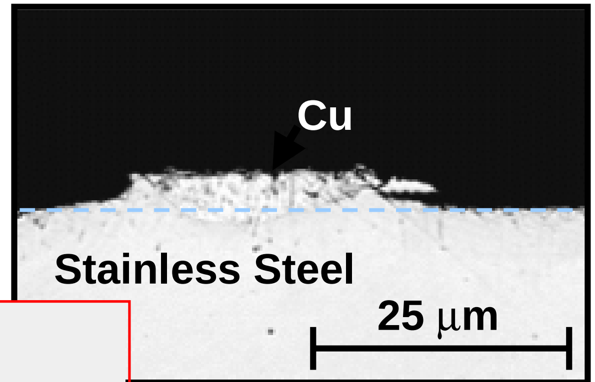
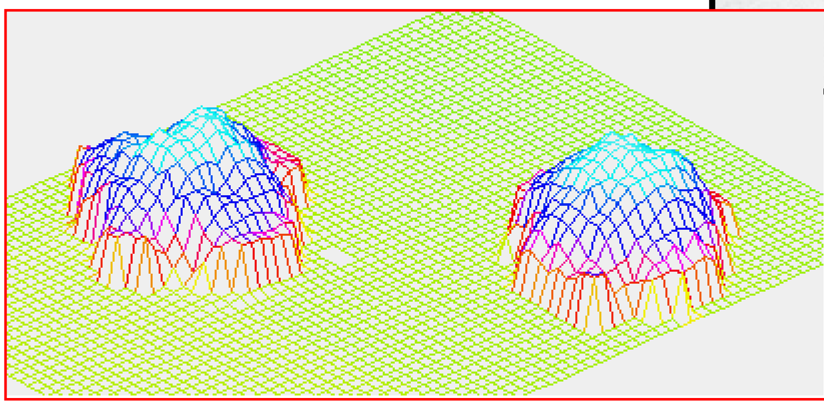
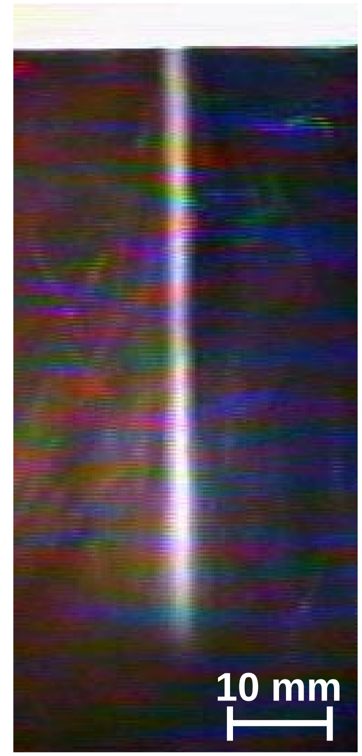
Cold Spray R&D Activities at Sandia

Thermal
Spray
Research
Laboratory

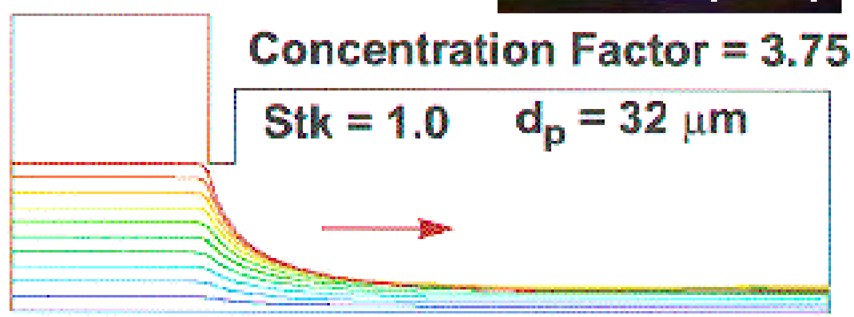
Dr. Richard A. Neiser
Dr. Delwyn L. Gilmore







Presented at the Cold Spray Workshop
July 14th & 15th, 1999
Sandia National Laboratories
Albuquerque, New Mexico



Outline

- Introduction to the TSRL
- Examples of some TSRL projects
- Cold spray R&D activities at Sandia
- Barriers to commercialization of the cold spray process
- Cold spray R&D results

TSRL Personnel (Extended Family)

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- **Thermal spray R&D** - Richard Neiser, Delwyn Gilmore, Timothy Roemer, and Mark Smith
  - coating technology, materials science, optics, process science
- **Engineering sciences** - Ronald Dykhuizen, John Brockmann, William Oberkampf, Amalia Lopez, Timothy O'Hern, Michael Kanouff, and Basil Hassan
  - modeling of gas & particle dynamics, depostion modeling, particle diagnostics, nozzle design
- **Wear & Corrosion** - Michael Dugger and Rob Sorensen
- **Statistical analysis** - Floyd Spencer and Edward Thomas
- **NDE** - David Moore
- **Robotics** - Ross Burchard
- **Extensive characterization capabilities**

Some examples of TSRL programs

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- CRADA partnership with General Motors
  - Goal: to develop a high-velocity oxy-fuel process for coating aluminum engine blocks

- Partnership with Fisher-Barton and the Institute for Paper Science & Technology
  - Goal: to develop ceramic coatings for impulse drying of paper stock

- Collaboration with SUNY Stony Brook's Center for Thermal Spray Research
  - A consortium of academia, national labs, and industry studying the science & technology of thermal spray processes

Some Existing Aluminum Cylinder Bore Technologies & Their Limitations

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CAST-IN LINERS

- THICK, HEAVY LINERS ADD WEIGHT
- SCRAP BLOCKS INCLUDE LINERS
- POSSIBLE MISALIGNMENT

SLEEVE INSERTION

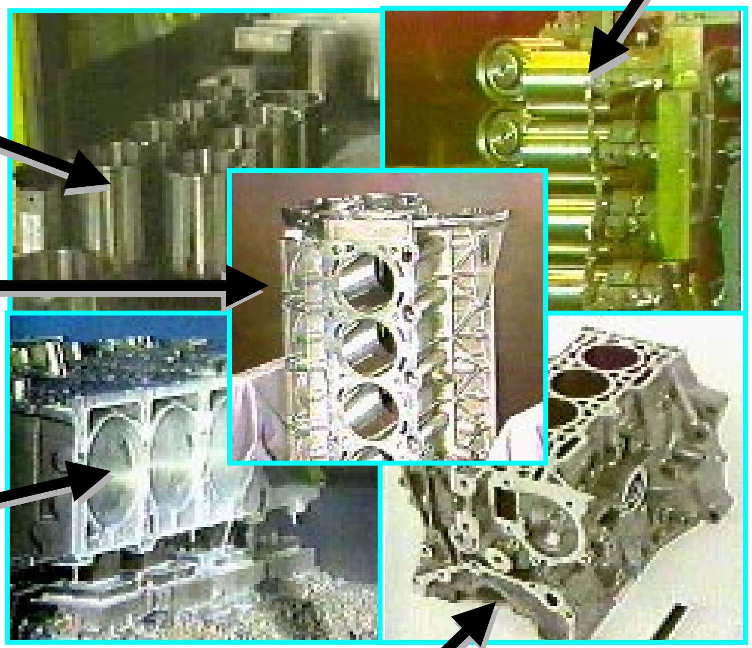
- EXPENSIVE
- REDUCED DISPLACEMENT
- POSSIBLE GAPS / BORE DISTORTION

NIKASIL PLATING

- EXPENSIVE
- NOT ENVIRONMENTALLY FRIENDLY

CAST 390 ALLOY

- DIFFICULT TO CAST
- DIFFICULT TO MACHINE
- REQUIRES COATED PISTONS



SQUEEZE CAST MMC

- EXPENSIVE
- COMPLICATED
- REQUIRES COATED PISTONS

The HVOF "Spray Bore" Process

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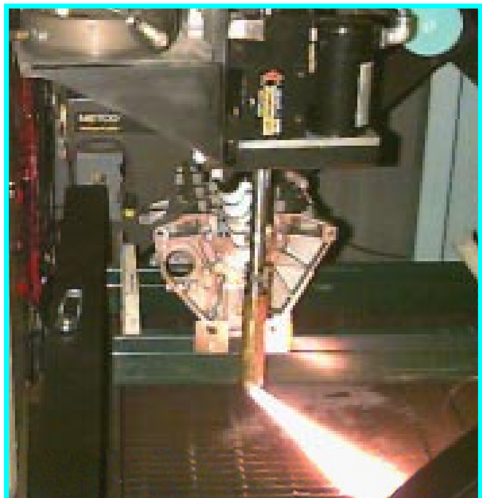

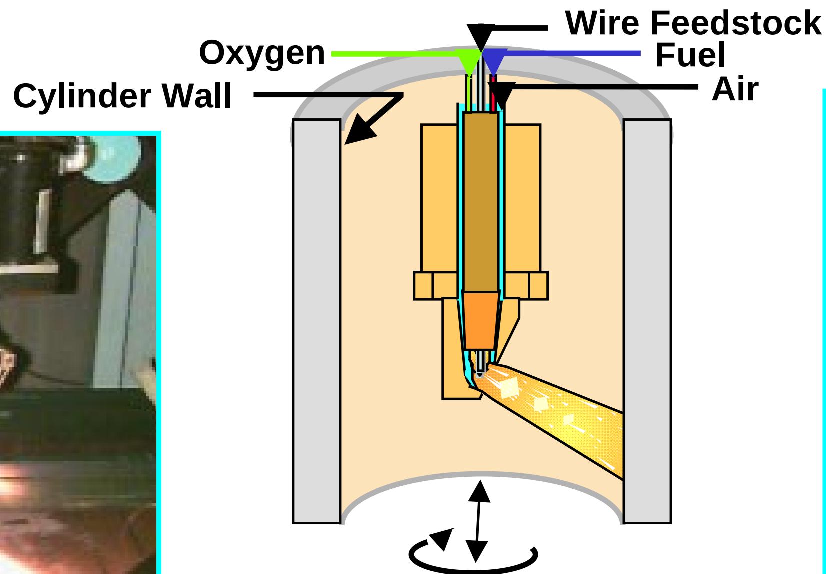

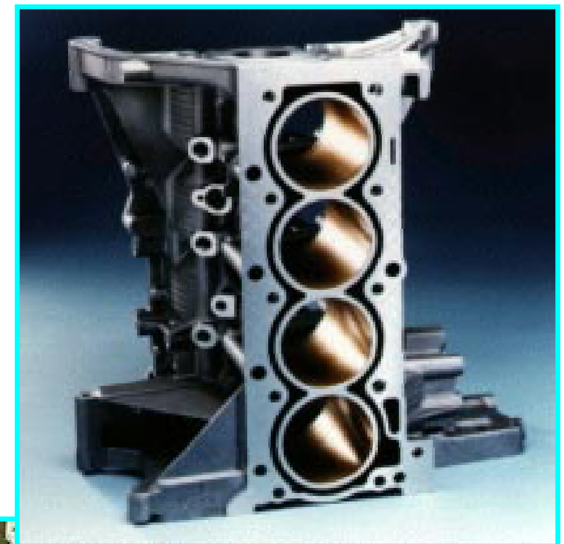

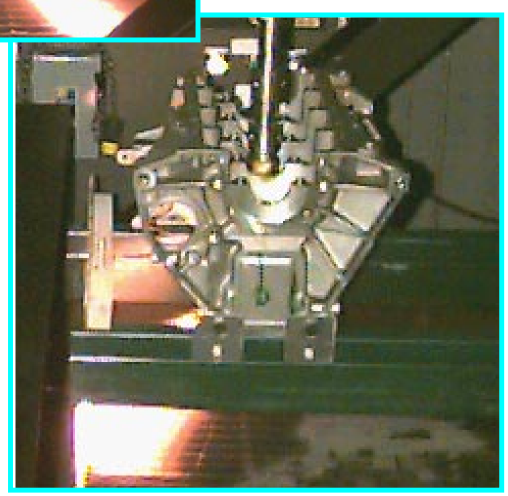

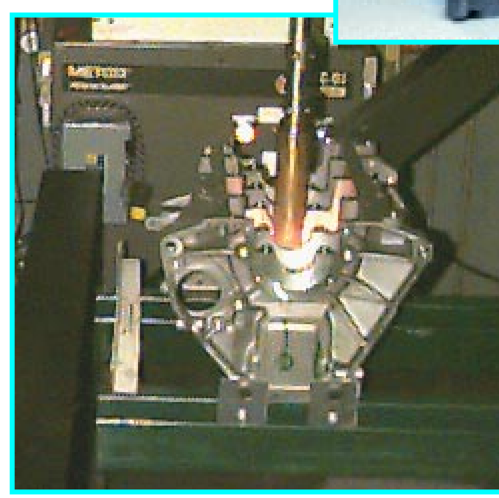

Spray Bore Technology Offers Important Potential Advantages

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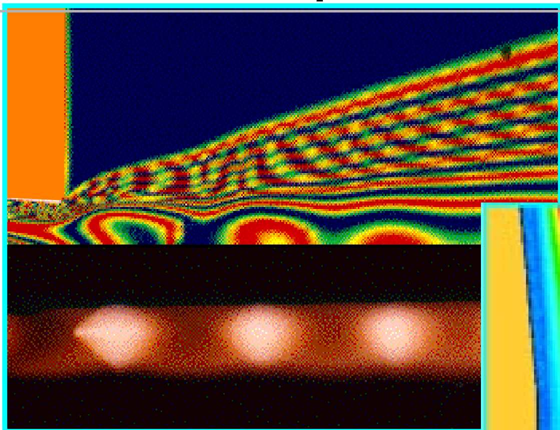
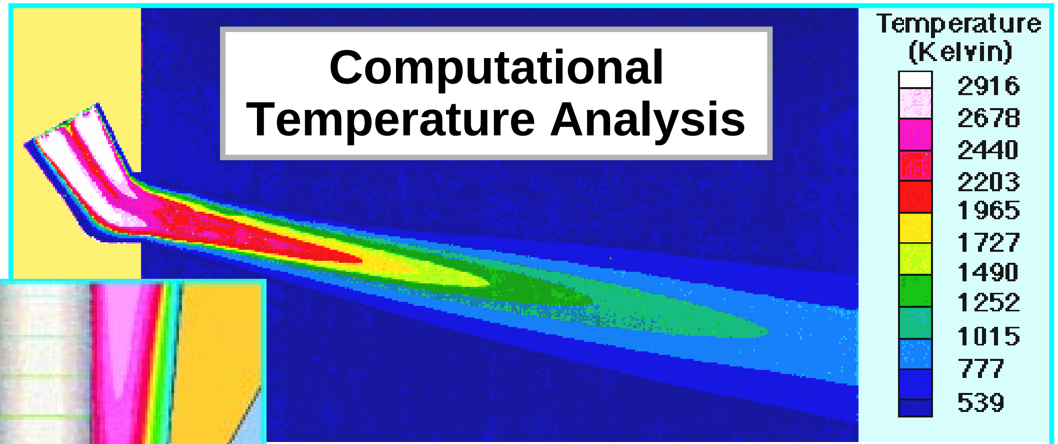
- Reduced Cost & Weight
- Greater Design & Mfg. Flexibility
- Superior Wear Resistance
- Tight Piston Fit
- Good Thermal Conductivity

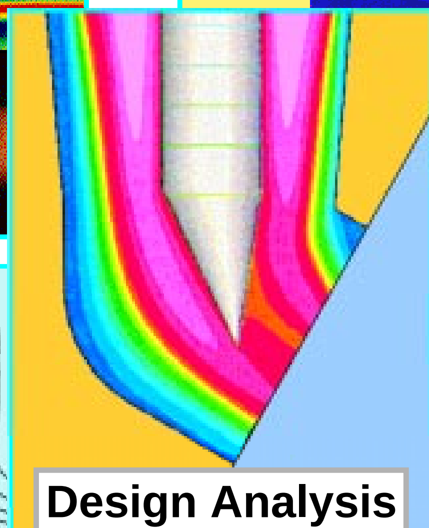
Process Modeling

Multi-Phase Supersonic Flow

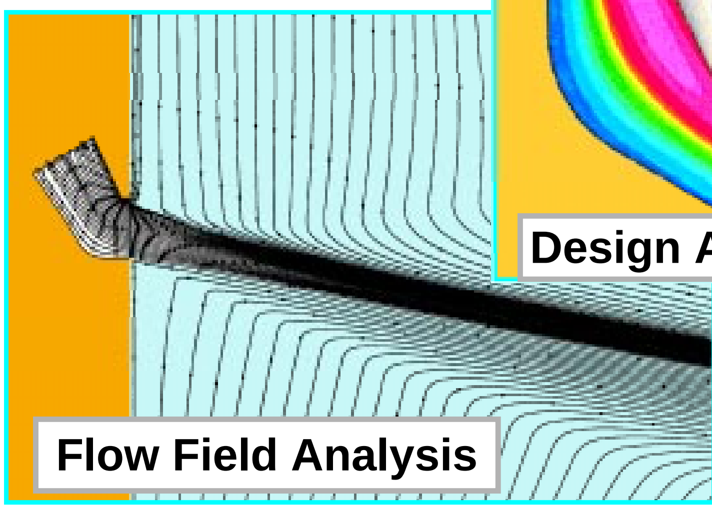


Computational Temperature Analysis



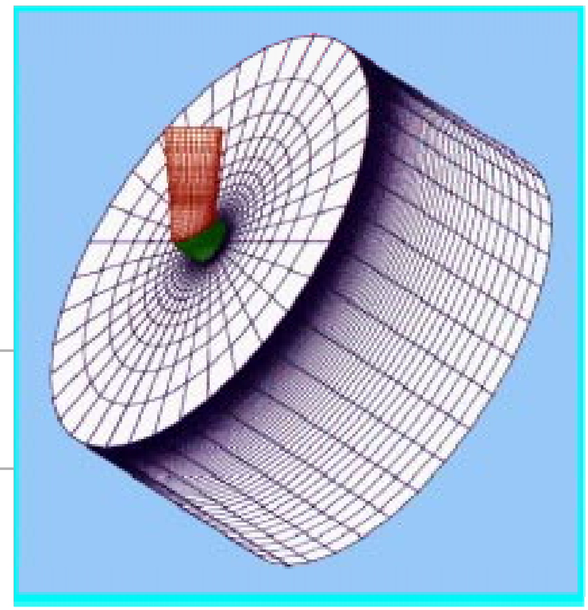


Design Analysis



Flow Field Analysis

Full 3-D CFD Analysis



GM/Sandia Thermal Spray CRADA . . .
a Mutually Beneficial Partnership

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GM Commercialization Required:

- **Increased throughput/gun service lifetime**
- **Uniform macro/micro deposition**
- **Controlled composition/microstructure**

Sandia also Needed Enhanced Technology:

- **Additional production responsibilities**
- **Continuous quality improvement**

GM Engine Block

CRADA Teaming Benefits:

- **Unique Sandia capabilities/expertise in spray diagnostics, modeling, & materials science**
- **Key GM capabilities/expertise in system design, process monitoring, & control methodology**

Sandia N-Generator

Results of Joint R&D Benefit GM, Sandia, DOE, & the US Taxpayer

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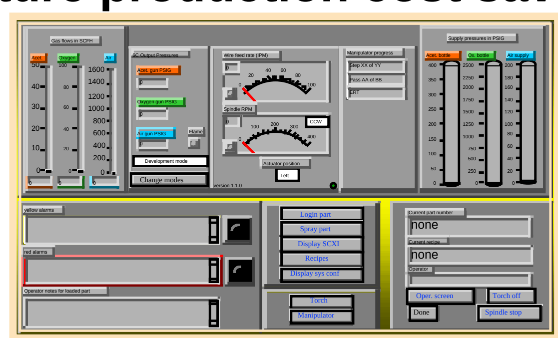
- **GM goals met or exceeded**
  - **> 200% throughput increase**
  - **> 1000% spray gun service life increase**
  - **~ 50% capital cost reduction**
  - **outwears cast iron in lab tests**
- **Potential multi-million $$$ savings**

- **New Sandia production control system**
- **Cost savings now & in the future**
  - **Joint R&D reduced system dev. costs**
  - **Potential future production cost savings**



Impulse Drying of Paper -
A collaboration with Fisher-Barton & IPST

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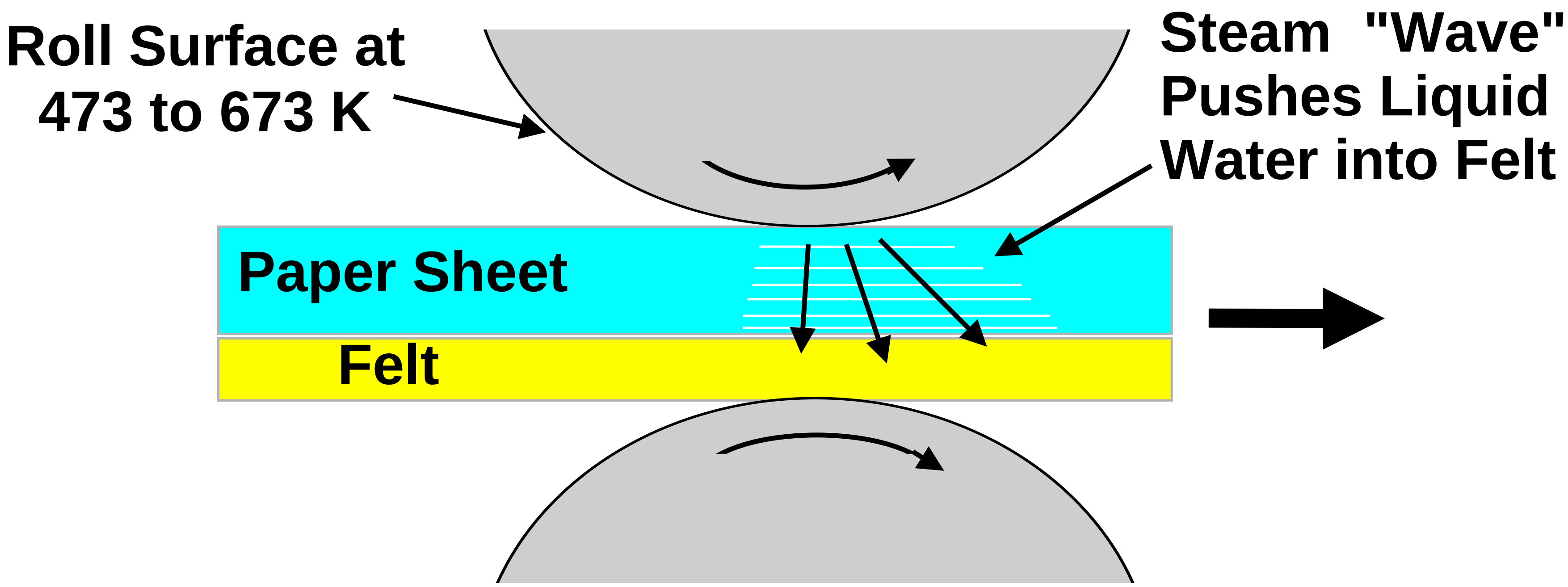

"Impulse drying will likely be one of the largest advances in papermaking as we enter the 21st century"

-- TAPPI water removal committee

Excessive Heat Transfer Causes Superheating and Delamination of Paper

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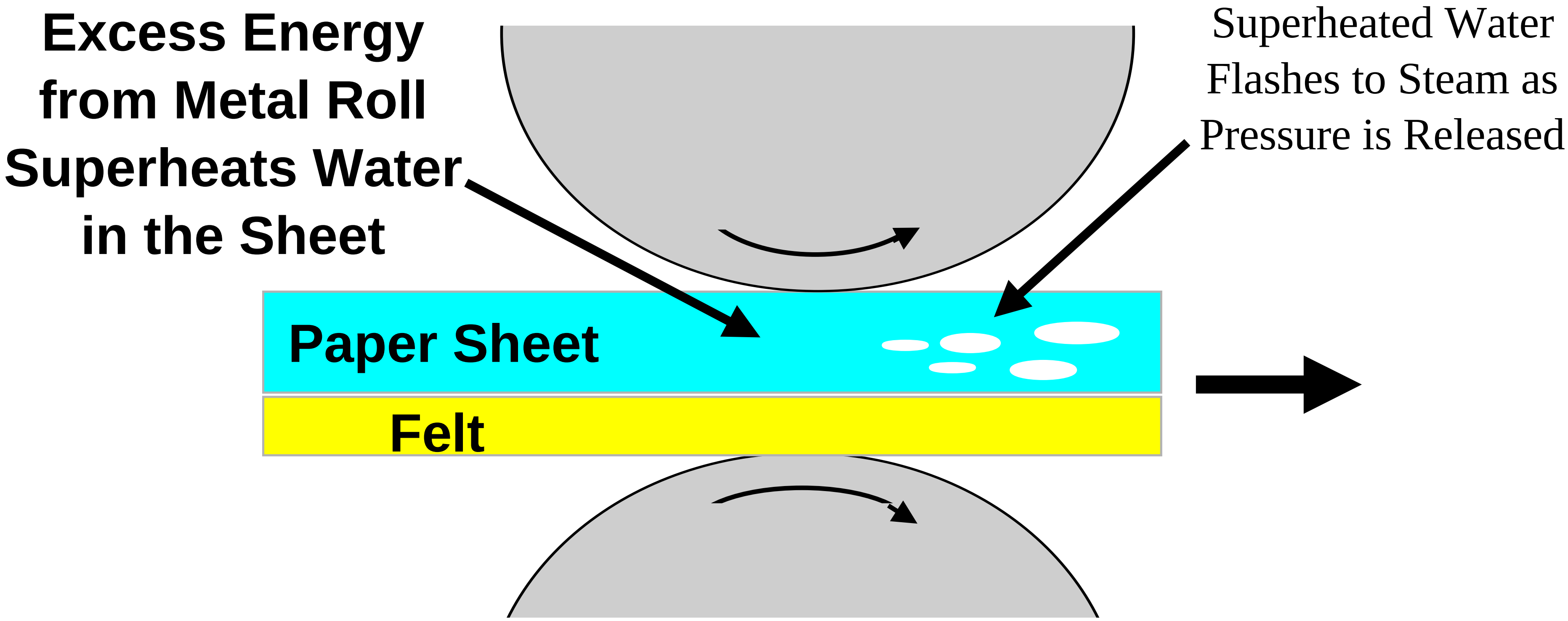

Conventional uncoated rolls cause delamination even at moderate temperatures due to excessive energy transfer

Coating permits control of the energy transfer to produce a brief, intense pulse necessary to prevent delamination

Coated Roll Requires Only 1/3 of the Energy Used in Conventional Drying

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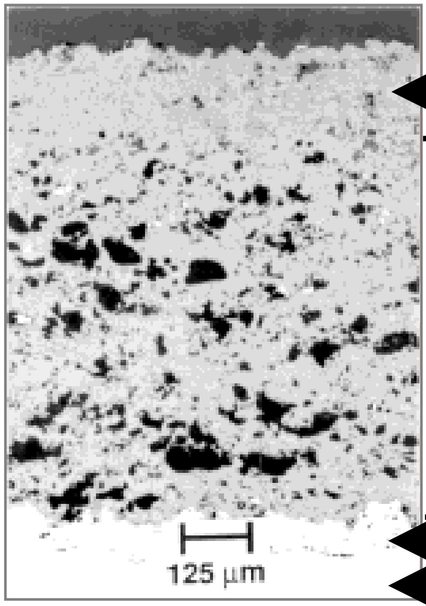
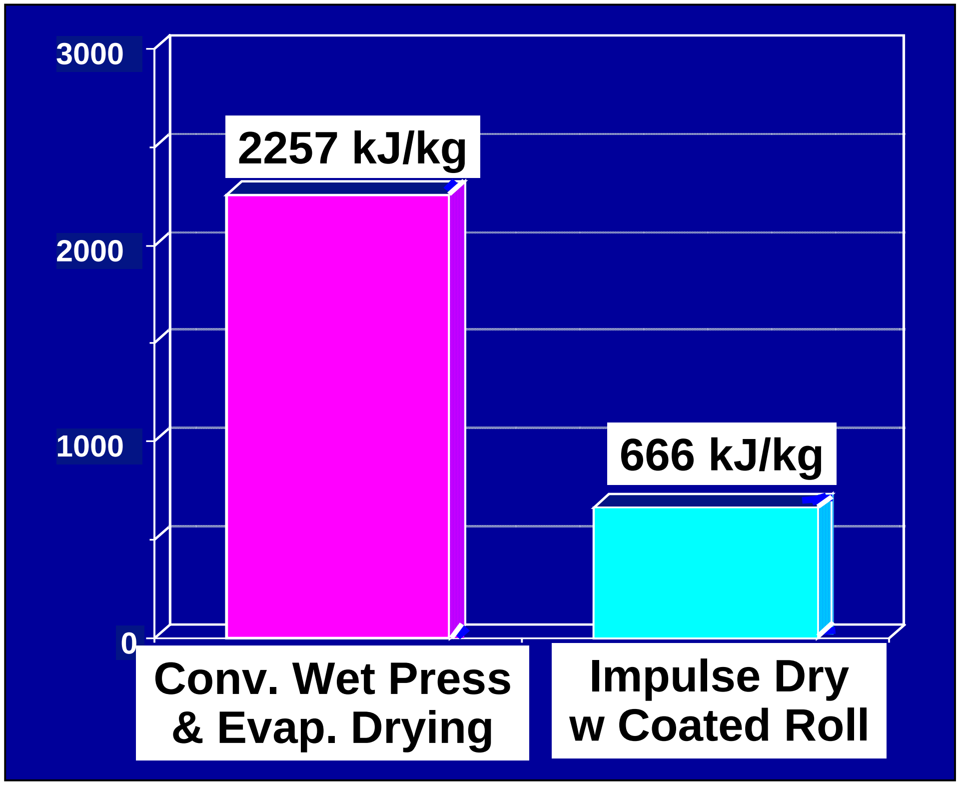


Drying Energy Used (kJ/kg)



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TSRL Research Programs

Thermal **S**pray **R**esearch **L**aboratory

Research projects at the TSRL are directed towards:

- Improving our understanding of process fundamentals through diagnostics, modeling, and materials characterization
- Pioneering new technologies & developing novel materials
- Developing innovative process control methodologies
- Collaborating with internal and external research groups to remain at the forefront of thermal spray science

Collaboration with Center for Thermal Spray Research - Stony Brook

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- **Building a process map for plasma sprayed molybdenum**
- **Diagrams relating processing to particle properties were constructed.**

<u>Parameters</u>

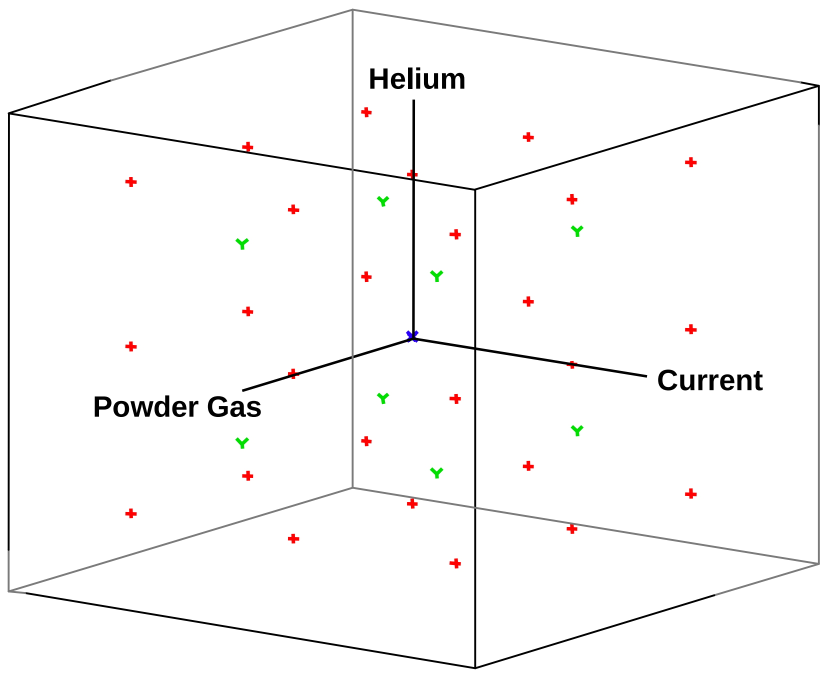
(44 pt. DOE, 5 levels, 10 center pts.)

- Current : 500 - 900 A
- Helium : 12 - 24 SLPM
- Powder Gas (Ar) : 1 - 3 SLPM
- Gas Ring : Laminar / CW Swirl

<u>Responses</u>

(Measured by Tecnar DPV)

- Particle Temperature
- Particle Velocity
- Particle Diameter



Particle thermal and kinetic energy maps provide insights and guide further experimentation

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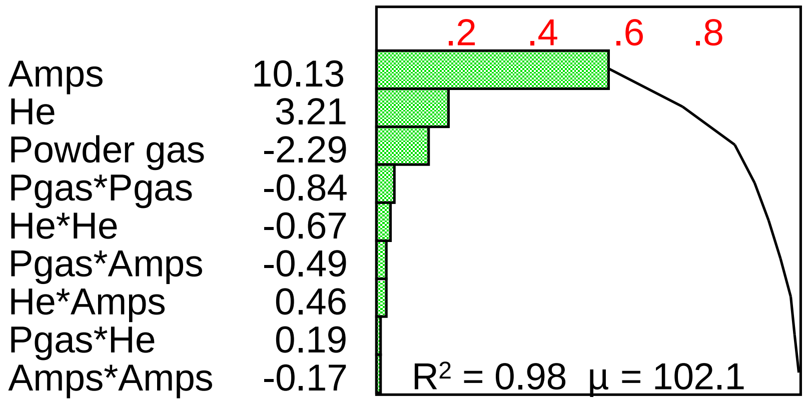
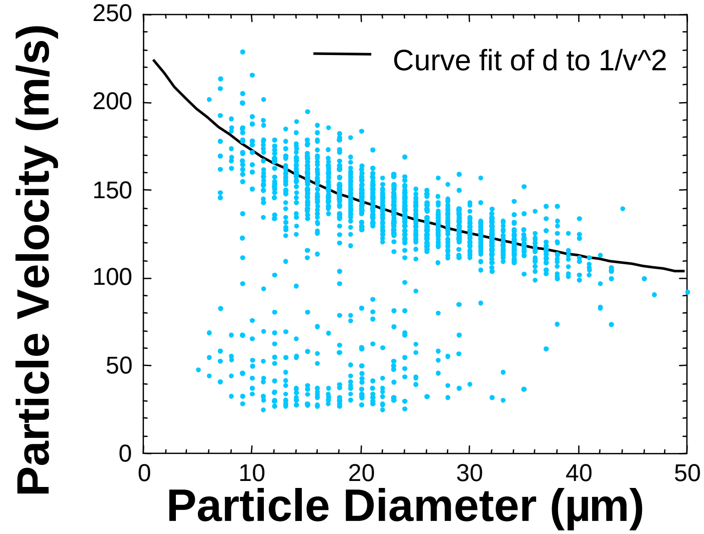


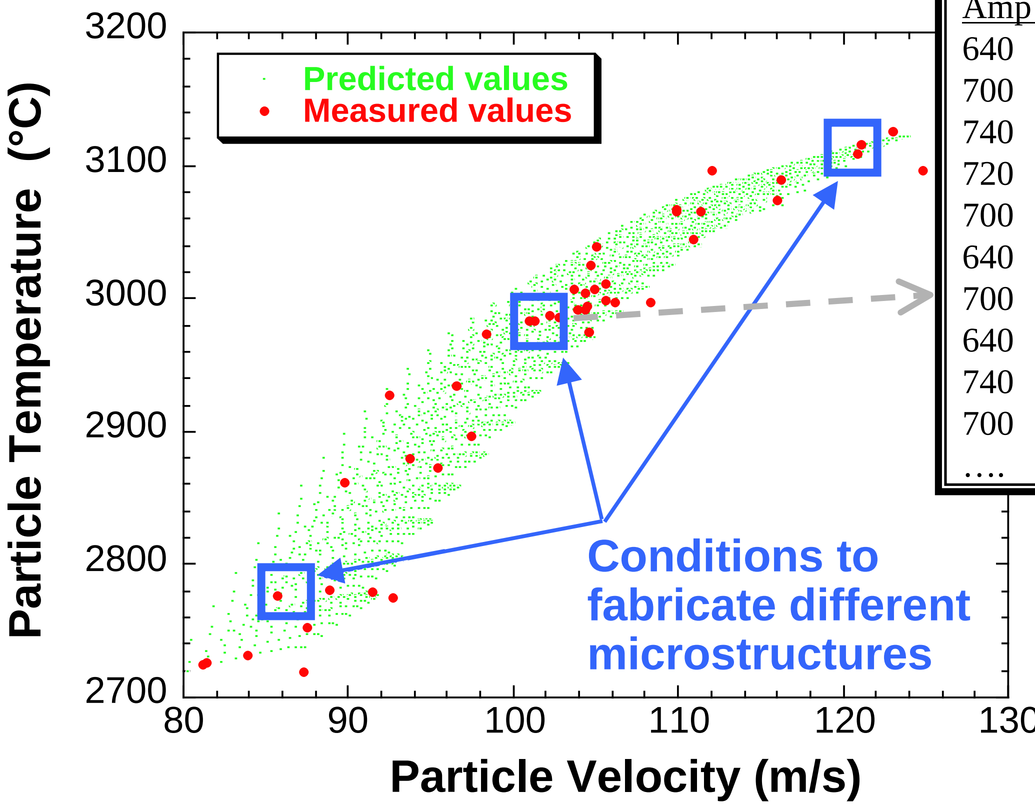
Particle Velocity (m/s)



- **Particle properties are fit to a quadratic surface in parameter space.**
- **Pareto plots show normalized importance of each process parameter.**

- **Particle velocity & size are strongly correlated, in good agreement with simple modeling.**
- **Outliers are indicative of poorly injected particles.**

Quantitative process models can be constructed from the analyzed data



Amp	He	PGas
640	23	1.8
700	23	3.0
740	17	2.8
720	16	2.8
700	12	1.0
640	24	1.0
700	23	2.8
640	22	1.8
740	16	3.0
700	16	2.0
….	….	….

- **Good model fit allows accurate data interpolation.**
- **Process conditions that should yield different µstructures can be identified.**
- **A variety of parameters should give similar V_p & T_p.**
- **This variety allows optimization for economics or process stability.**

Process models can be used to intelligently select conditions for specimen fabrication

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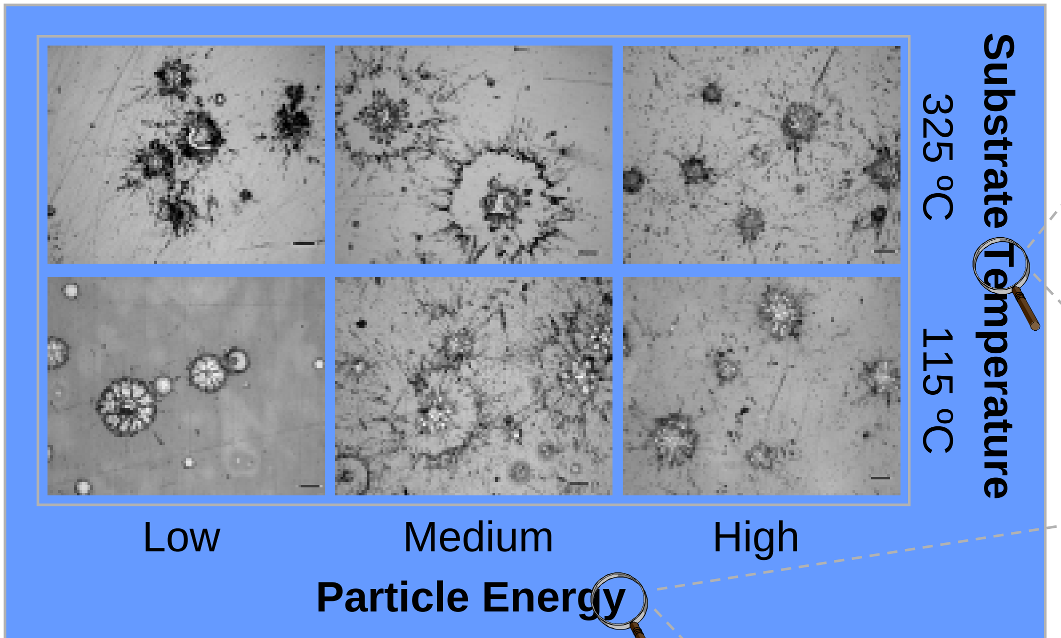

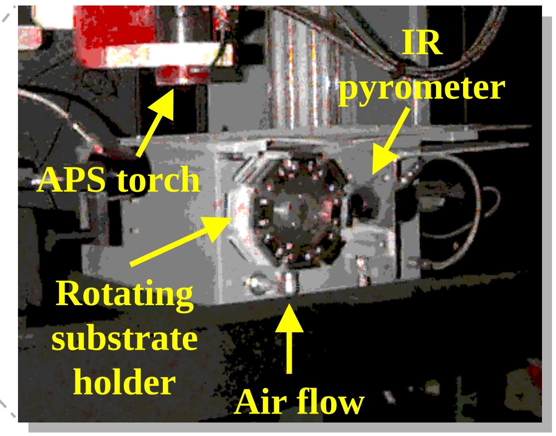

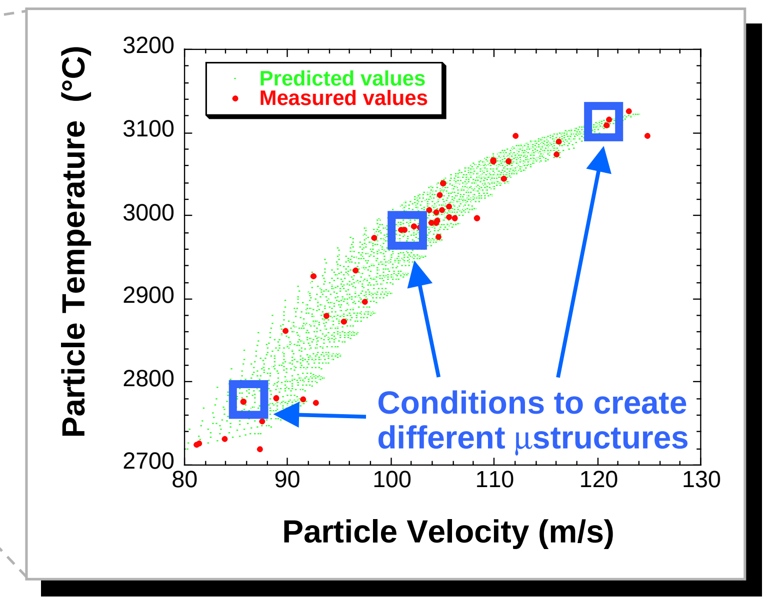

Samples Produced

- Splats: quenching stress & morphology
- 100 µm coatings: residual stresses, wear
- 1.2 mm coatings: thermal properties, µstructure

Primary Cold Spray Research Activities to Date

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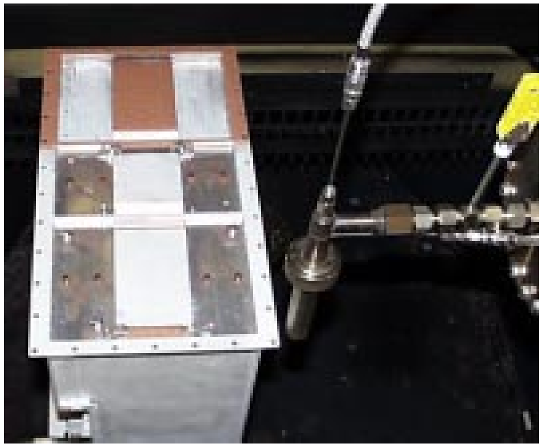
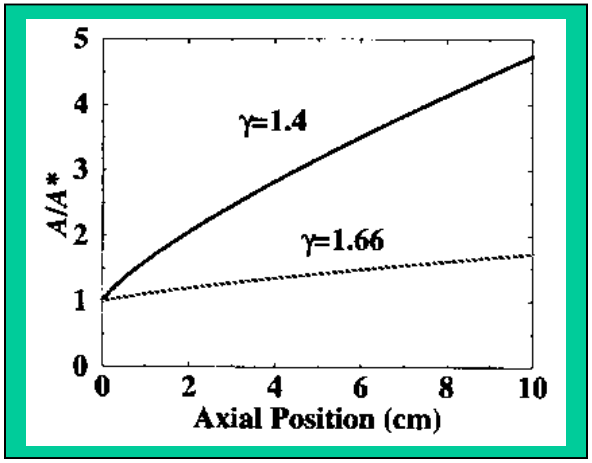
- Analytical & experimental studies of gas & particle dynamics
- Nozzle design for maximum particle velocity
- Particle stream focussing
- Particle impact and deformation & substrate cratering
- Deposit characterization (microstructure & properties)

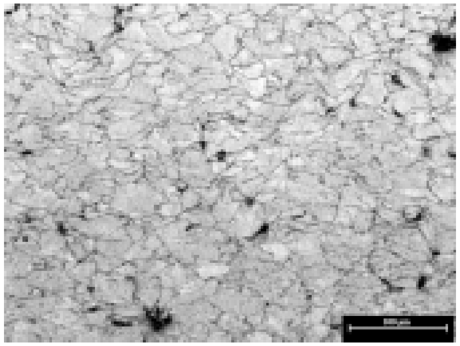


Applications



Modeling

Diagnostics



Characterization

Barriers to commercialization of cold spray

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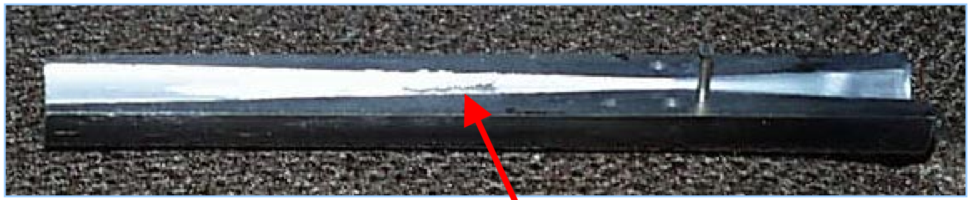
- Technical issues
  - Nozzle design that gives maximum particle velocity with
    - Minimum gas cost
    - Maximum throughput
    - Minimal fouling
  - Nozzle design for focused particle streams (near-net-shape fabrication)
  - Improved ability to predict and understand what combinations of feedstock and substrate work
    - Bonding mechanisms,
    - Substrate preparation effects
    - Critical velocity phenomenon
  - Deposit microstructures & properties
  - In-situ or post-deposition heat treatments to enhance performance



Build-up in nozzle

Particle acceleration in nozzle

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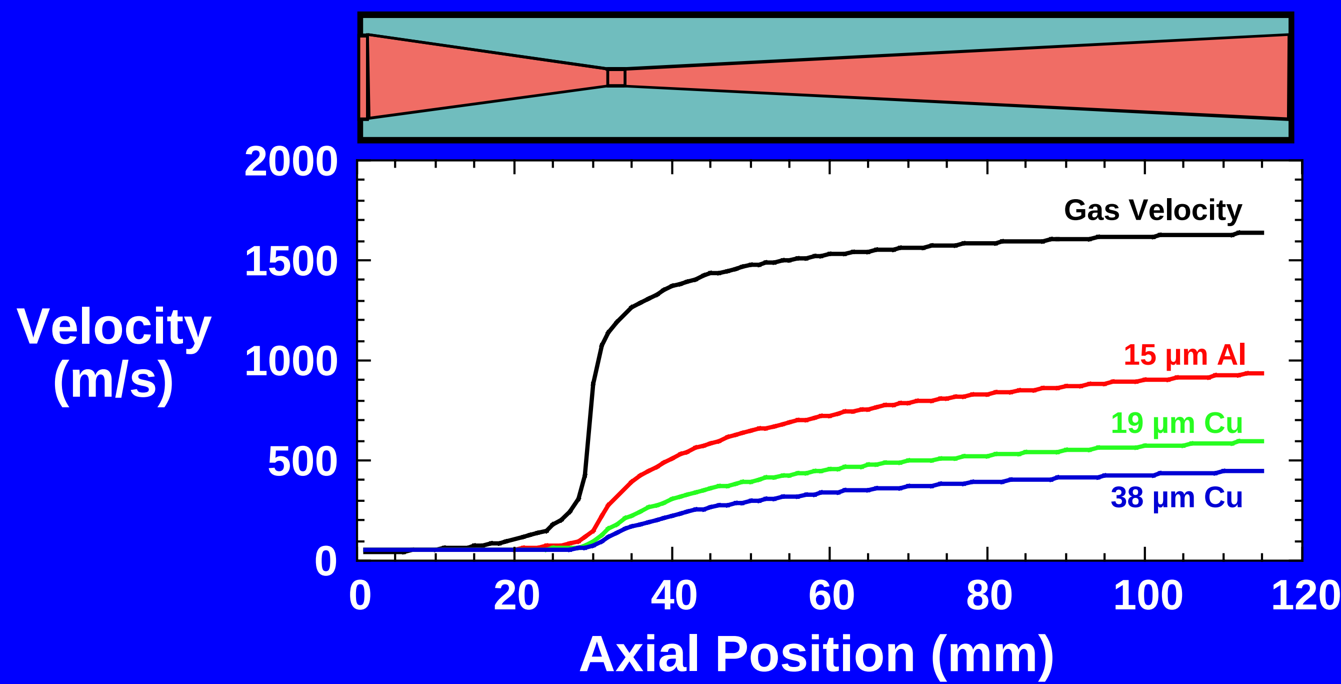

Gas conditions affect the particle size that can be sprayed & process economics:

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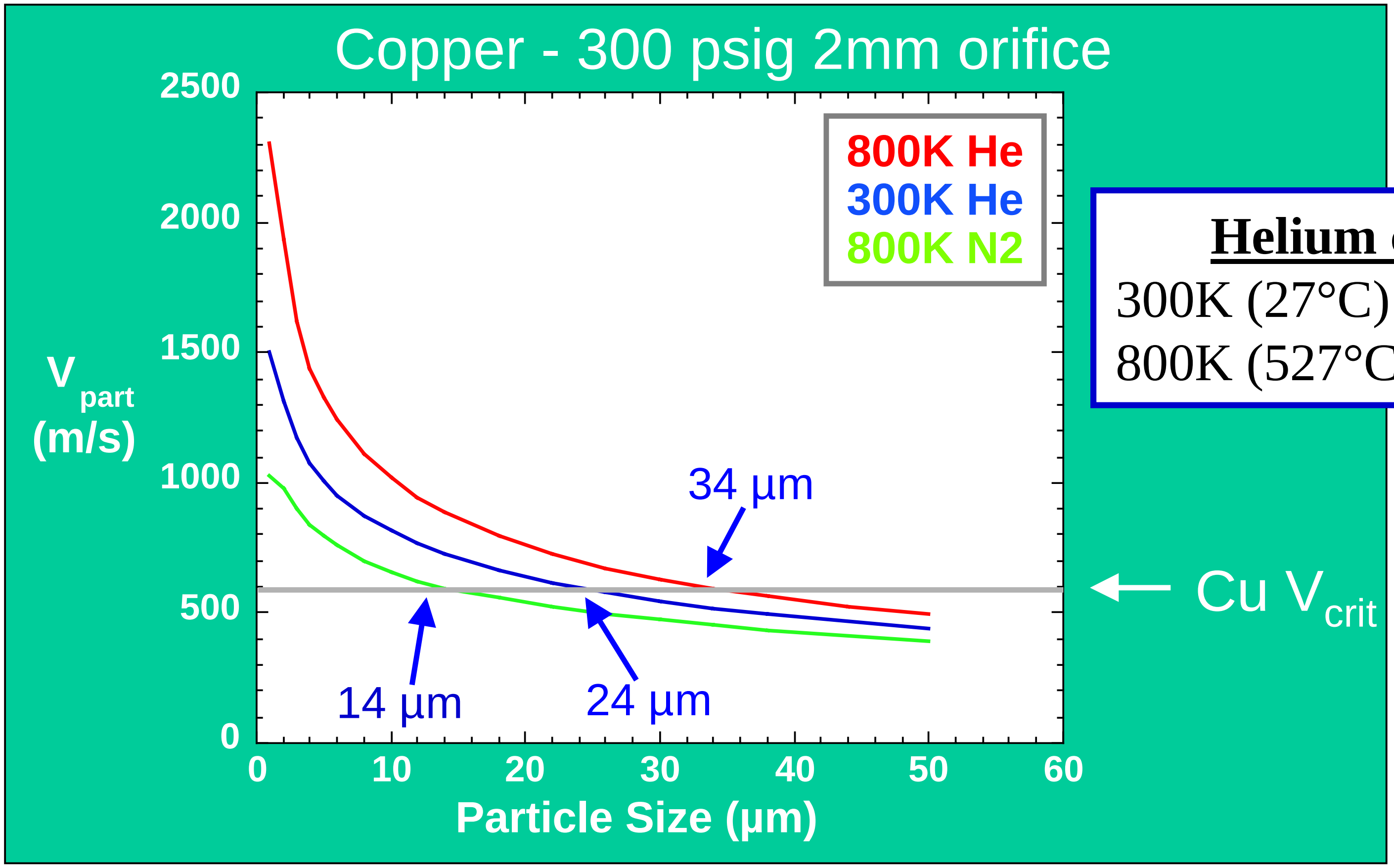

Helium consumption	
300K (27°C)	2100 SLPM
800K (527°C)	1300 SLPM

Barriers to commercialization of cold spray

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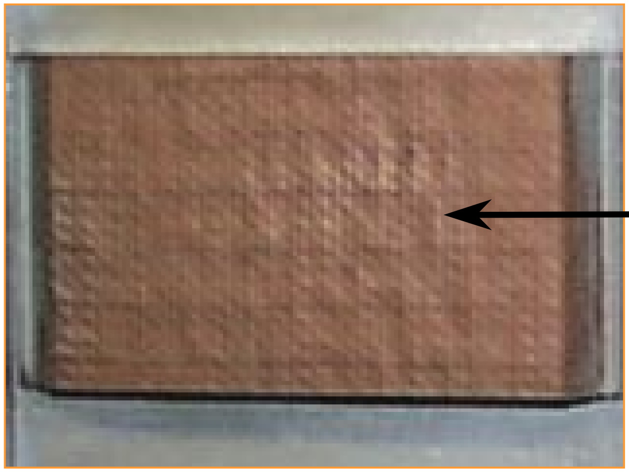
- Engineering issues
  - Lack of commercial supplier - custom-built equipment is costly
    - results in high marginal costs for design changes
  - Portability - current system is bulky
  - Fine powders used w/ cold spray require better feed technology



Uneven deposition due to uneven powder feed

Low velocity particles can build poor coatings

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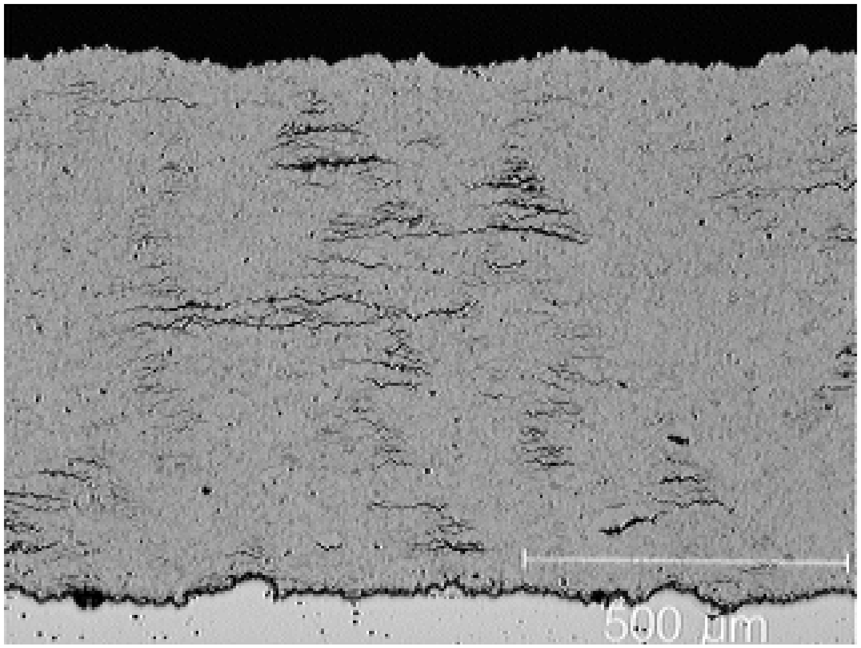

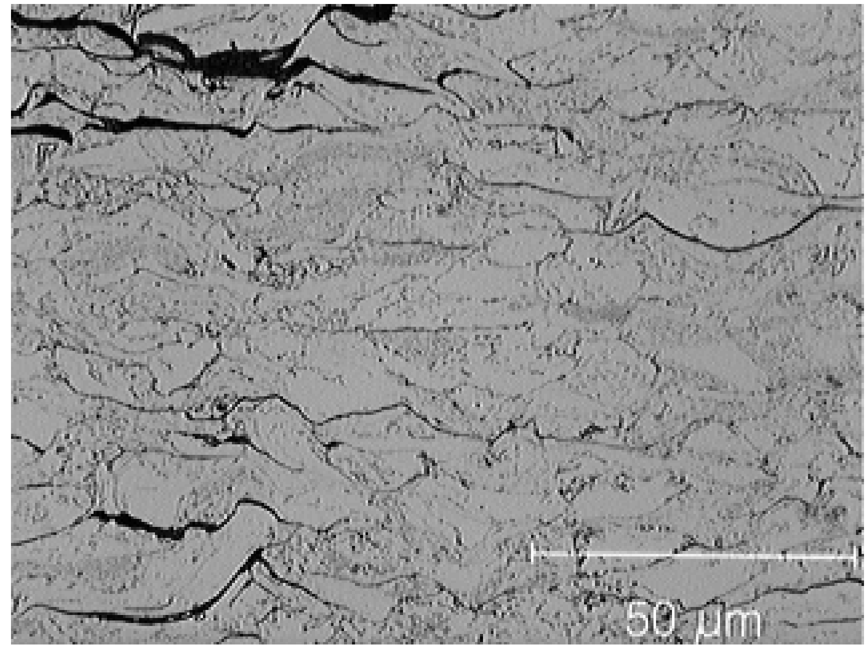

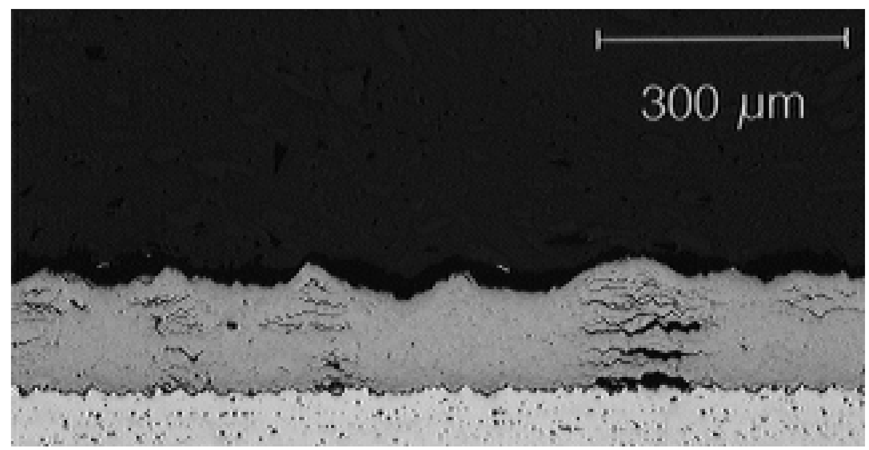

Cold sprayed copper deposited using 225 psig He at room temperature.

Average V_p ~ 600 m/s

V_{crit} ~ 640 m/s