Microstructural Evolution and Mechanical Behavior of Cold sprayed Ti-6Al-4V Coatings

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Introduction

Ti-6Al-4V

- α–β alloy predominantly used in aerospace applications.
  - Good mechanical and electrochemical properties.
- Expensive compared to materials like aluminum.
  - Pound of titanium sheet 15 times more expensive than aluminum[1].
- MRO of aerospace components is a big market.
  - Expenditure for aerospace components is $62 billion[2].

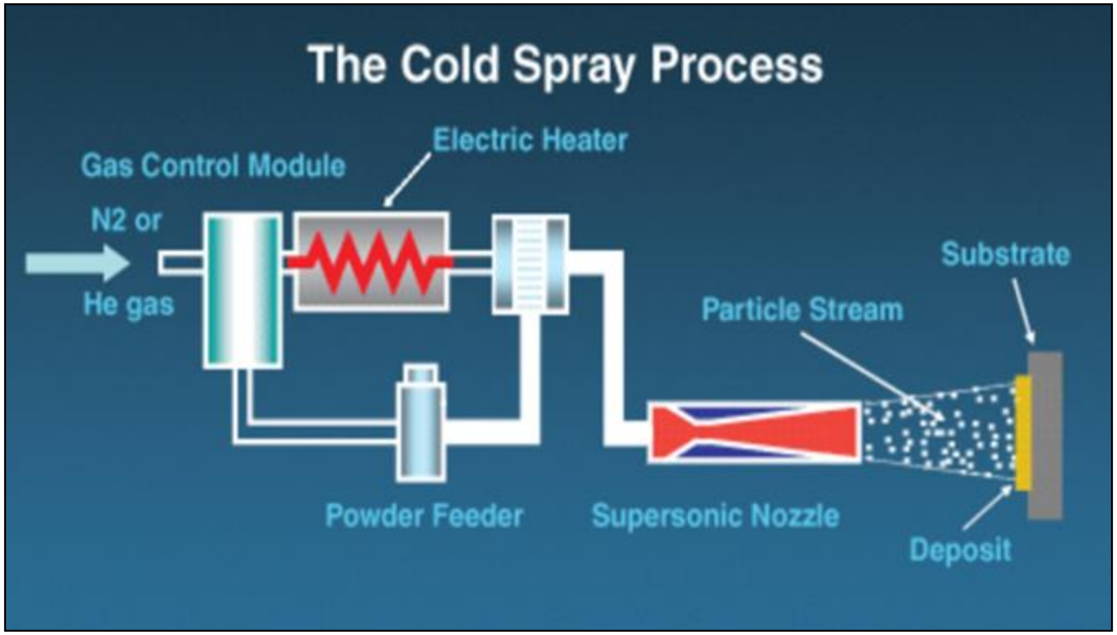

Gabriel, et al.[3]

1. Dutta, et al., (2017). Met. Powder Rep. (72) 96-106
2. Supply chain research insights. (2017). http://aviation week.com

3. Gabriel et al ., (2012, May). 2012 15th International IEEE Conference on Intelligent Transportation Systems

Introduction

- MRO of aerospace components using cold spray is well established[1,2].
- **Cold spray process**
  - Solid state material deposition process.
  - Bonding due to SPD of powder particles.



vrcmetalsystems.com[3]

1. Jones, R.et al., (2011). Int. J. Fatigue (33) 1257-1267
2. Champagne, V et al., (2015). Mater. Sci. Technol (31) 627-634

3. Technology: Cold Spray. (2017). http://vrcmetalsystems.com/technology

Motivation

- Reported scientific literature on cold sprayed Ti-6Al-4V (Ti64) coatings have poor properties.
- Plastic deformation of HCP metals is lower than FCC metals.

Objective: Conduct a systematic investigation of the microstructure and mechanical property evolution of Ti-6Al-4V during cold spray deposition.

***Presentation focus*: Influence of feedstock powder microstructure and cold spray processing parameters on properties of cold sprayed coatings.**

Powder Processing

Gas Atomization (GA)

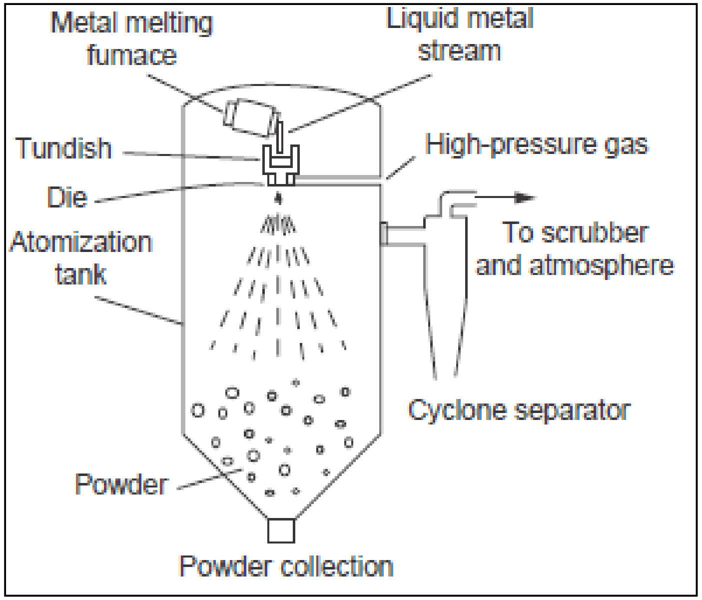
- High velocity Argon gas disrupts flow of molten metal.
- Cooling rate 1000-10000°C/s.

Plasma Atomization (PA)

- Wire is fed to three plasma torches.
- Cooling rate 100-1000°C/s.

Hydride-de Hydride (HDH)

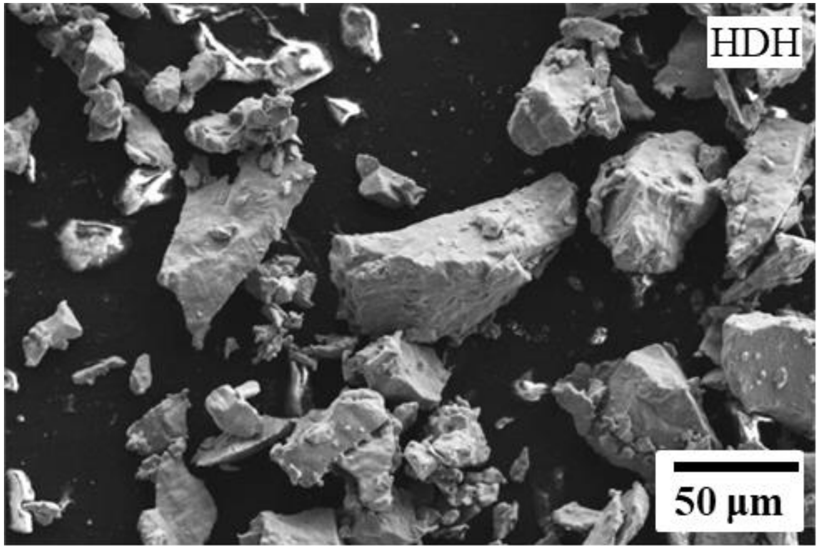
- Hydrogenation (650°C), milling, and dehydrogenation (350°C).

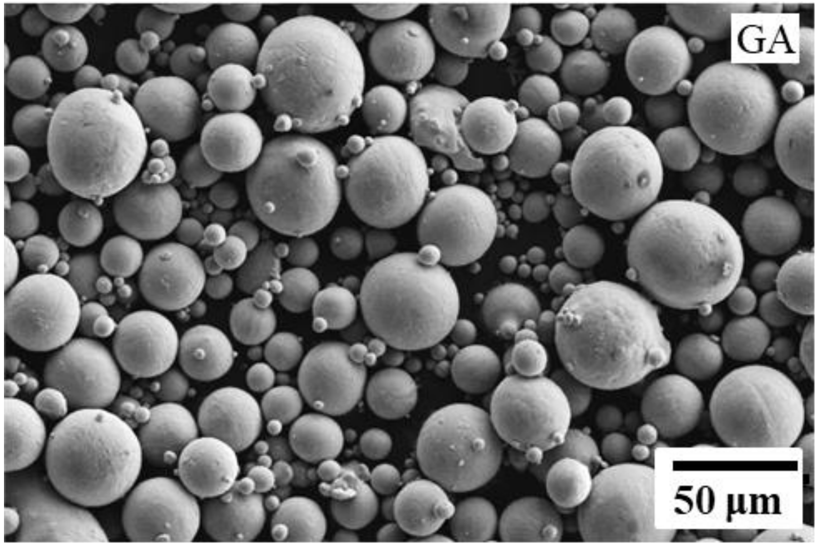


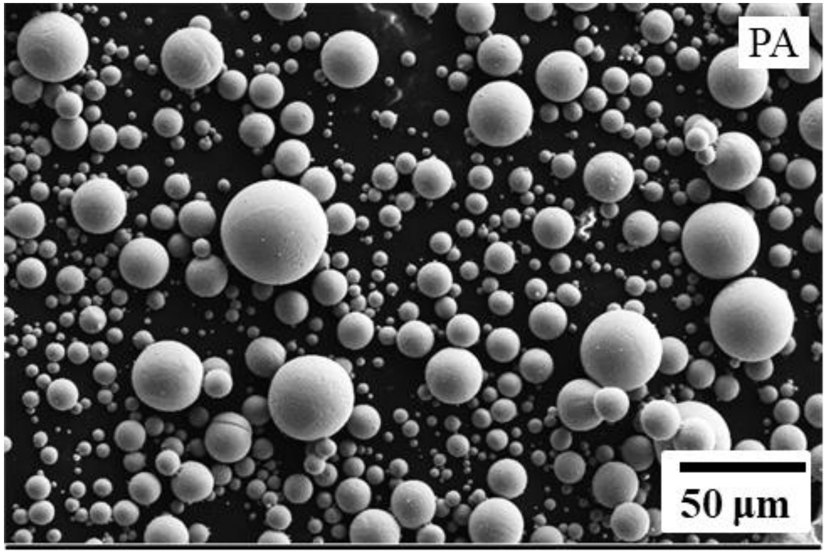
Overall view of atomization facility[1]

1. Davis, J.R., (2004). Handbook of thermal spray technology, ASM International.

Feedstock Powder Characterization





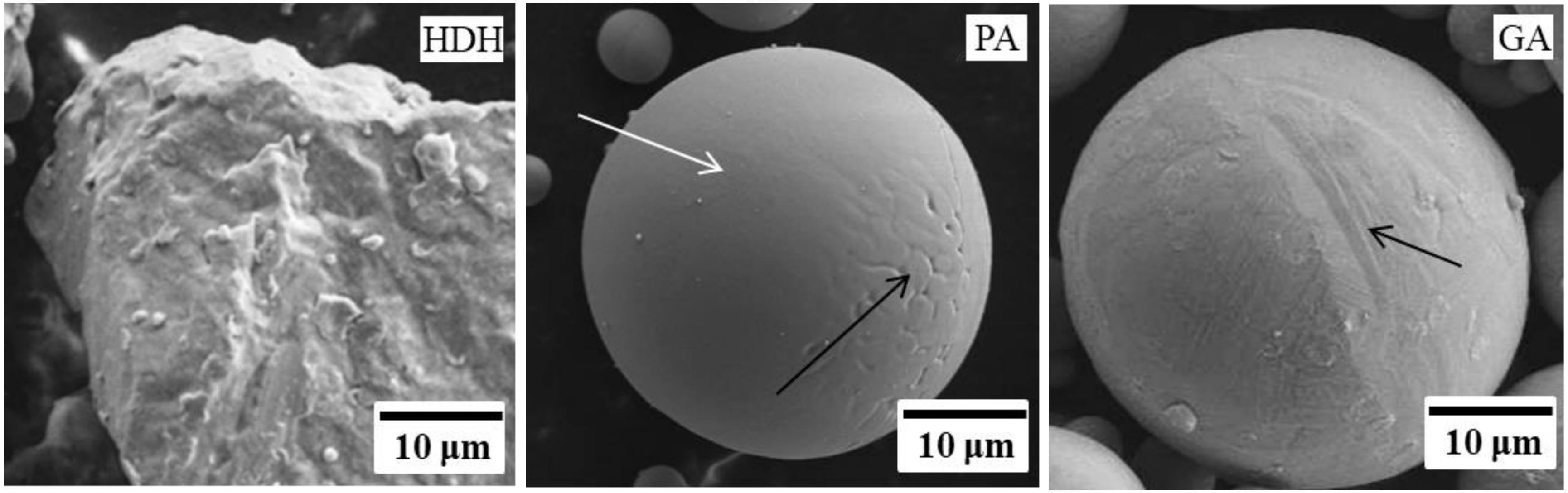


- HDH: Irregular Morphology
- GA and PA: Spherical Morphology

Sizes

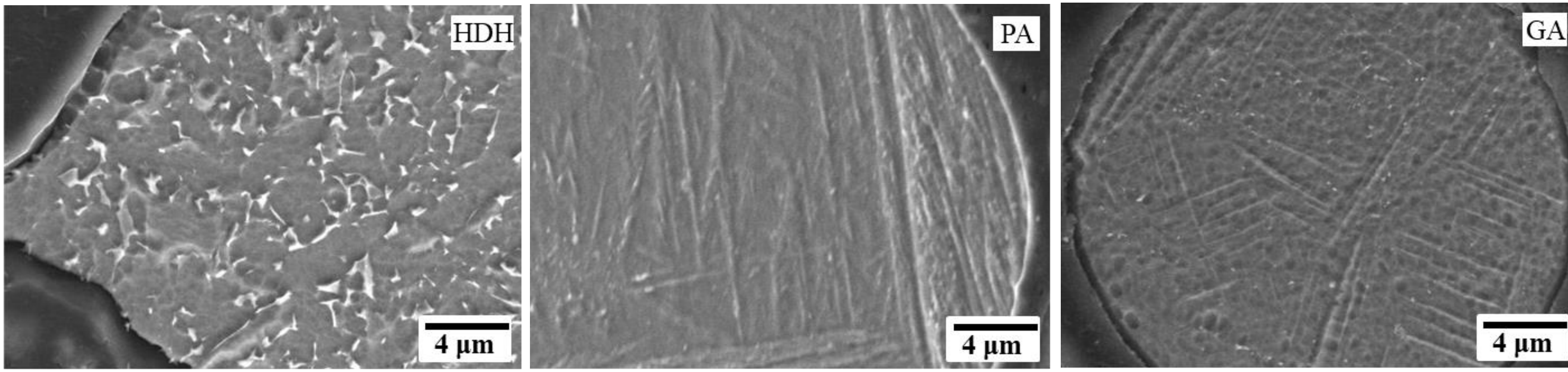
- HDH: 41 ± 13 µm
- PA: 33 ± 12 µm
- GA: 31 ± 8 µm

Feedstock Powder Characterization



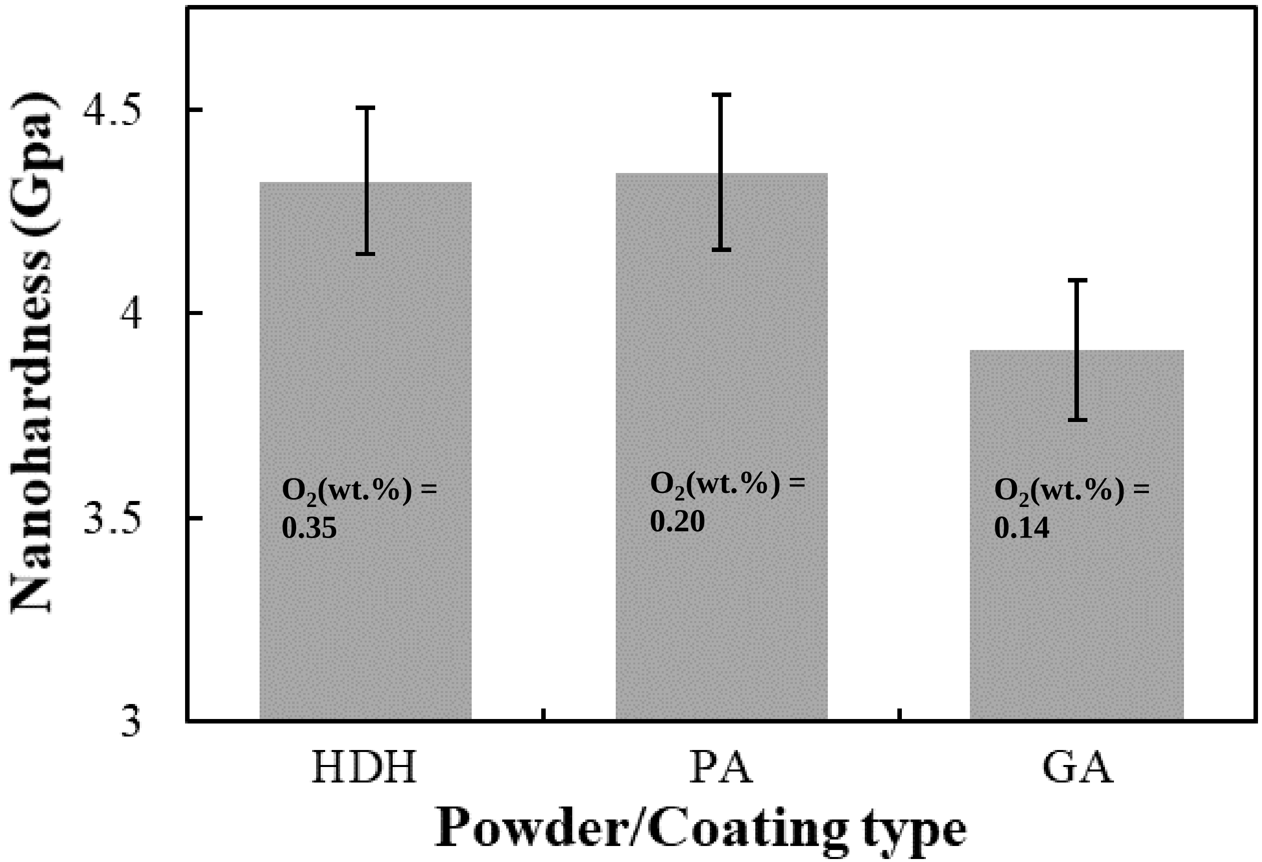
- Atomized powders have three surface textures.
  - Equiaxed grains.
  - Featureless surfaces.
  - Martensitic alpha grains.
- Different levels of undercooling and velocity of solid-liquid interface result in above textures.

Feedstock Powder Characterization



- HDH powder characterized by fine equiaxed alpha grains with intergranular beta (β) precipitates.
- Atomized powders are characterized by martensitic alpha (α′) with different morphologies.
  - PA: Needle like α′.
  - GA: Acicular α′.
- Processing history of powders result in the above microstructures.

Feedstock Powder Characterization



- Powder microstructure influences powder properties.
- High oxygen content resulted in high hardness observed for HDH and PA powder.

Cold Spray Processing

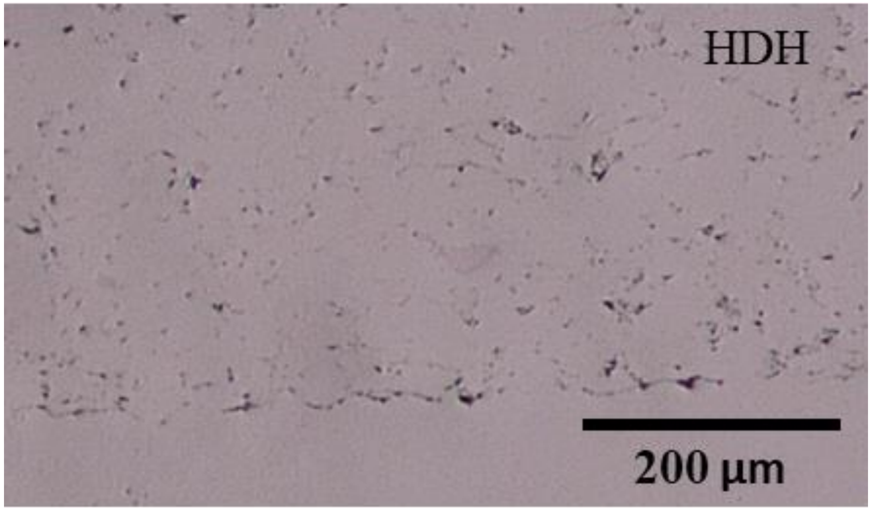
- Critical velocity: velocity at which particles adhere to substrate; for Ti64 ≈ 960 m/s.
- Impact velocity of powder particles[1] > critical velocity for a good cold spray deposit.

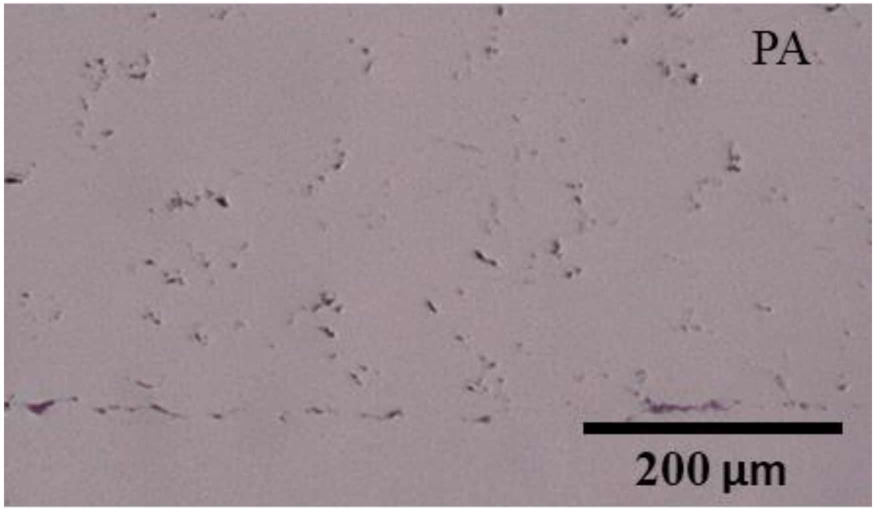
Cold Spray Conditions

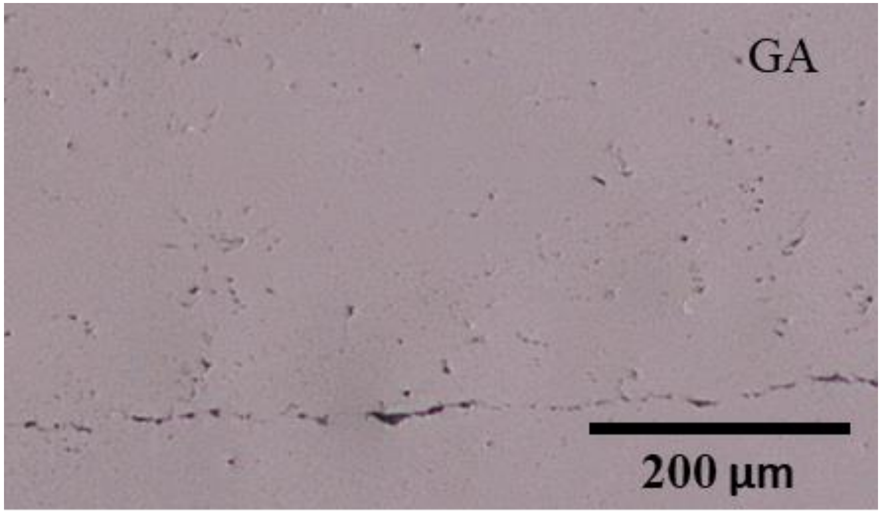
Impact Velocity (m/s)			Gas temperature (°C)	Gas Pressure (psi)	Nozzle length (mm)
PA	GA	HDH			
882	906	810	425	600	120 (short)
897	922	814	500	600	120 (short)
908	933	822	400	600	200 (long)

Widener, C.A et. al.[2]

Deposition Quality

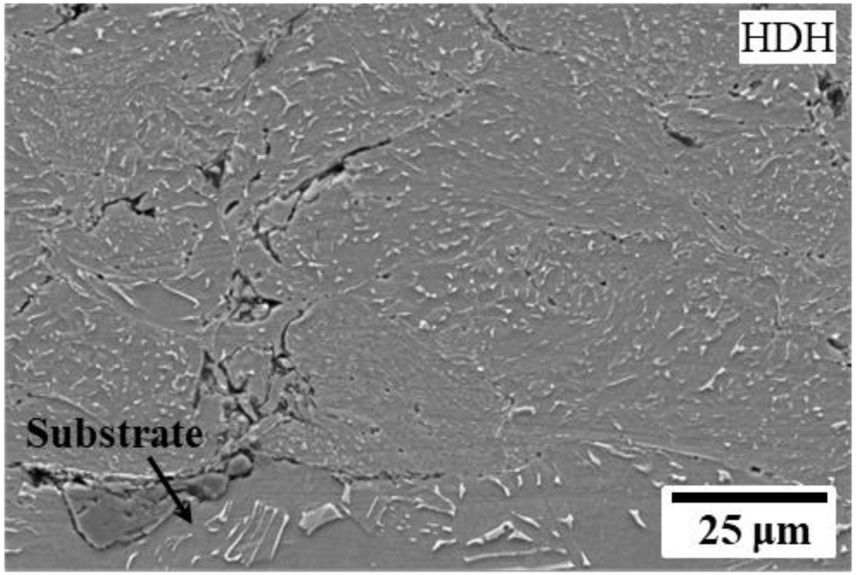


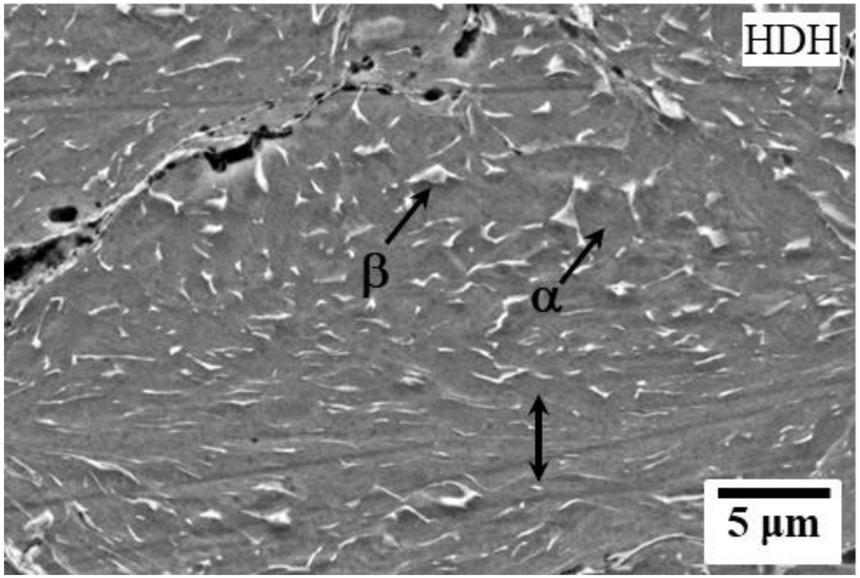




- Dense coating with some particle-particle voids
- Qualitatively GA coating has the lowest porosity
  - Low hardness
  - Low oxygen content

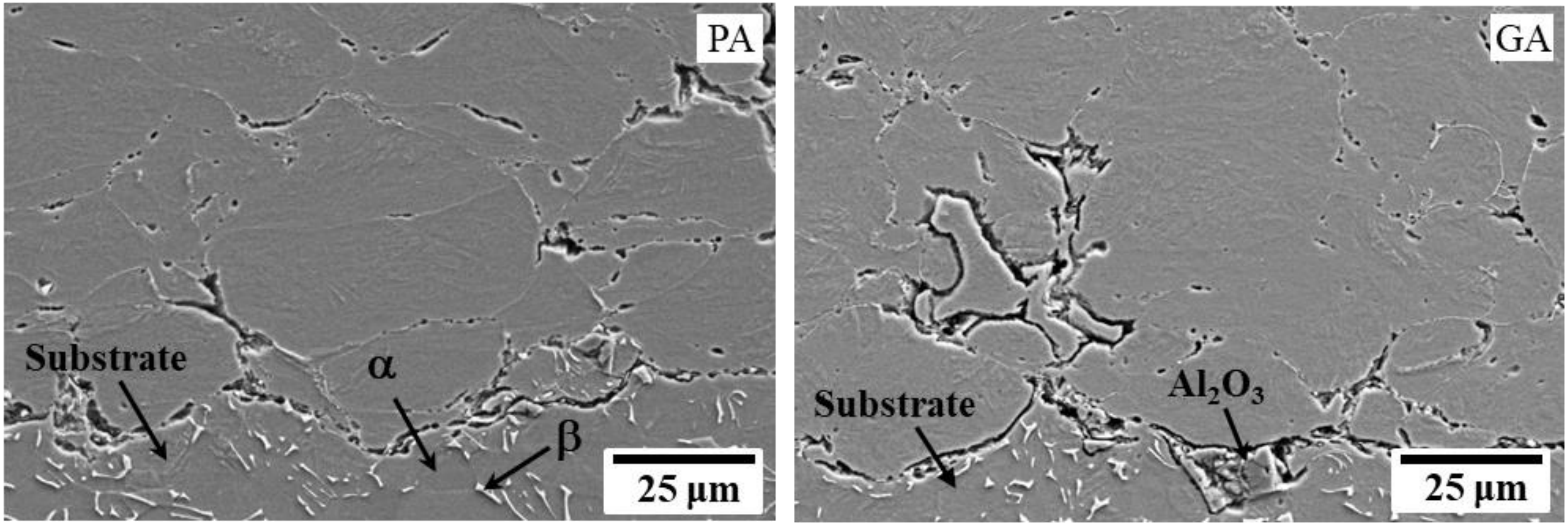
Cold Spray Coating Characterization





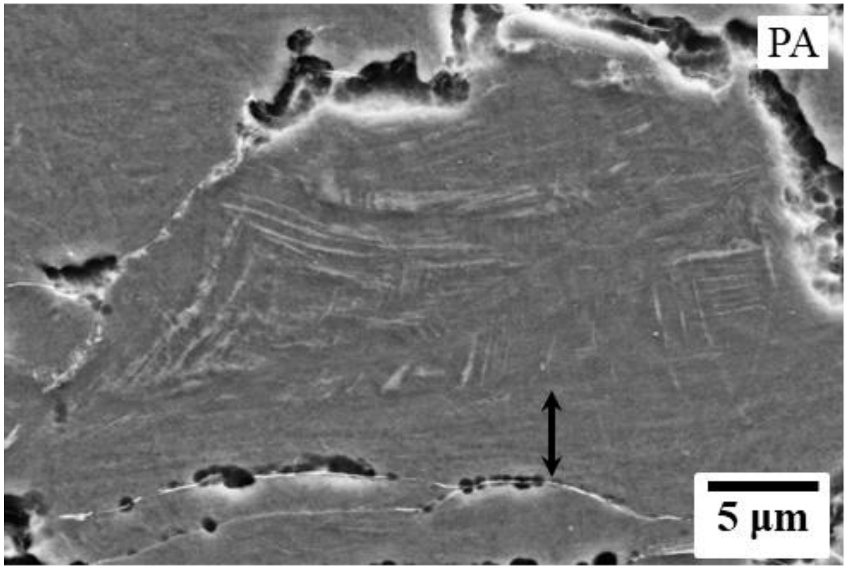
- Cold sprayed particle characterized by two different microstructures.
  - As-received powder microstructure away from particle interface.
  - Elongated and fine scale β precipitates near the particle interface.
  - β precipitates perpendicular to deposit direction near particle interface.

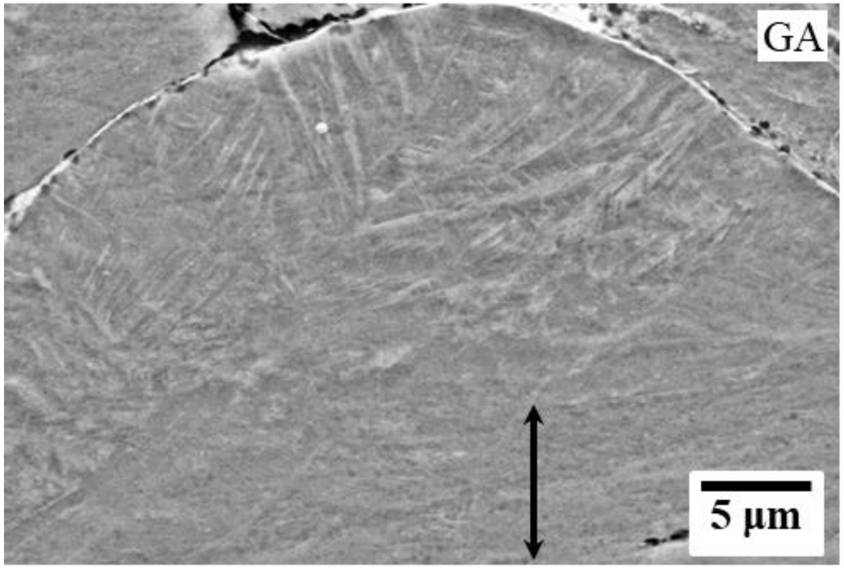
Cold Spray Coating Characterization



- Substrate microstructure is characterized by equiaxed alpha with intergranular beta precipitates similar to HDH powder.
- Embedded Al_2O_3 seen due to grit blasting prior to deposition.

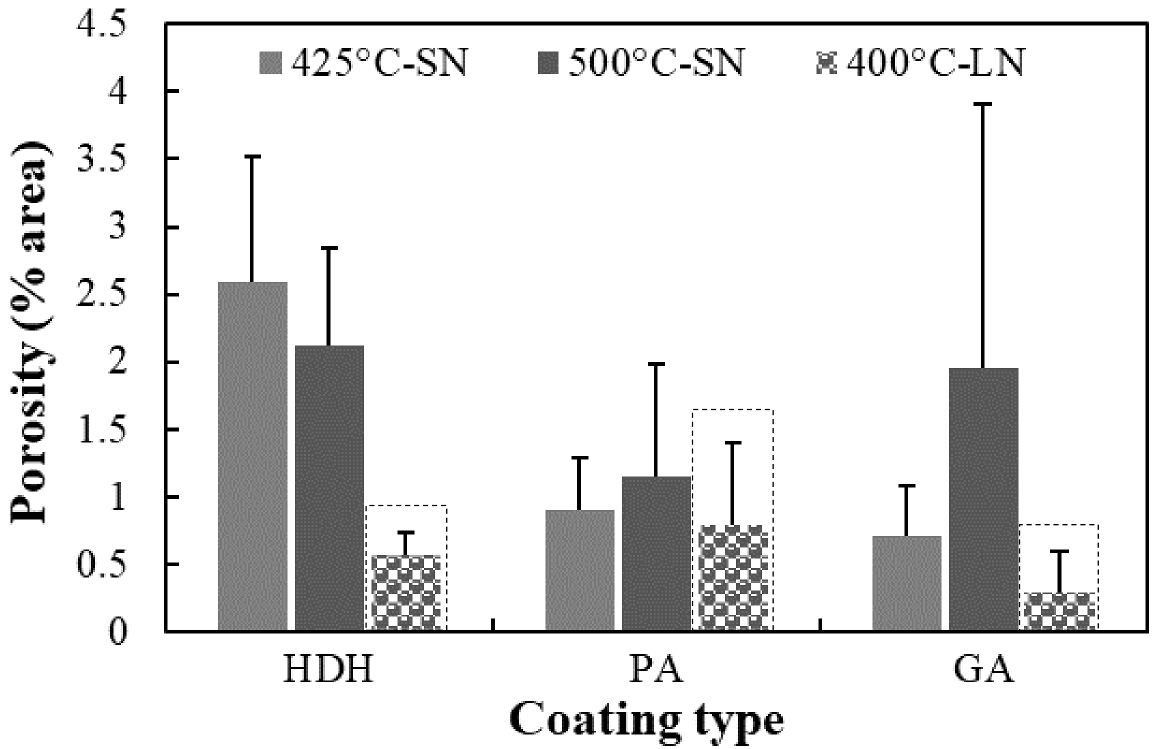
Cold Spray Coating Characterization





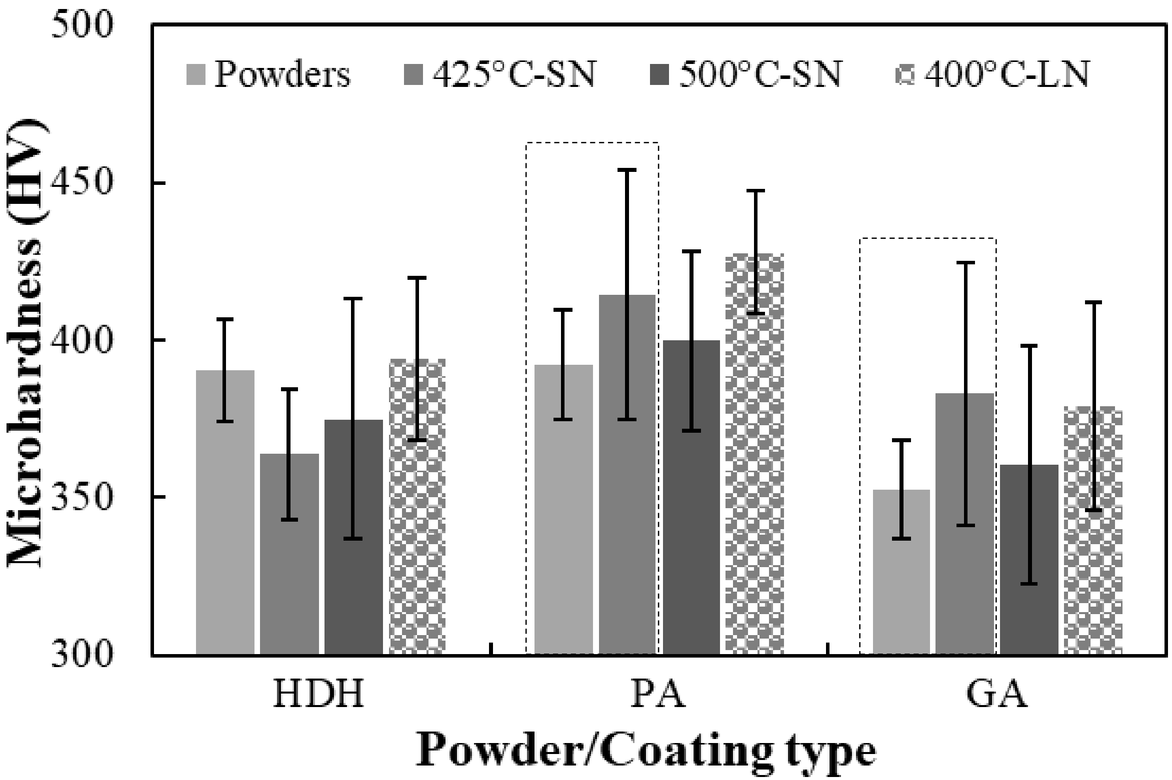
- Cold sprayed particle characterized by two different microstructures.
  - As-received powder microstructure with some lath distortion away from particle interface.
  - Featureless microstructure near particle-particle interface.

Porosity Comparisons



- Increase in nozzle length resulted in a decrease in porosity for all powder types.
  - Increase in particle velocity largely responsible for the behavior.

Hardness Comparisons

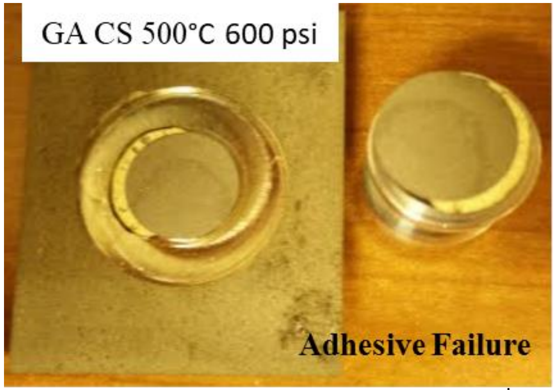


- Cold sprayed coatings in general have higher hardness than powders due to strain hardening and introduction of compressive residual stresses.
- An increase in porosity resulted in a decrease in microhardness.

Bhattiprolu, V.S. et al. (2018). Surf. Coat. Technol. (335) 1-12

Adhesion Test Calculations

Automatic PosiTest instrument used for pull off adhesion tests[1]



ASTM Standard D 4541

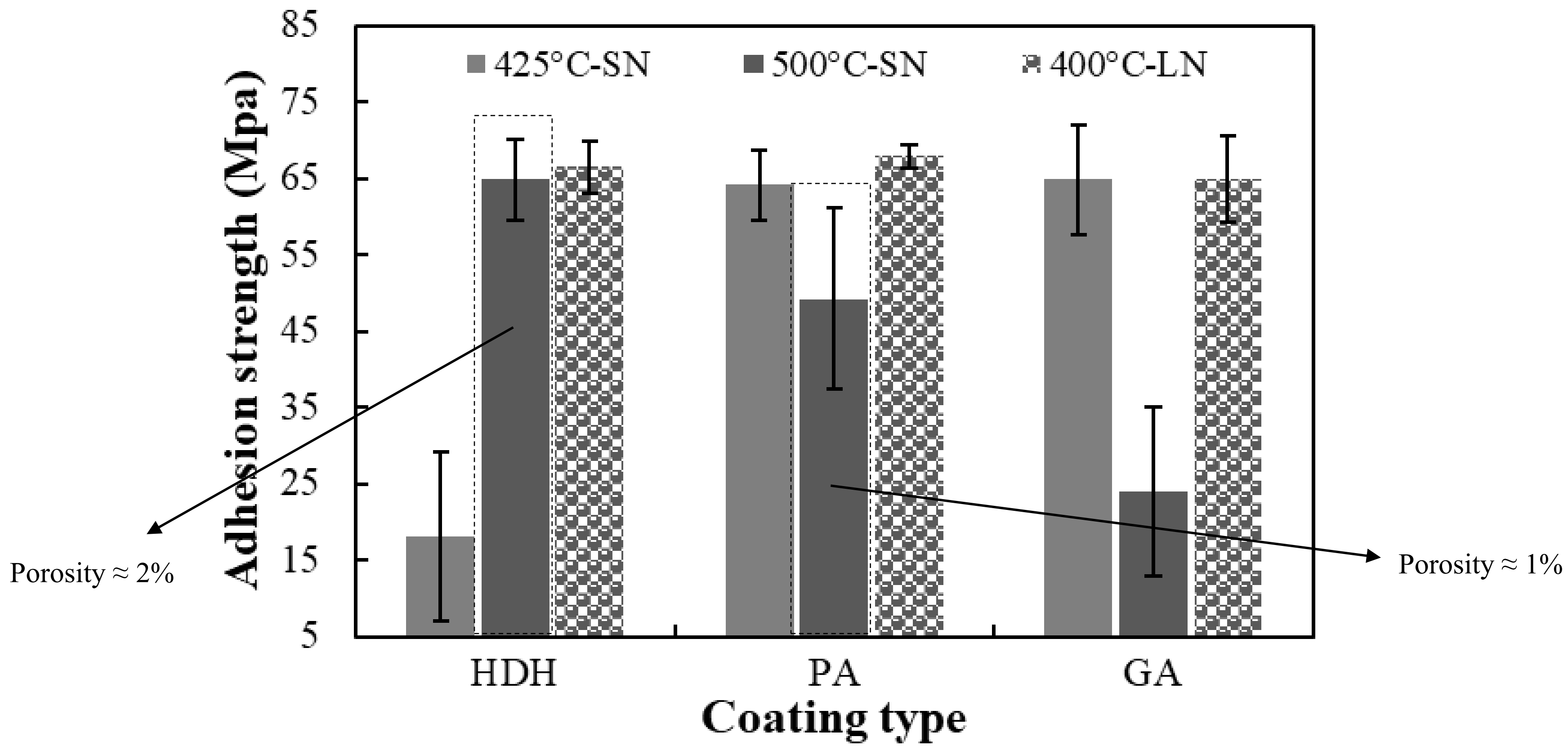
Glue Failure: Adhesion strength > 69 MPa

Adhesive Failure (Adhesive Coating Failure): Failure at Coating/Substrate interface

	425°C -SN	500° C-SN	400°C-LN
GA	Glue	Adhesive	Glue
PA	Glue	Adhesive	Glue
HDH	Adhesive	Adhesive	Glue

1. PosiTest AT-A. (2017). http://www.defelsko.com/adhesion-tester/positest

Adhesion Test Comparisons



- Dual phase microstructure of HDH powder resulted in enhanced adiabatic shear instability resulting in high adhesion of particles.
- Increase in particle velocity due to utilization of long nozzle resulted in high adhesion strengths.

Conclusions

- Feedstock powders have microstructures appropriate to their processing temperatures and conditions.
- Cold sprayed coatings retain as-received powder microstructure.
- Particle velocities significantly influence deposition quality/properties.
- All cold sprayed coatings demonstrate high deposition quality with porosities reaching as low as 0.3%.
- Long nozzle cold sprayed coatings depicted the best coating properties with low porosity and high adhesion strength.
- Cold spray process shows promising potential as a repair application for Ti-6Al-4V components

Future Work

- Cold spray processing of HDH, PA and GA coatings using N_2 gas.
- Investigations on effect of different powder blends on Ti-6Al-4V cold sprayed deposition quality/properties using N_2 gas.
- In depth microstructure characterization of Ti-6Al-4V cold sprayed depositions using TEM.

Acknowledgements

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Questions