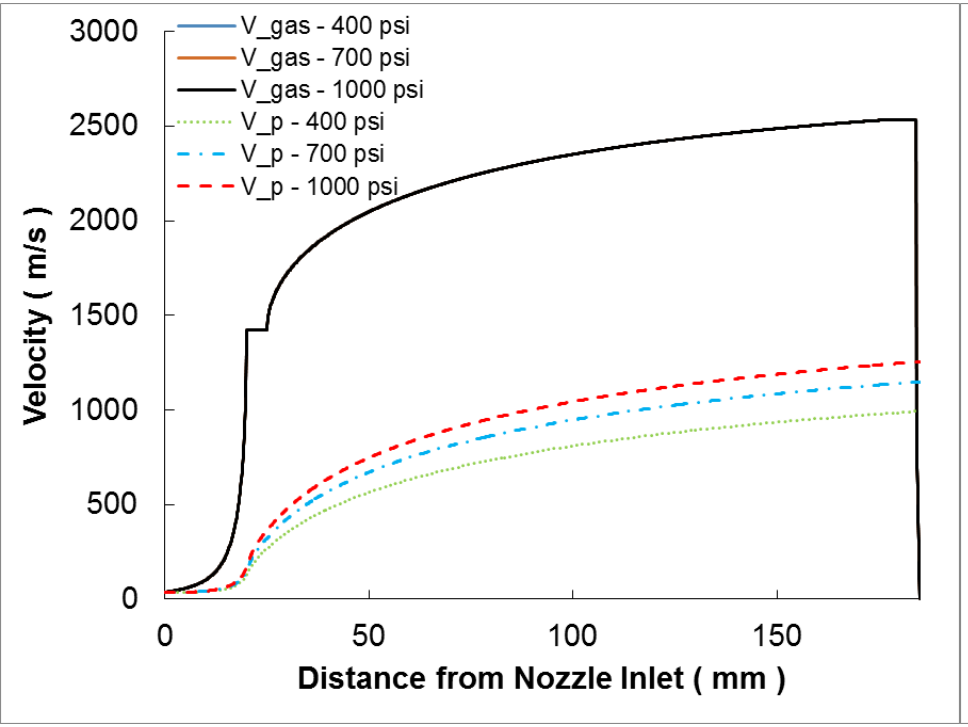
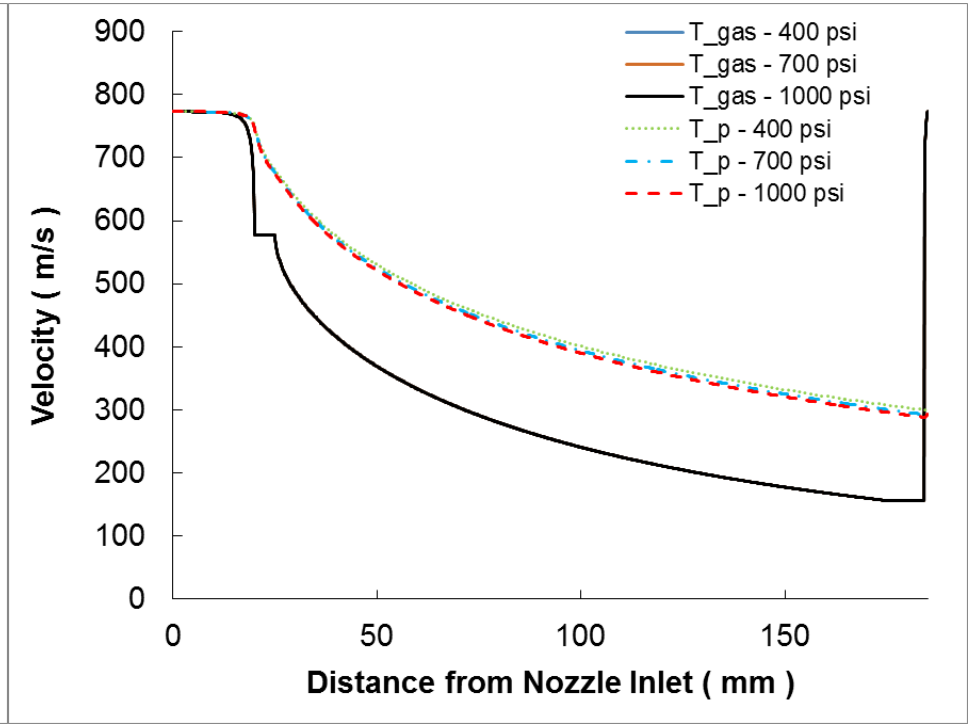
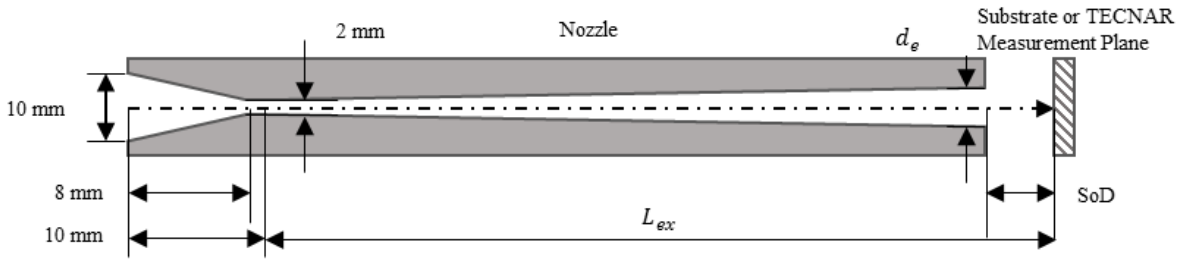
Velocity



Temperature





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Changing Gas Pressure Particle Impact

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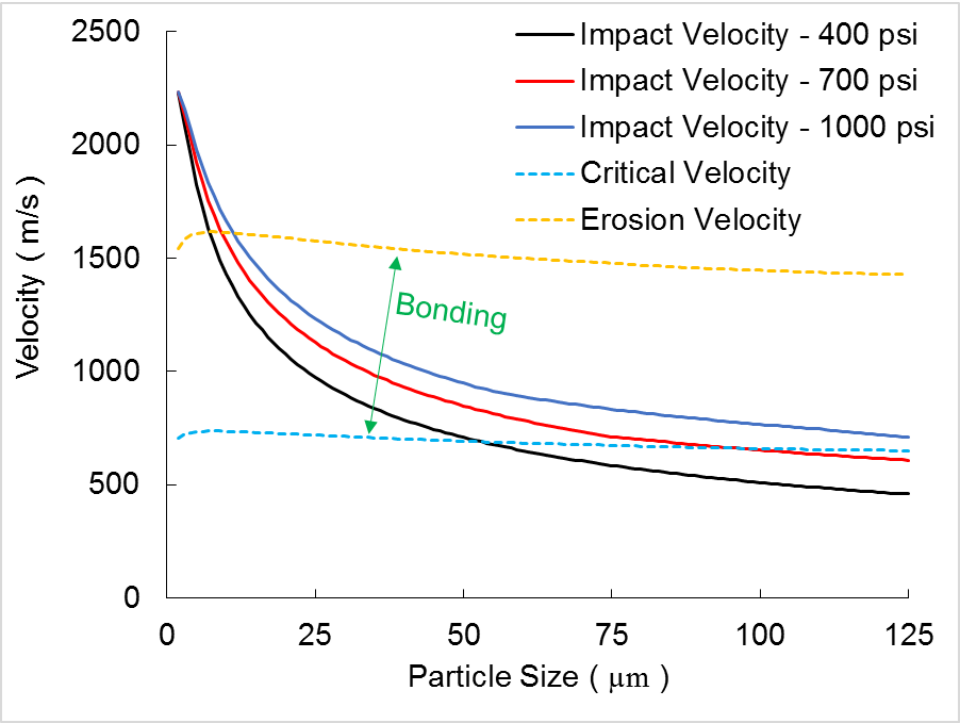
Velocity



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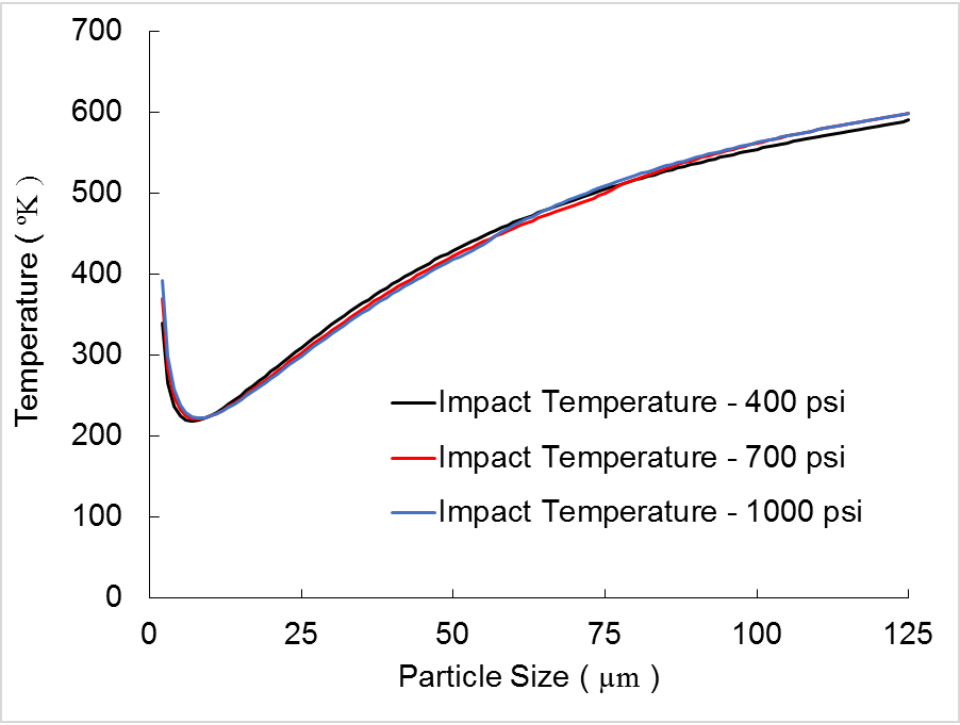

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Changing Gas Temperature Nozzle

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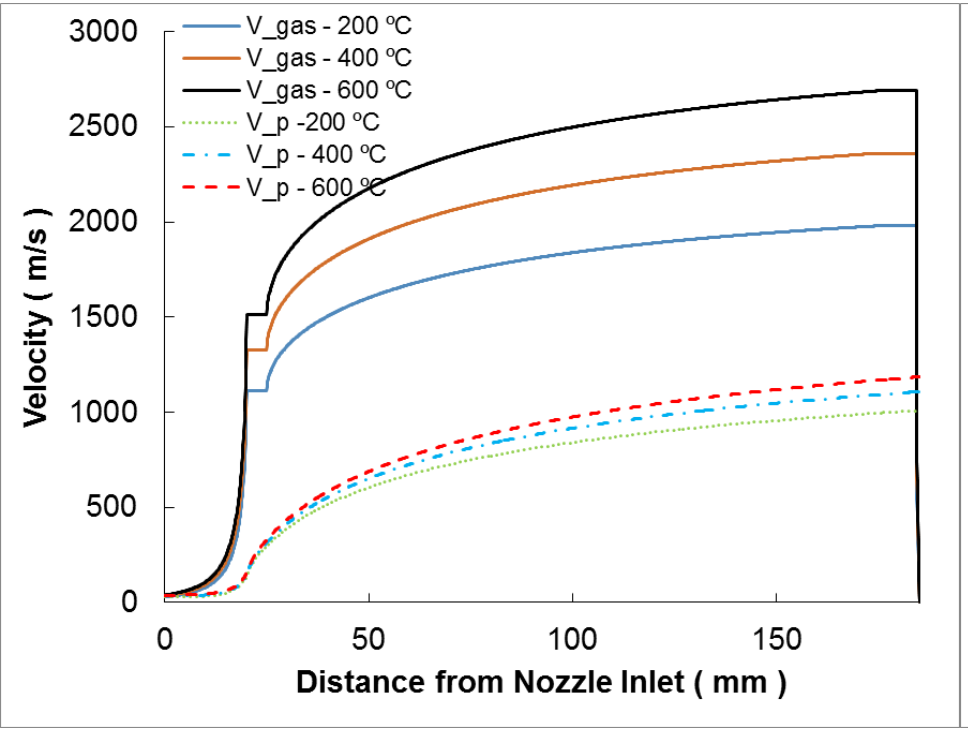
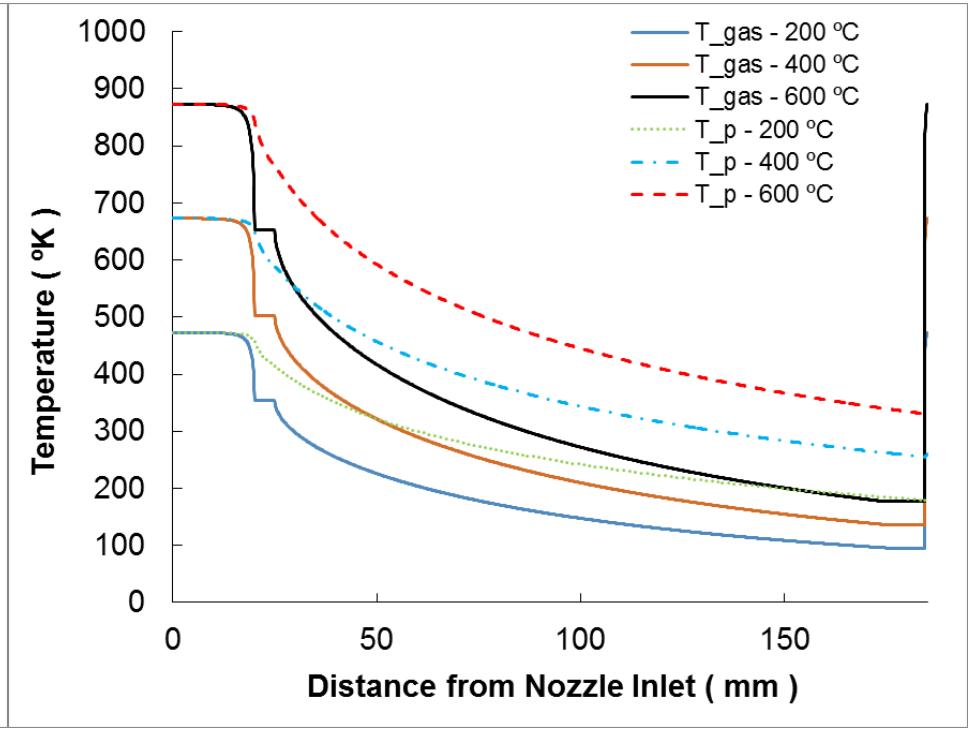
Velocity



Temperature



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Changing Gas Temperature Particle Impact

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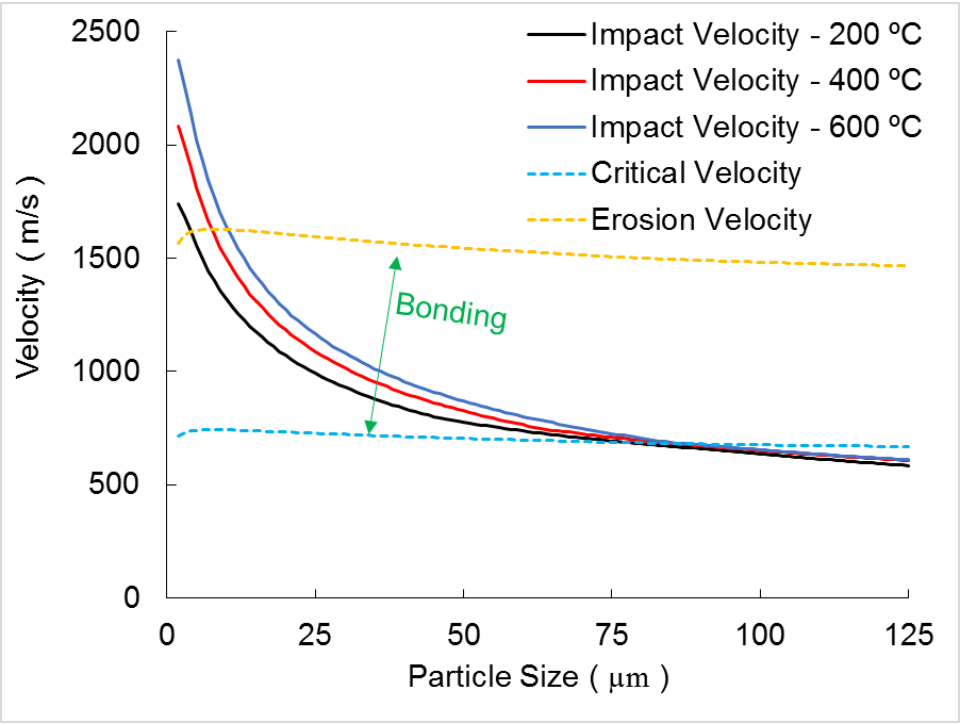
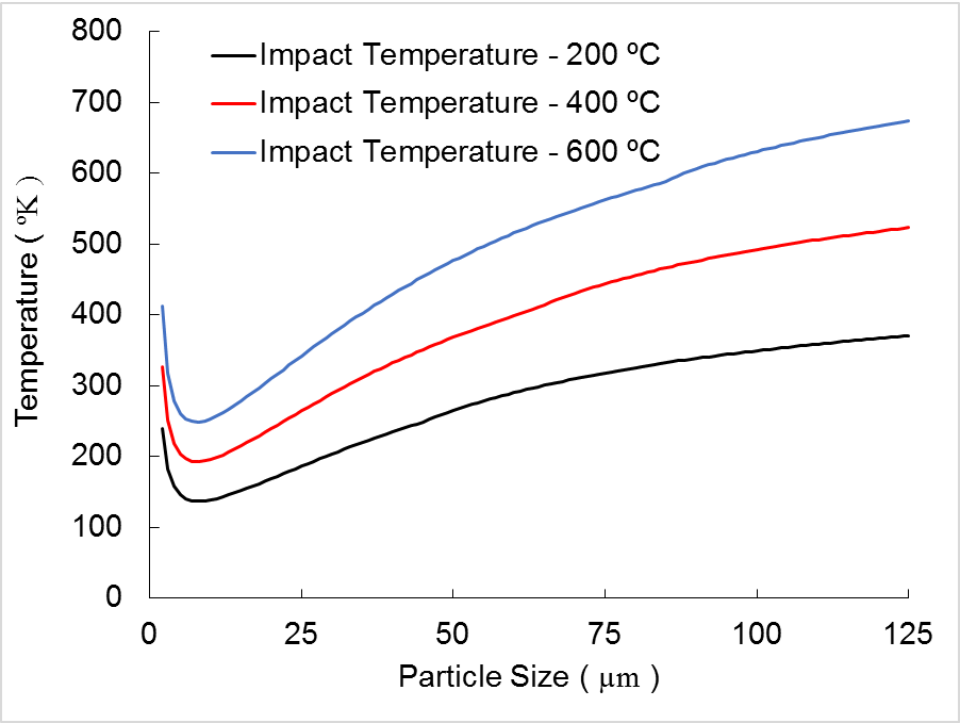
Velocity



Temperature



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Changing Nozzle Expansion Ratio Nozzle

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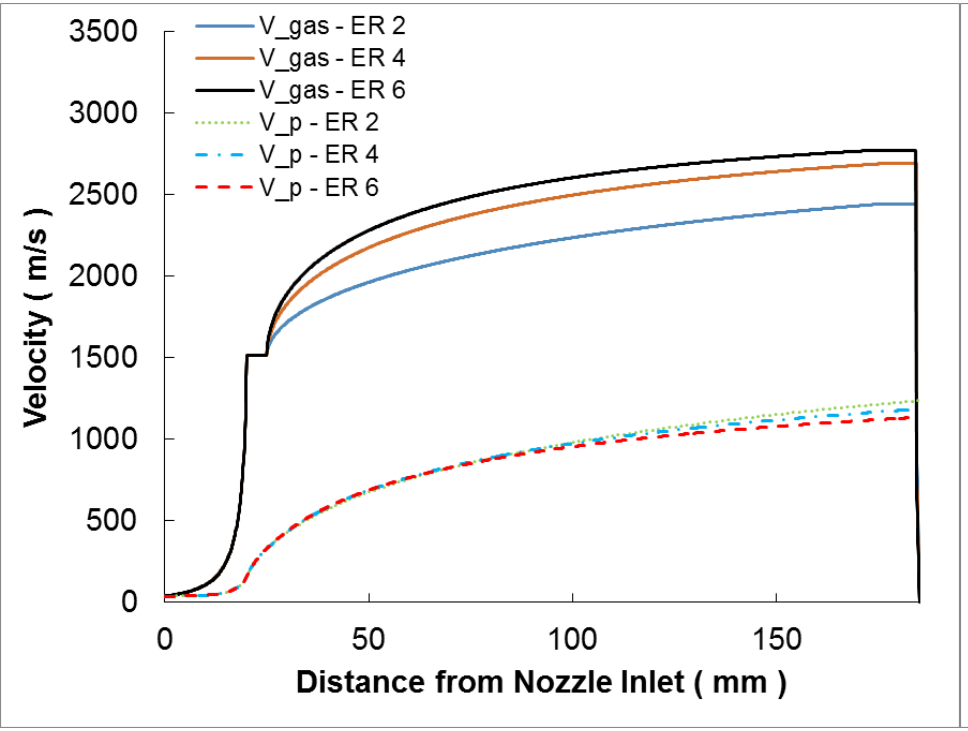
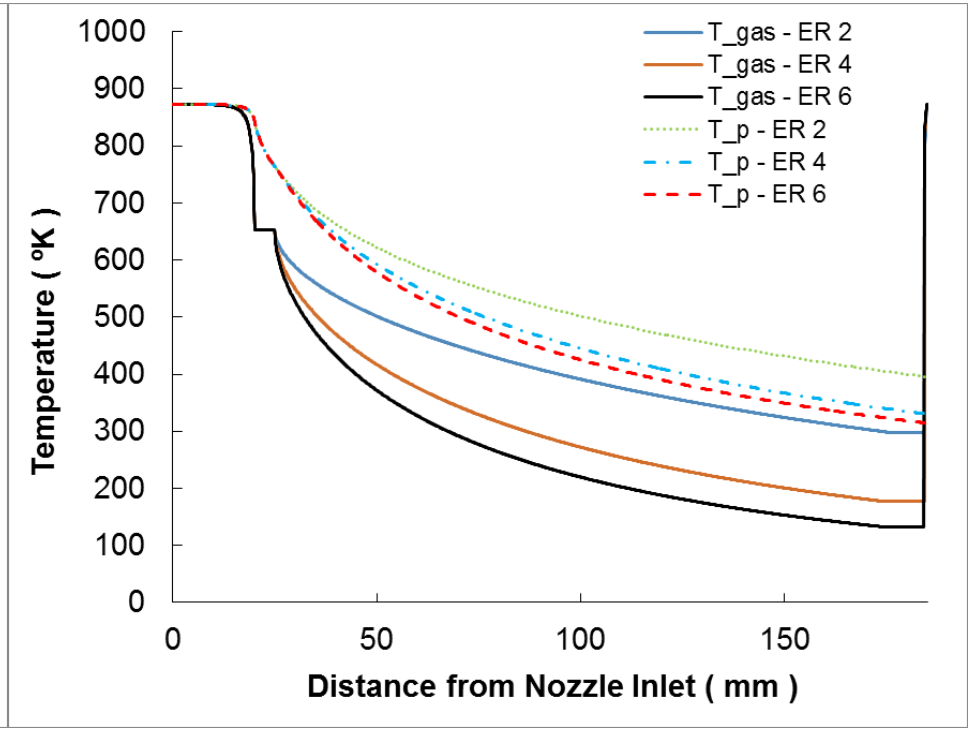
Velocity



Temperature



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Pressure Temperature Selection

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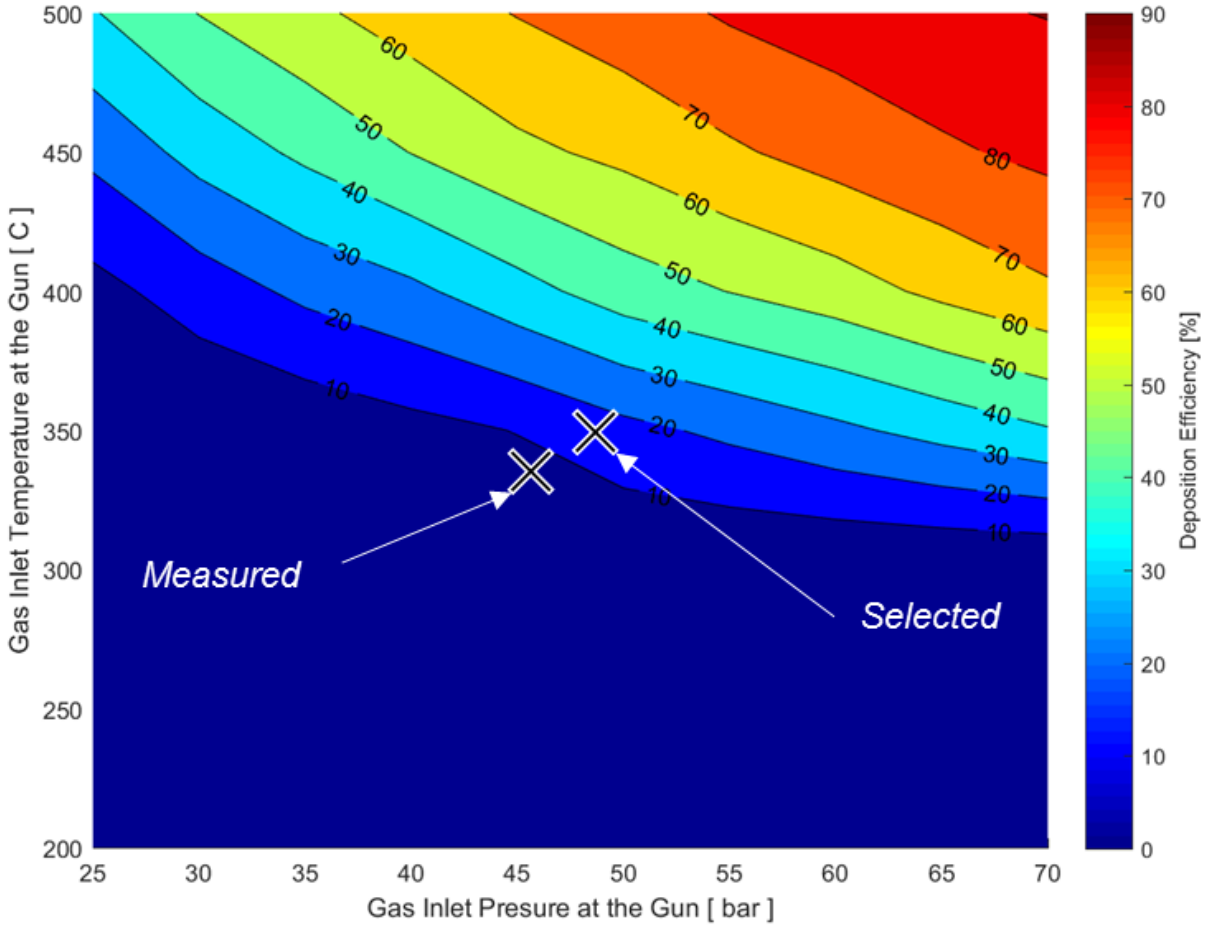

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Changing Nozzle Expansion Ratio Particle Impact

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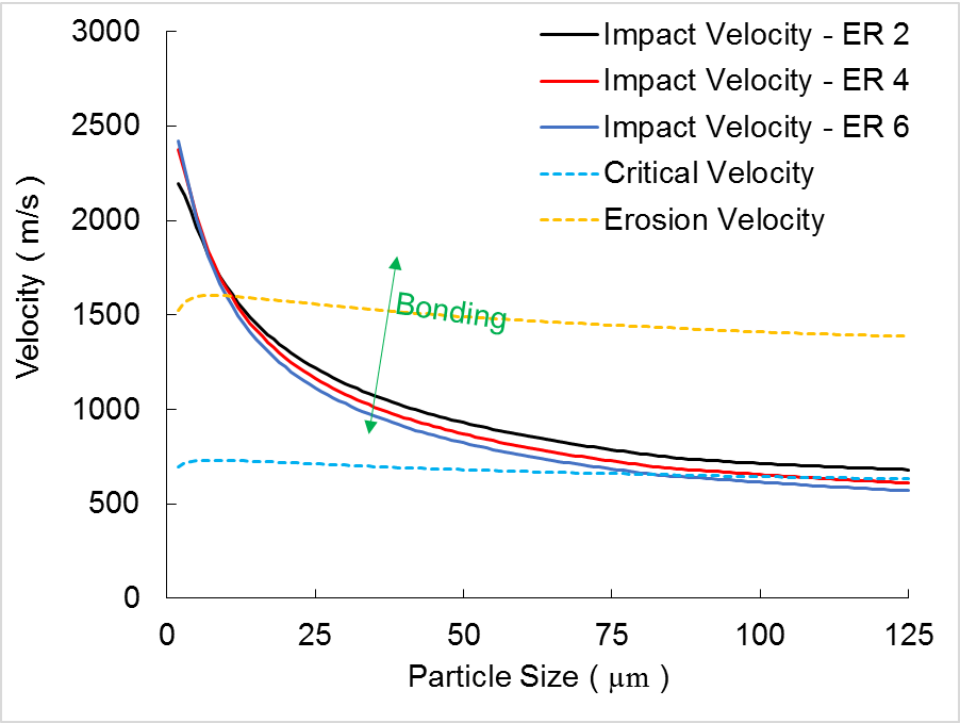
Velocity



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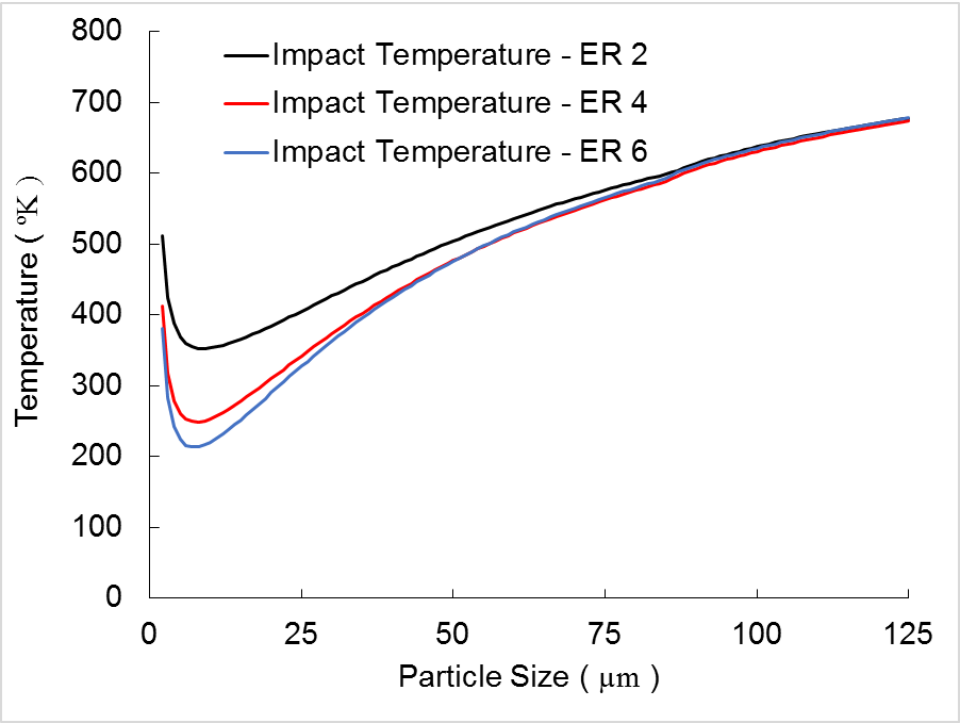

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Changing Nozzle Length Nozzle

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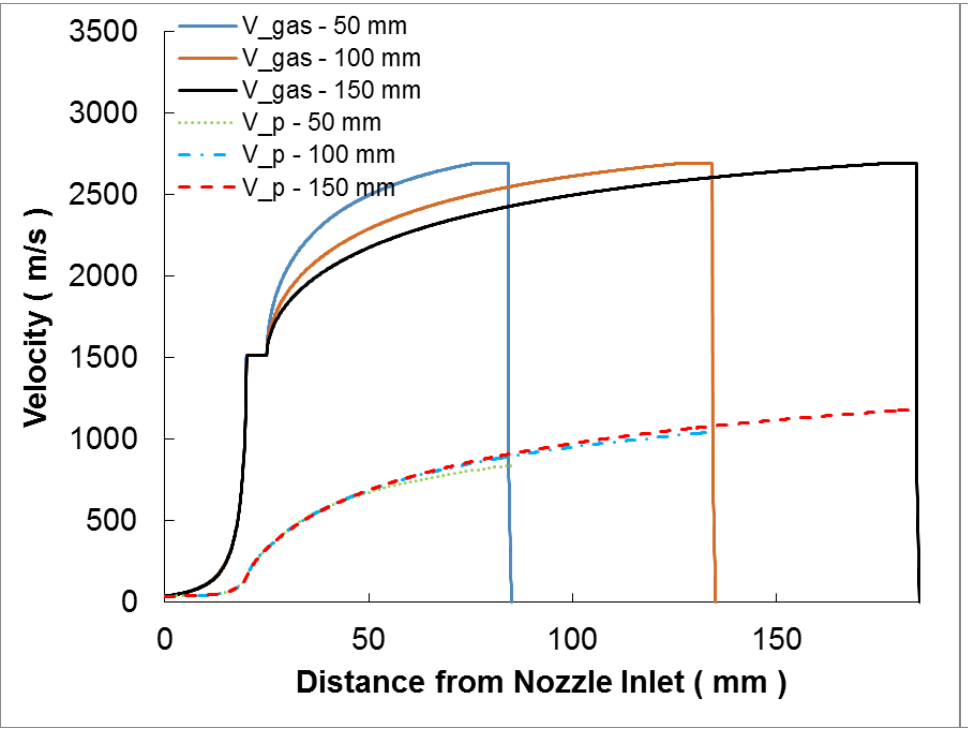
Velocity



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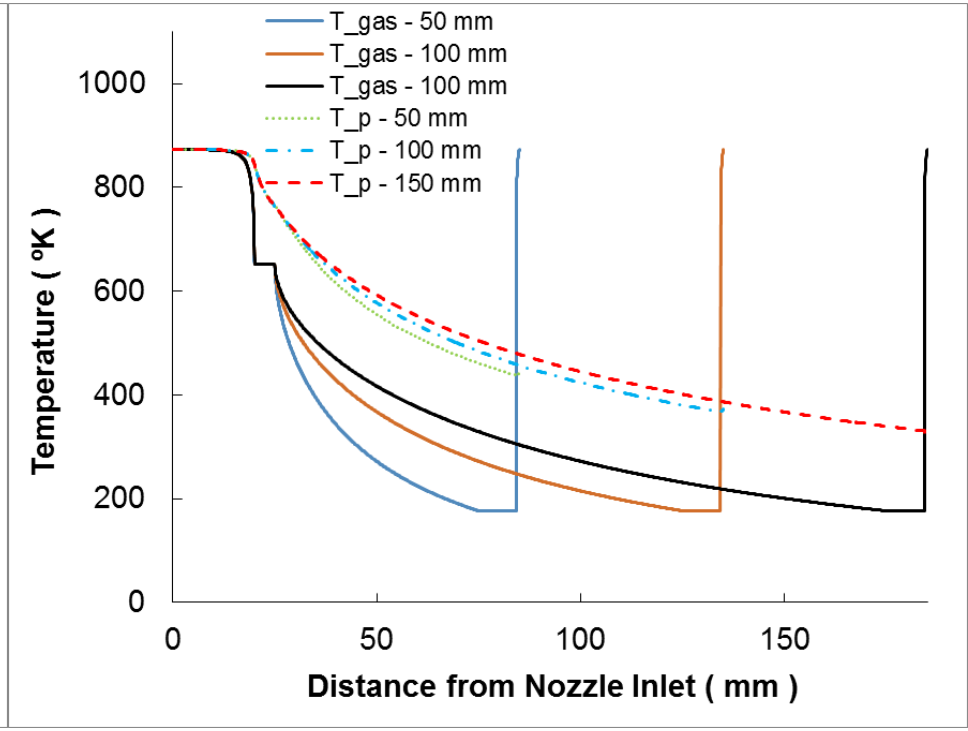

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Changing Nozzle Length
Particle Impact

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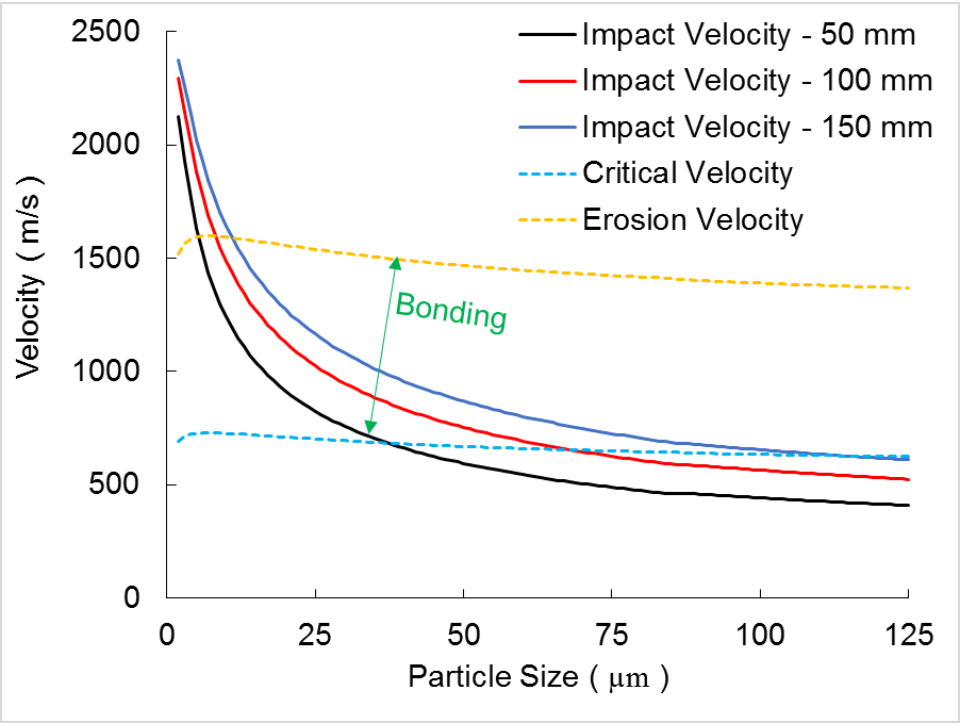
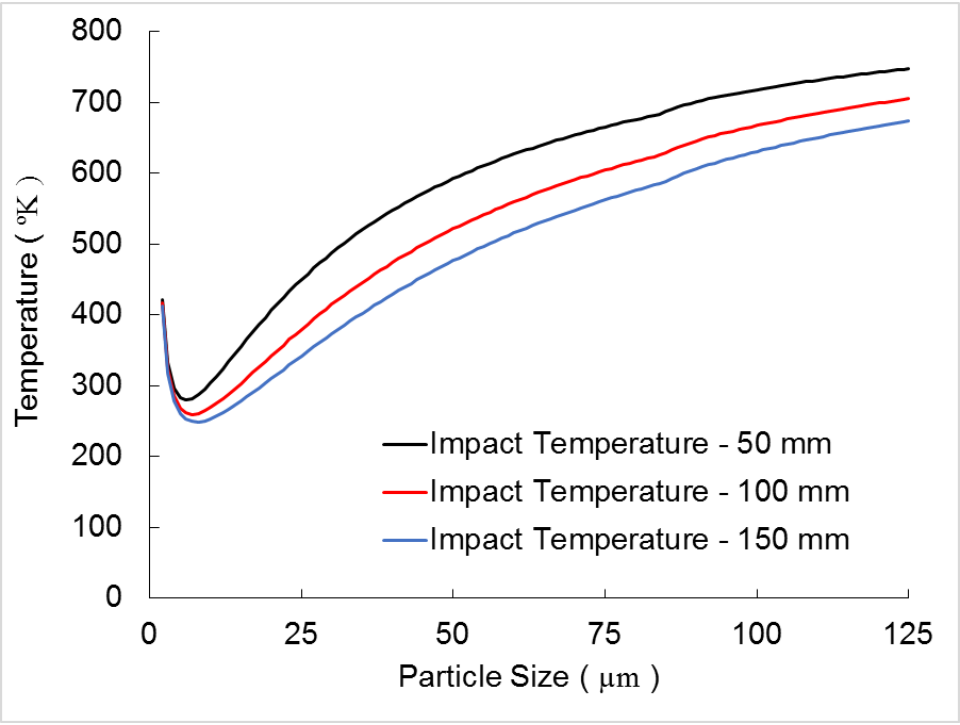
Velocity



Temperature



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Standoff Distance Nozzle

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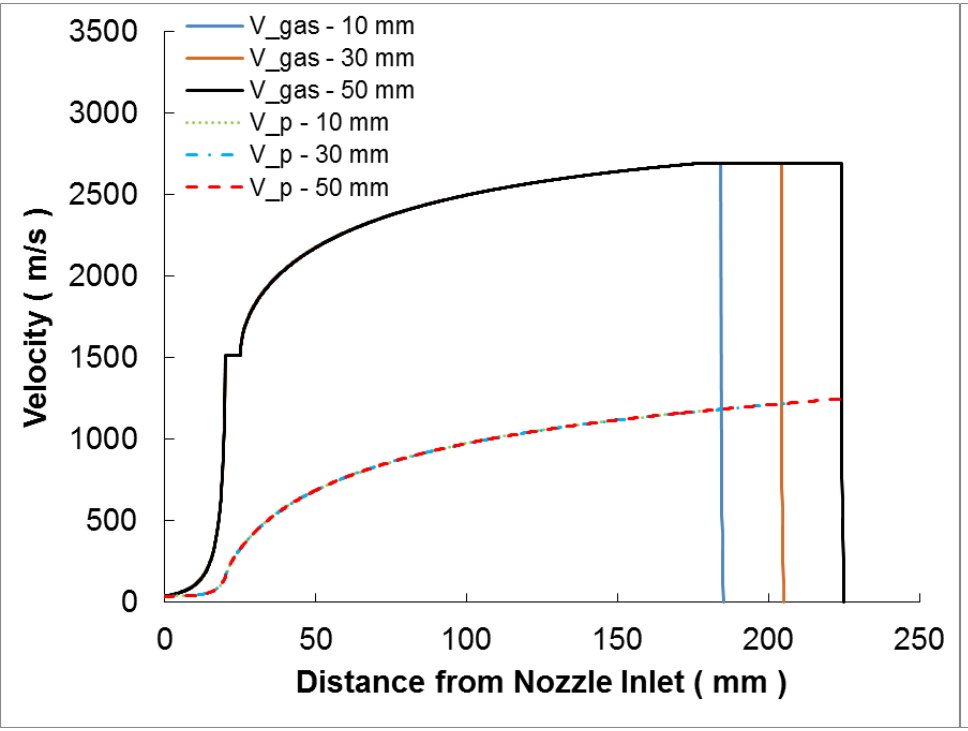
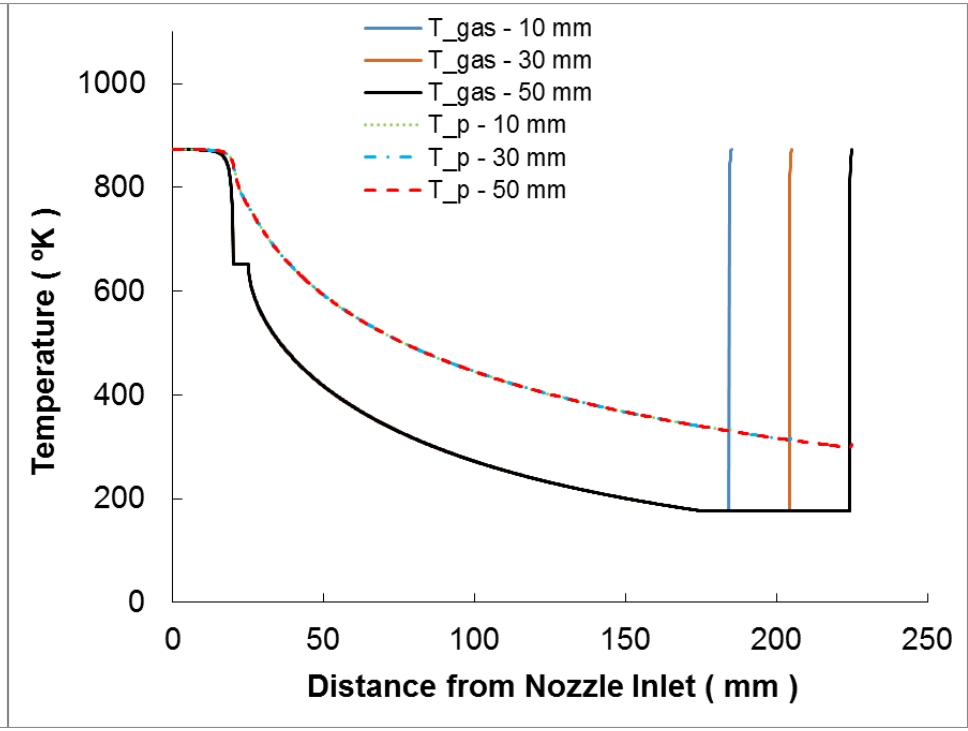
Velocity



Temperature



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Standoff Distance Particle Impact

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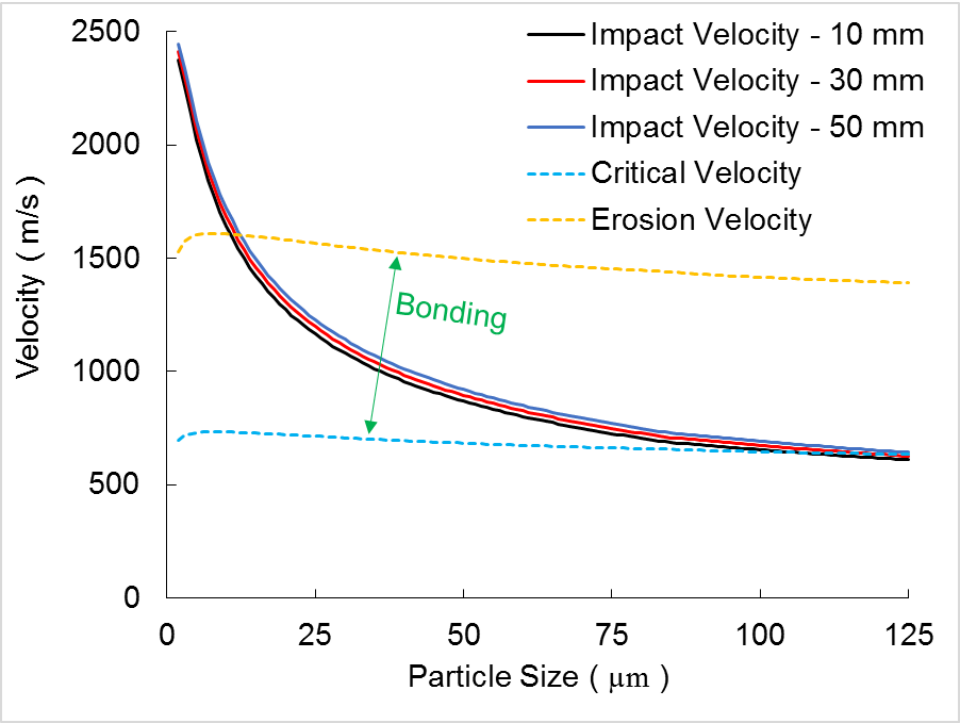
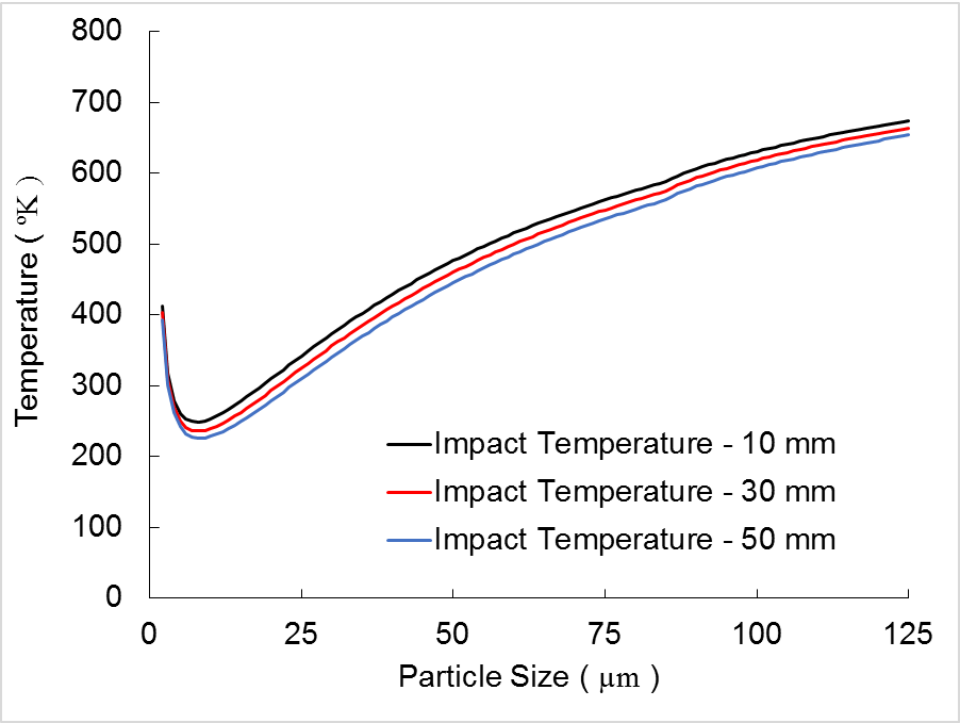
Velocity



Temperature



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Powder Material Nozzle

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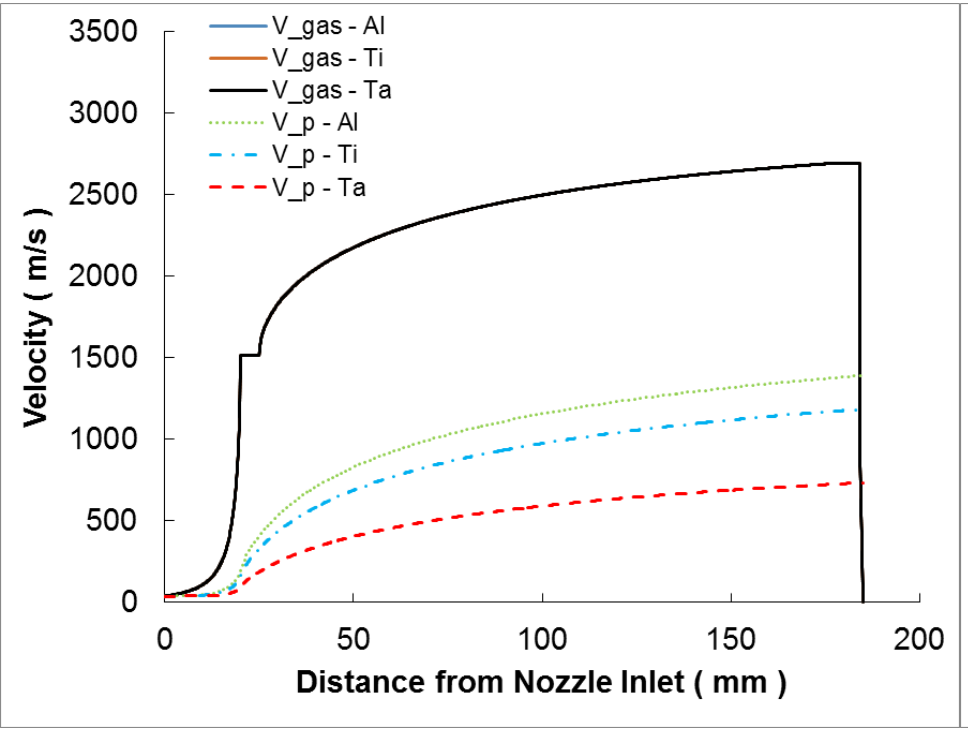
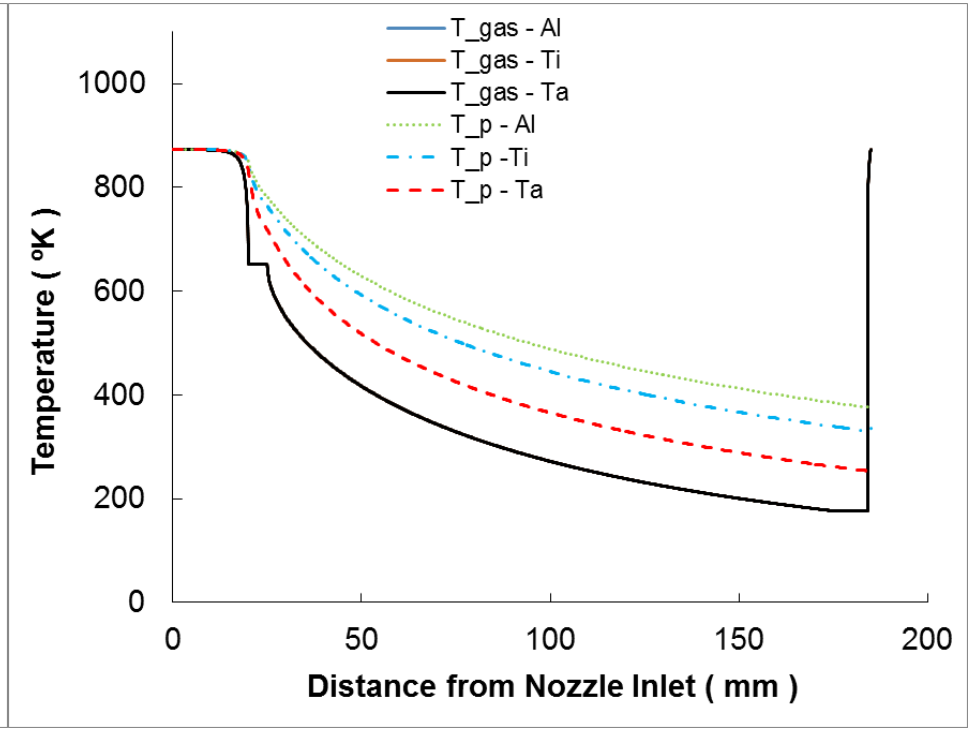
Velocity



Temperature



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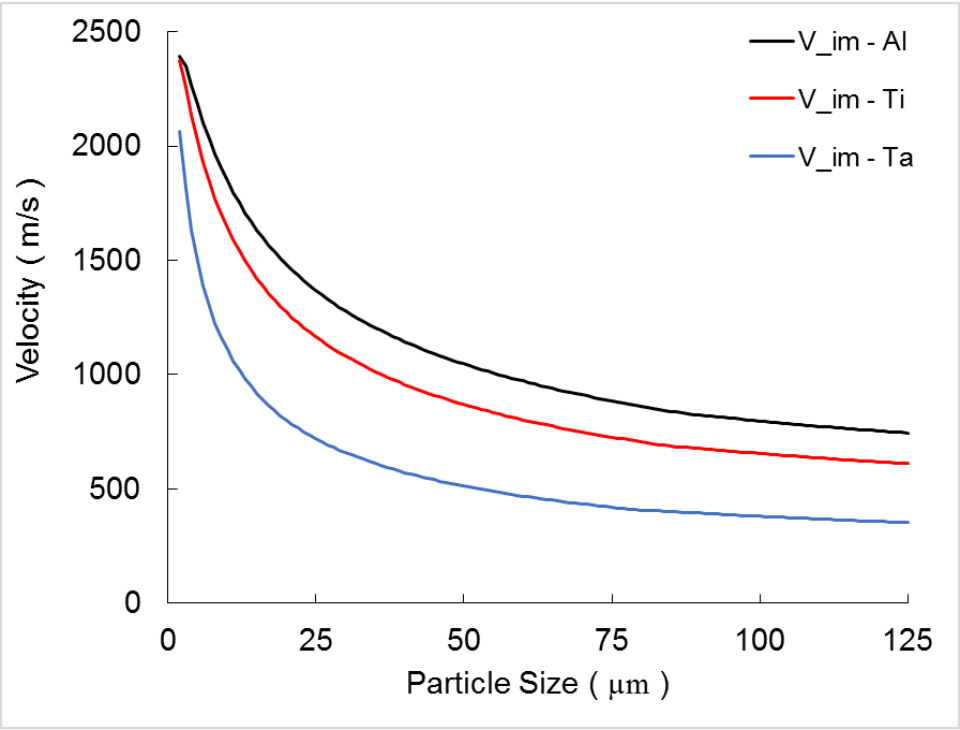
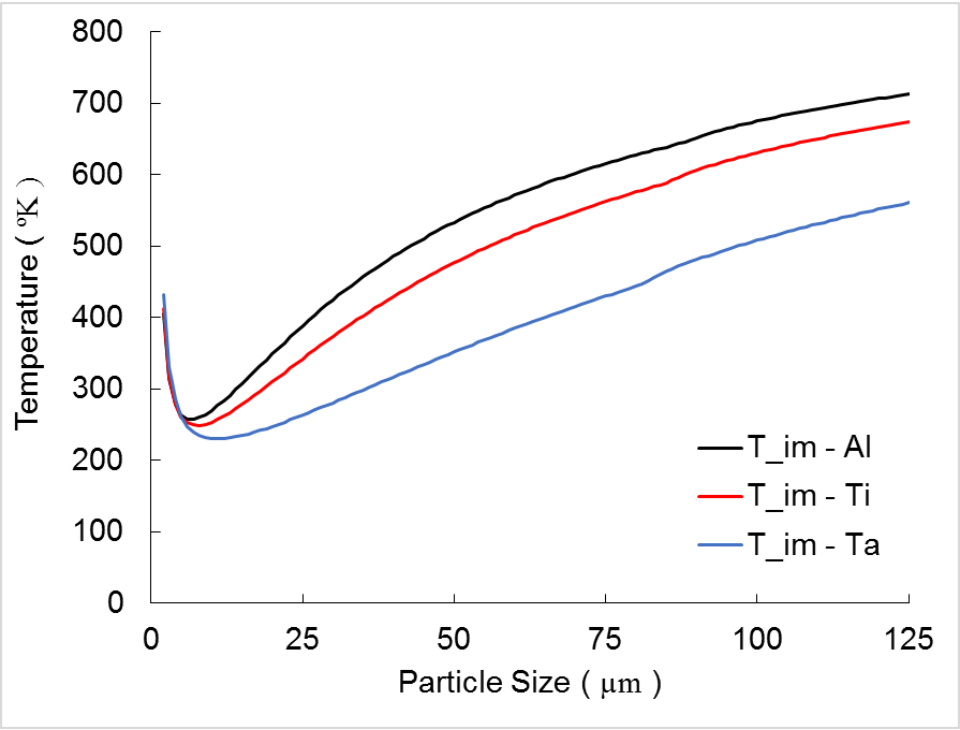
Powder Material Particle Impact

AMP SDSM&T

Velocity



Temperature



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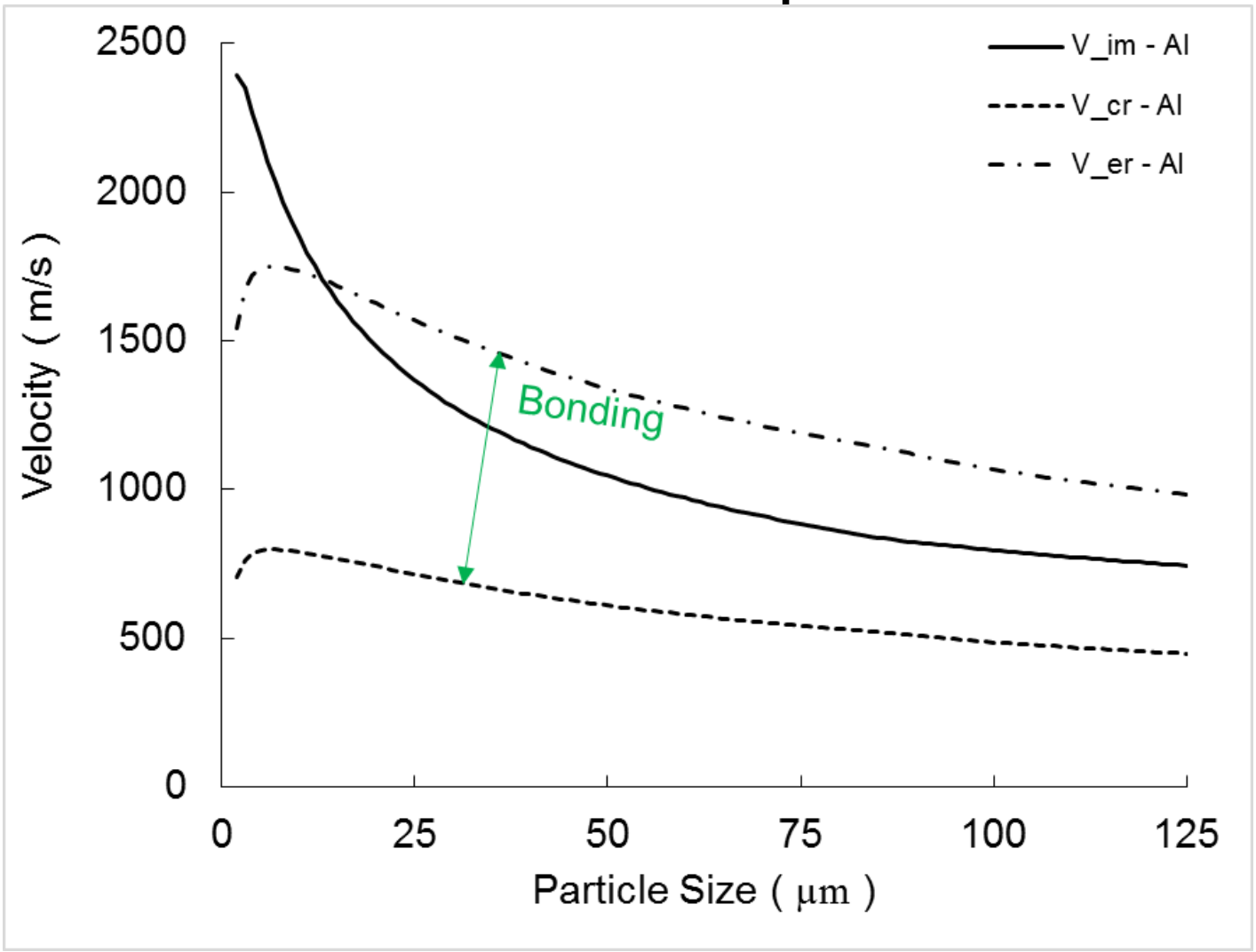
Powder Material
Aluminum Impact

AMP SDSM&T



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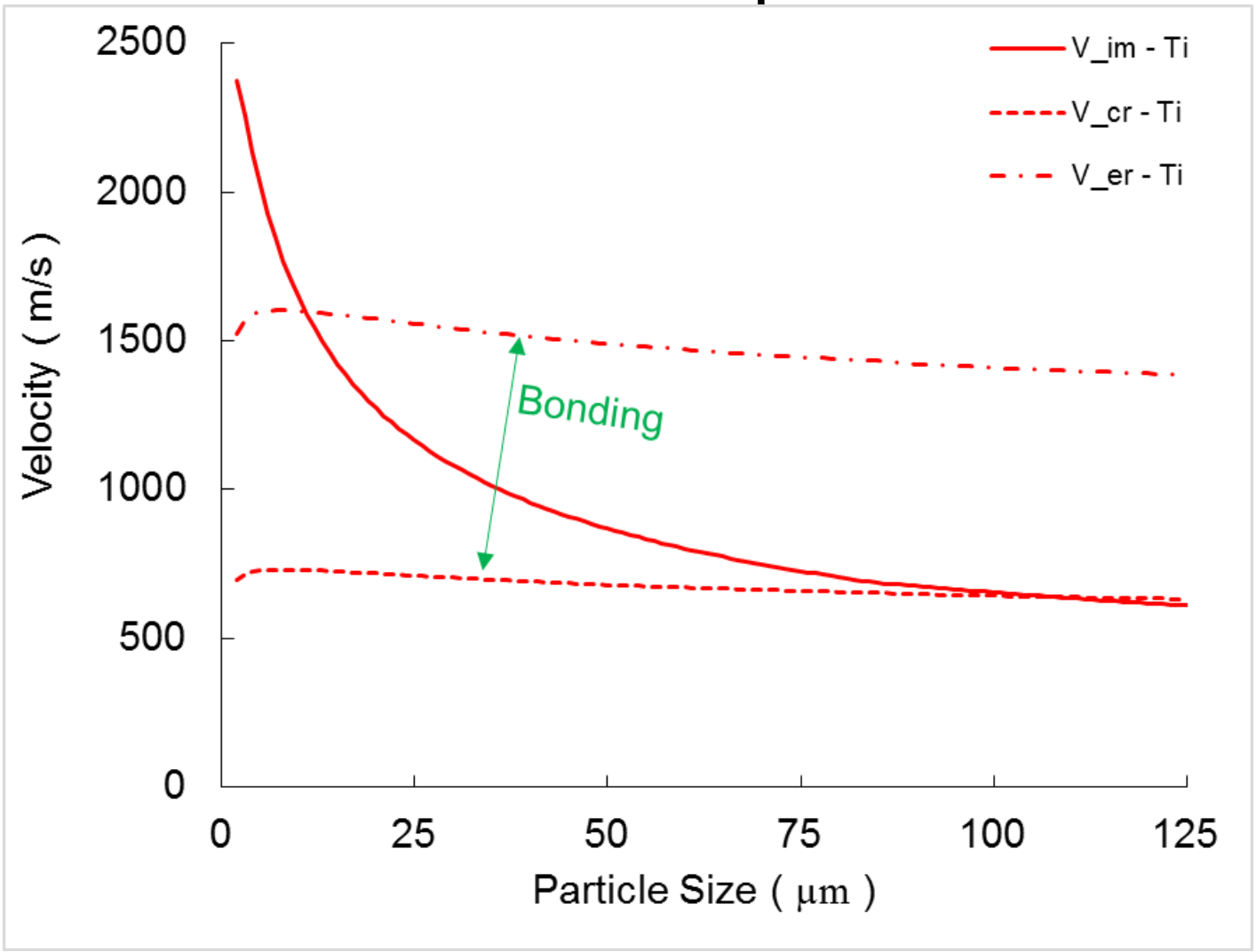
Powder Material Titanium Impact

AMP SDSM&T



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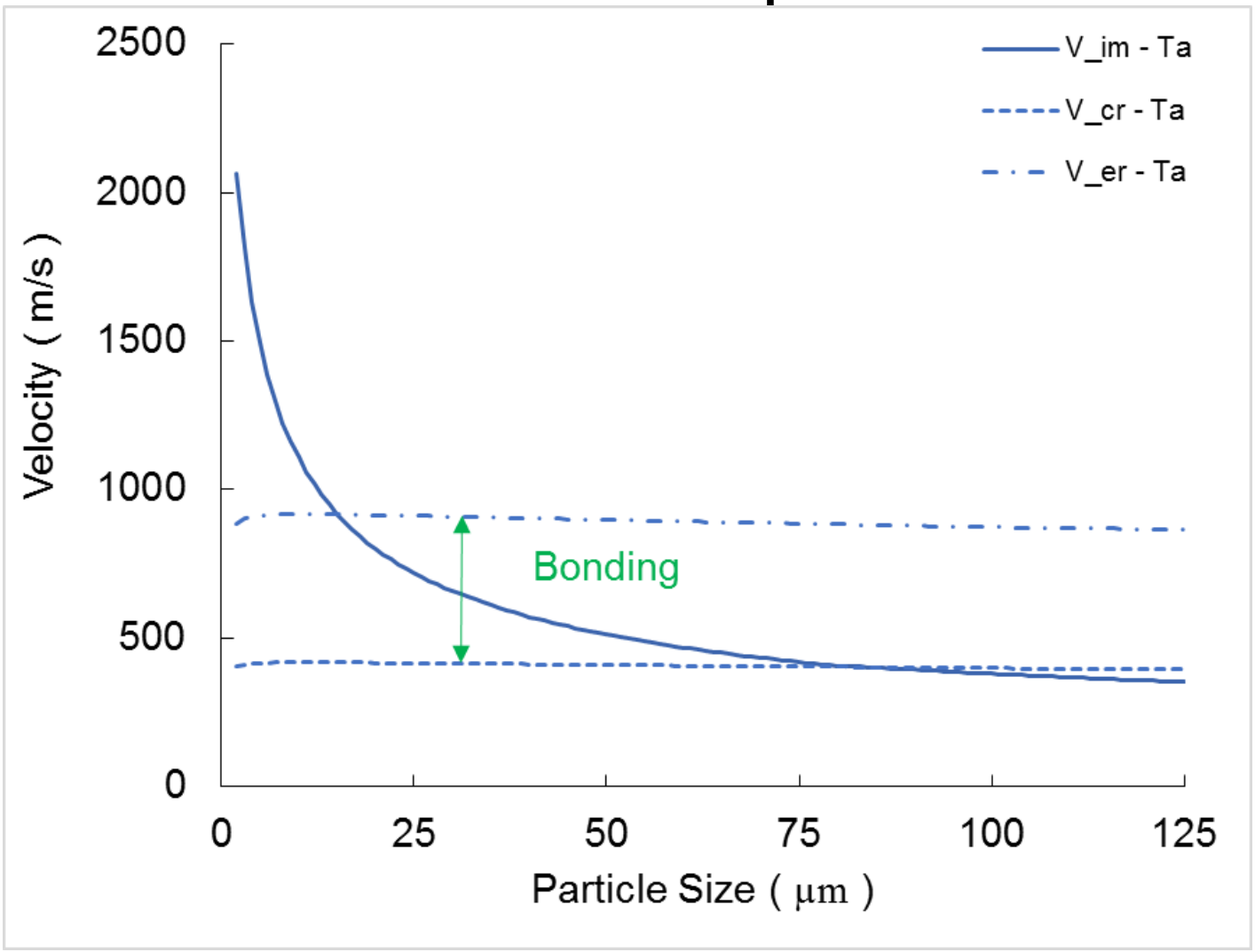
Powder Material
Tantalum Impact

AMP SDSM&T



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Powder Heat Treatment

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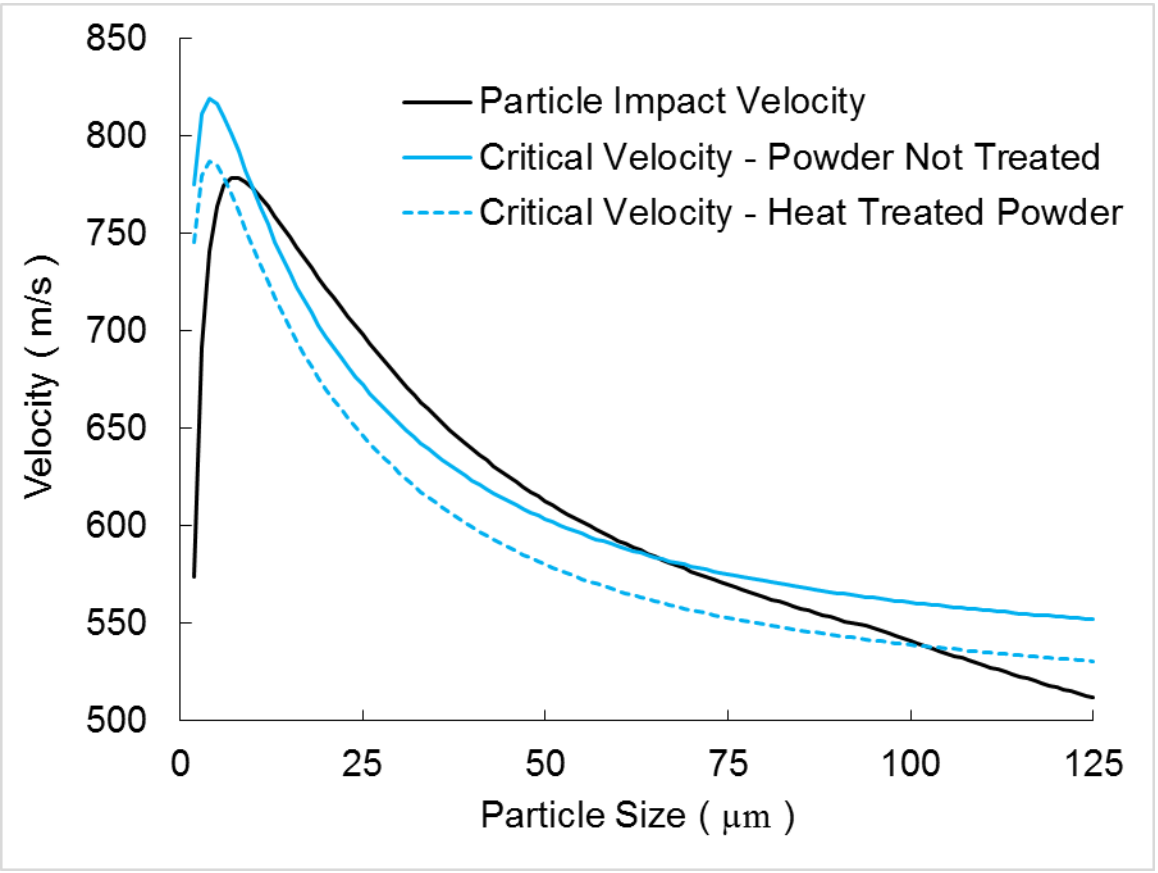
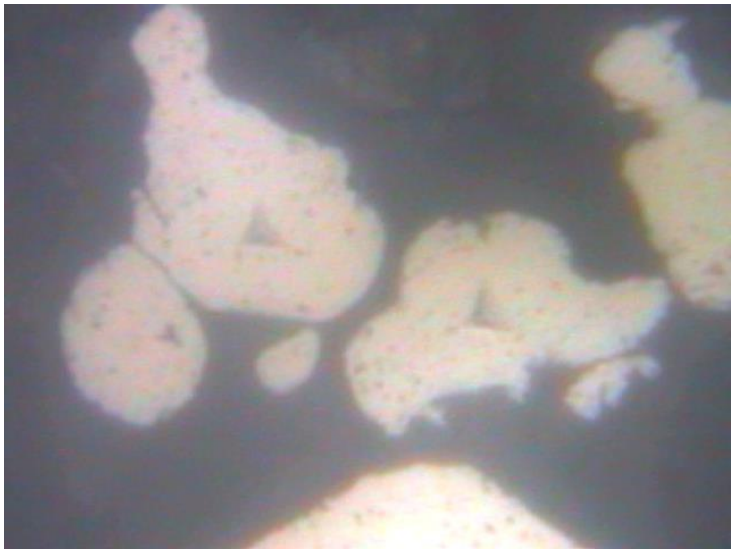


If we get 20% softening with heat treatment

Particle testing with nanoindentation



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Economics

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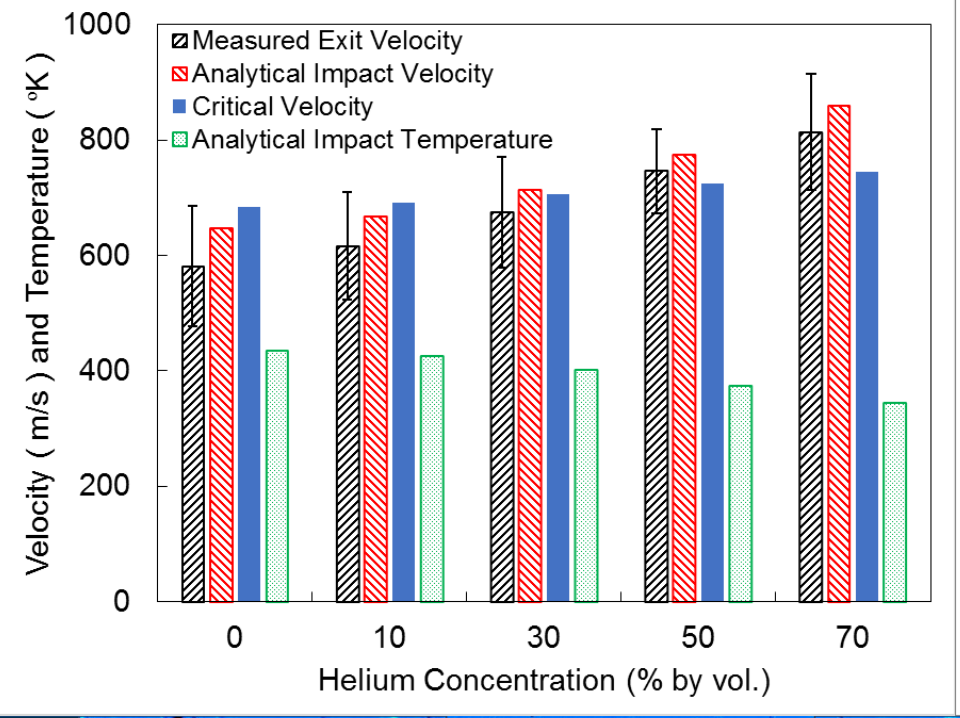
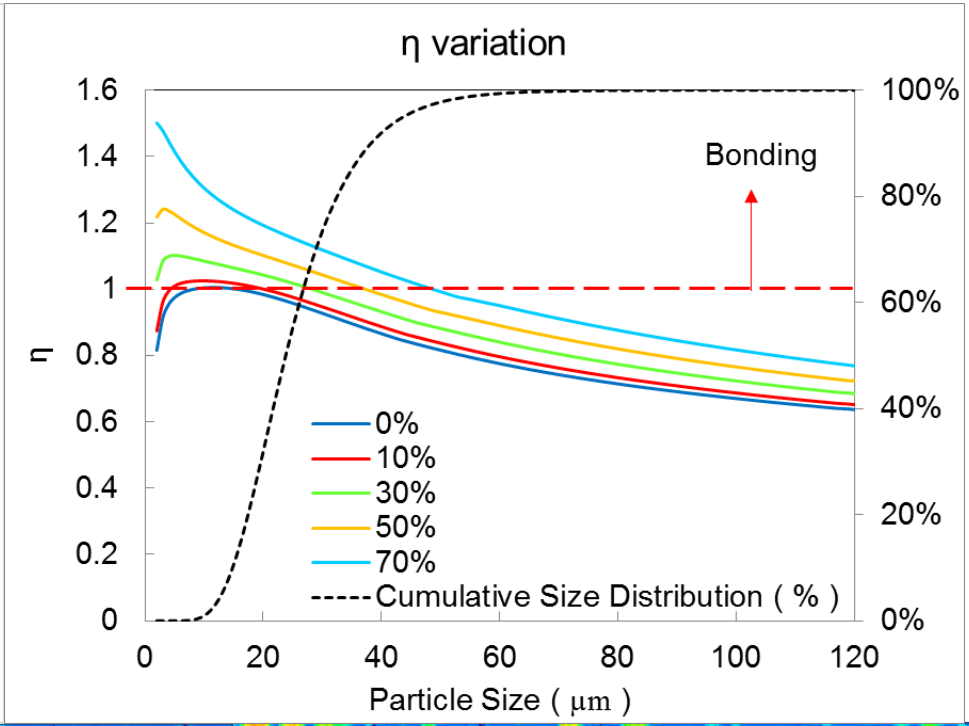
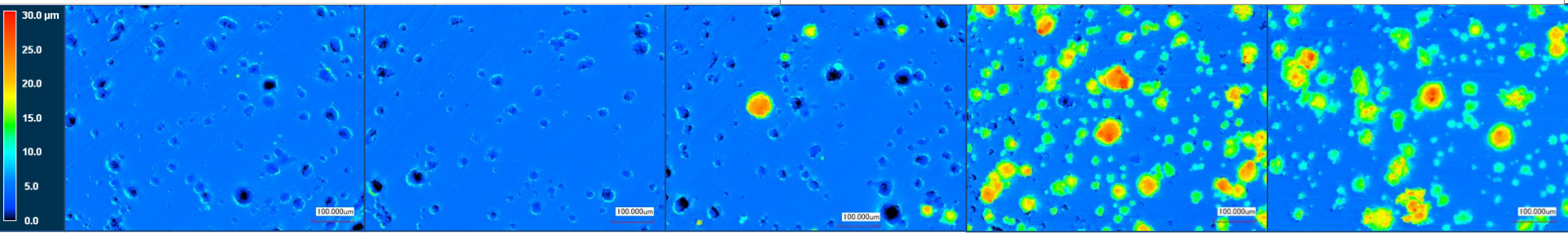
- Total spray time
- Pressure and temperature optimization
- Deposition efficiency
- Deposition rate per volume of gas
- Nozzle throat diameter
- Powder feeding rate
- Gas mixing

Gas Mixing for Impact Control







$0\%\ He$ $10\%\ He$ $30\%\ He$ $50\%\ He$ $70\%\ He$

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Powder Feed Rate

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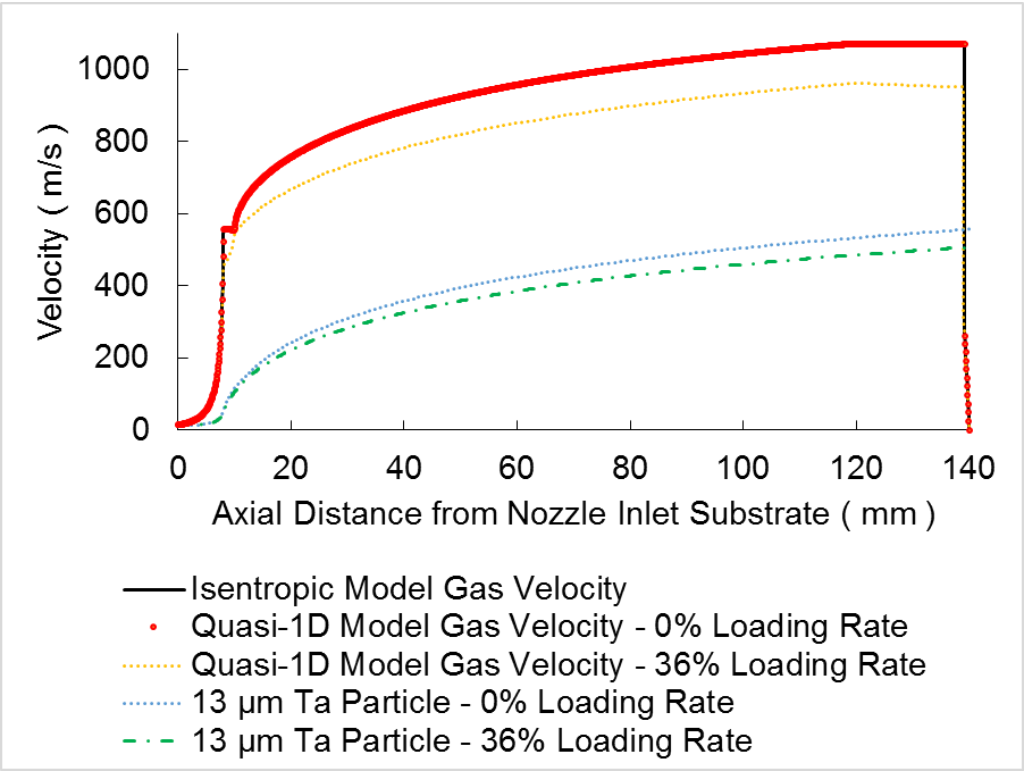

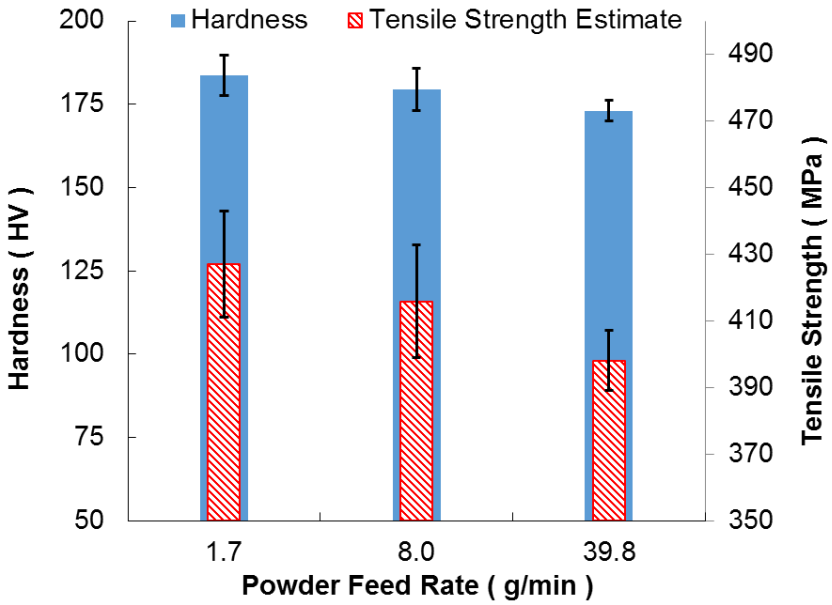

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Powder Feed Rate Particle Impact

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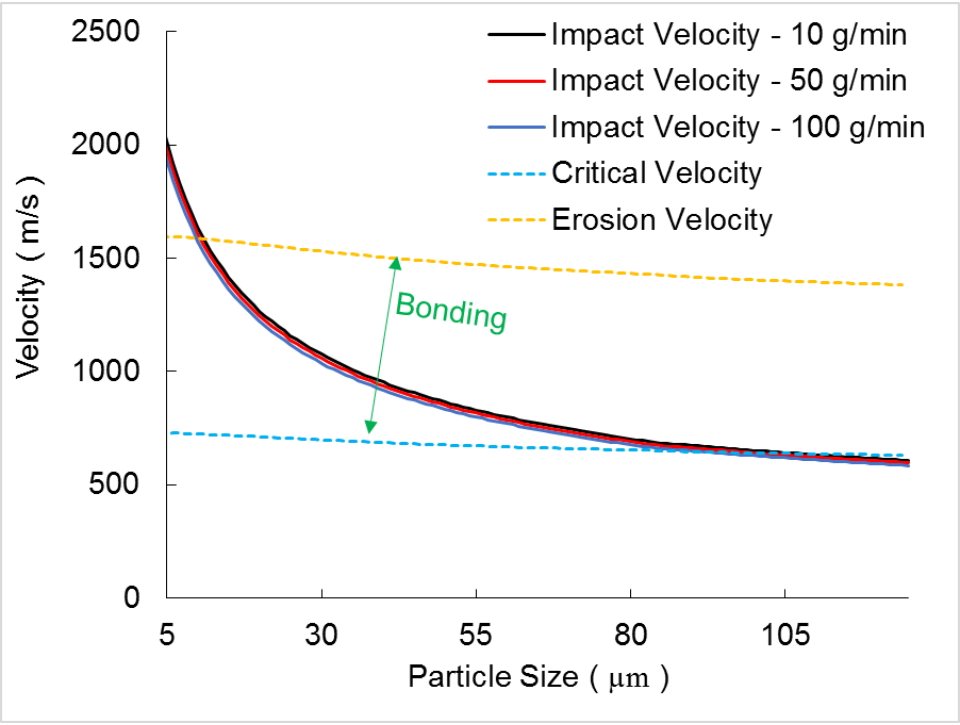
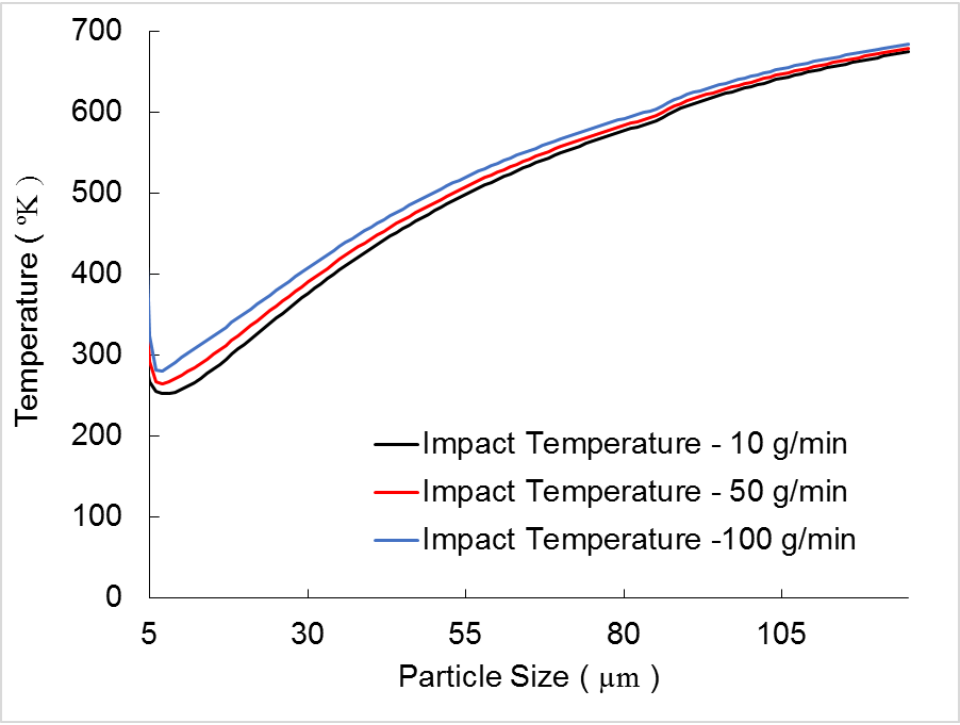
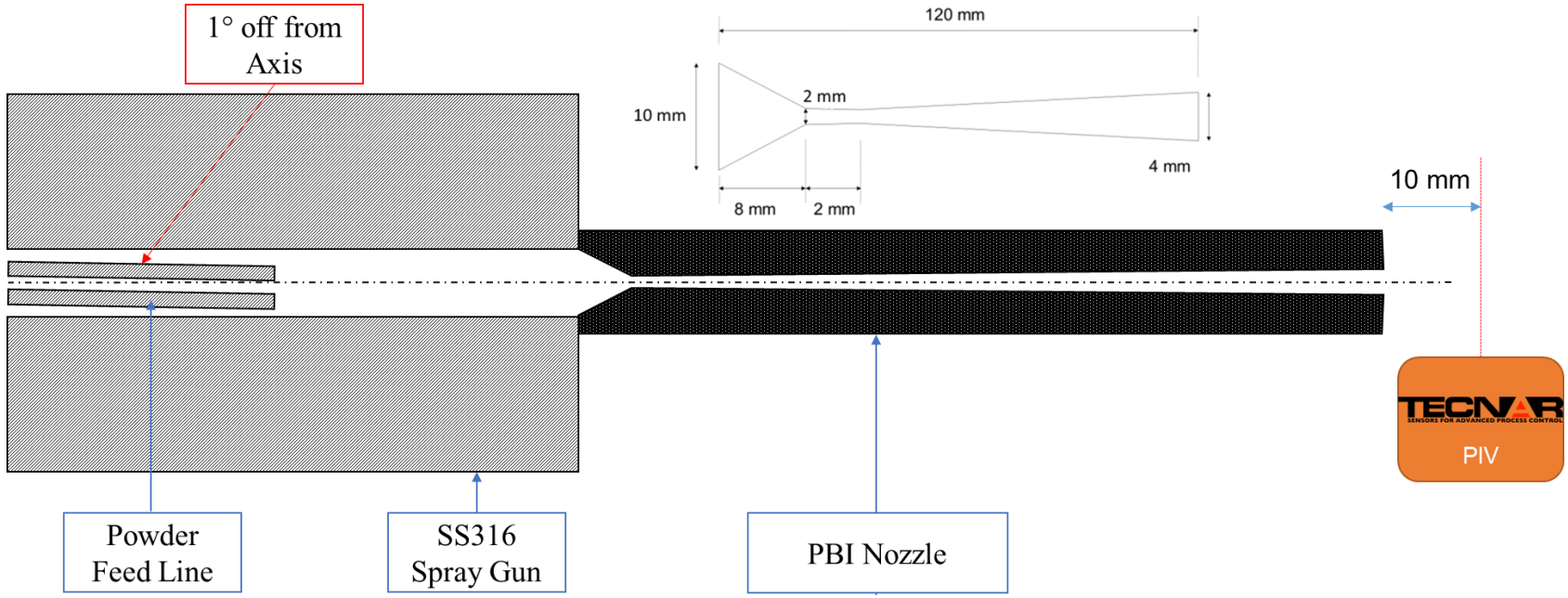
Velocity



Temperature



Equipment Inspection and Alignment



Nozzle Wear

Aligned vs Misaligned

Aligned

Video 1: https://youtu.be/HGUVTPXgWNQ

Misaligned

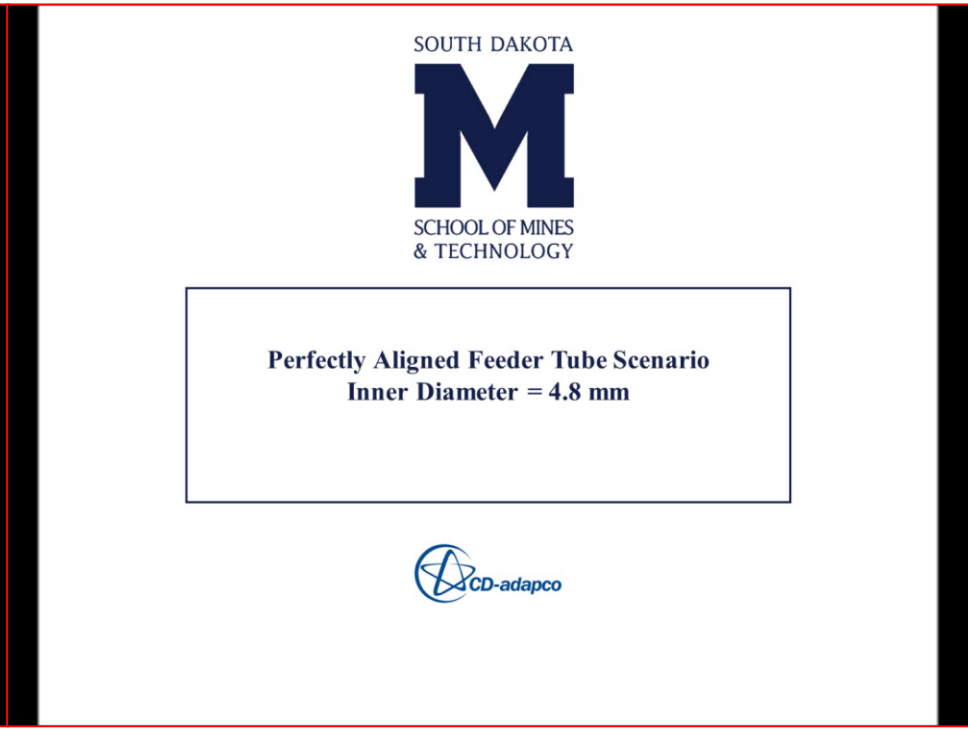
Video 4: https://youtu.be/qDbErxtm3Hc

Small vs Large Feeder Tube

Aligned Small Inner Diameter

Video 1: https://youtu.be/HGUVTPXgWNQ

Aligned Large Inner Diameter



Video 5: https://youtu.be/FhZb7bvNd9o

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Guide to Deposition

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particle range: 10 μm to 100 μm
in helium and nitrogen

Sample: 50 μm aluminum particle sprayed with helium

Gun Temperature		200 °C						300 °C						400 °C						
		L_{div} (mm)						L_{div} (mm)						L_{div} (mm)						
Gun Pressure	ER	50	70	90	110	130	150	50	70	90	110	130	150	50	70	90	110	130	150	
34.5 bar	2	0.86	0.93	1.00	1.05	1.09	1.13	0.95	1.04	1.10	1.16	1.21	1.25	1.07	1.15	1.22	1.28	1.33	1.38	
	3	0.82	0.90	0.96	1.01	1.06	1.10	0.91	0.99	1.06	1.12	1.17	1.21	1.02	1.10	1.17	1.23	1.28	1.33	0.50
	4	0.79	0.87	0.93	0.98	1.03	1.07	0.88	0.96	1.03	1.08	1.13	1.17	0.98	1.06	1.13	1.19	1.24	1.29	0.60
	5	0.77	0.85	0.91	0.96	1.00	1.04	0.85	0.93	1.00	1.05	1.10	1.14	0.95	1.04	1.10	1.16	1.21	1.25	0.70
	6	0.75	0.83	0.89	0.94	0.98	1.02	0.83	0.91	0.98	1.03	1.08	1.12	0.93	1.01	1.08	1.13	1.18	1.23	0.80
	8	0.72	0.79	0.85	0.90	0.95	0.99	0.80	0.88	0.94	0.99	1.04	1.08	0.89	0.97	1.04	1.09	1.14	1.18	0.90
	10	0.70	0.77	0.83	0.88	0.92	0.96	0.78	0.85	0.91	0.96	1.01	1.05	0.87	0.95	1.01	1.06	1.11	1.15	1.00
	12	0.68	0.75	0.81	0.86	0.90	0.93	0.76	0.83	0.89	0.94	0.99	1.02	0.85	0.92	0.98	1.04	1.08	1.12	1.10
48.3 bar	2	0.96	1.04	1.10	1.15	1.19	1.23	1.06	1.14	1.21	1.27	1.32	1.36	1.18	1.27	1.35	1.41	1.46	1.50	1.20
	3	0.93	1.01	1.07	1.12	1.17	1.21	1.01	1.10	1.17	1.23	1.28	1.32	1.13	1.22	1.30	1.36	1.41	1.45	1.30
	4	0.90	0.98	1.04	1.09	1.14	1.18	0.98	1.07	1.14	1.19	1.24	1.29	1.09	1.18	1.25	1.31	1.37	1.41	1.40
	5	0.88	0.96	1.02	1.07	1.11	1.15	0.95	1.04	1.11	1.16	1.21	1.26	1.06	1.15	1.22	1.28	1.33	1.38	1.50
	6	0.86	0.94	1.00	1.05	1.09	1.13	0.93	1.02	1.08	1.14	1.19	1.23	1.04	1.13	1.20	1.26	1.31	1.35	1.60
	8	0.83	0.90	0.96	1.02	1.06	1.10	0.90	0.98	1.05	1.10	1.15	1.19	1.00	1.09	1.15	1.21	1.26	1.31	1.70
	10	0.80	0.88	0.94	0.99	1.03	1.07	0.87	0.95	1.02	1.07	1.12	1.16	0.97	1.05	1.12	1.18	1.23	1.27	1.80
	12	0.78	0.86	0.92	0.97	1.01	1.05	0.85	0.93	0.99	1.05	1.09	1.13	0.95	1.03	1.10	1.15	1.20	1.24	1.90
62.1 bar	2	1.07	1.14	1.20	1.24	1.28	1.32	1.16	1.24	1.31	1.36	1.41	1.45	1.27	1.37	1.44	1.50	1.55	1.60	2.00
	3	1.03	1.11	1.17	1.22	1.26	1.30	1.12	1.21	1.27	1.33	1.38	1.42	1.22	1.32	1.39	1.45	1.51	1.55	2.10
	4	1.00	1.08	1.14	1.19	1.24	1.27	1.09	1.17	1.24	1.30	1.35	1.39	1.18	1.28	1.35	1.41	1.46	1.51	2.20
	5	0.97	1.05	1.12	1.17	1.21	1.25	1.06	1.15	1.21	1.27	1.32	1.36	1.15	1.24	1.32	1.38	1.43	1.48	2.30
	6	0.95	1.03	1.09	1.15	1.19	1.23	1.04	1.12	1.19	1.25	1.29	1.34	1.13	1.22	1.29	1.35	1.40	1.45	2.40
	8	0.92	1.00	1.06	1.11	1.16	1.20	1.00	1.08	1.15	1.21	1.26	1.30	1.09	1.18	1.25	1.31	1.36	1.40	2.50
	10	0.89	0.97	1.03	1.08	1.13	1.17	0.97	1.05	1.12	1.18	1.22	1.27	1.06	1.14	1.21	1.27	1.32	1.37	
	12	0.87	0.95	1.01	1.06	1.10	1.14	0.95	1.03	1.10	1.15	1.20	1.24	1.03	1.12	1.19	1.25	1.30	1.34	

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Questions

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