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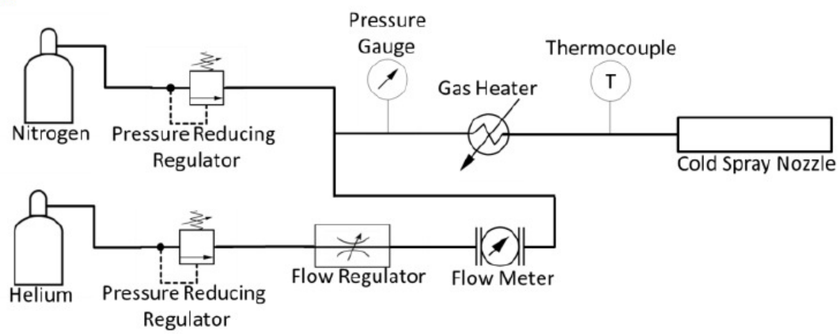
Practical Implementation of Helium-Nitrogen In-Line Gas Mixing for Enhanced Cold Spray Performance and Cost Optimization

Julio Villafuerte, Wally Birtch

He 4 g/mol

N_2 28 g/mol

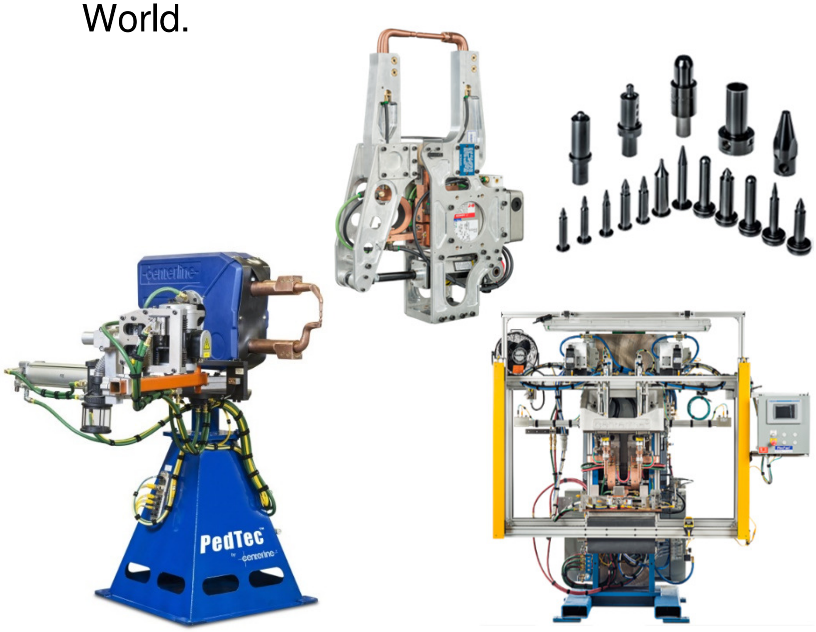


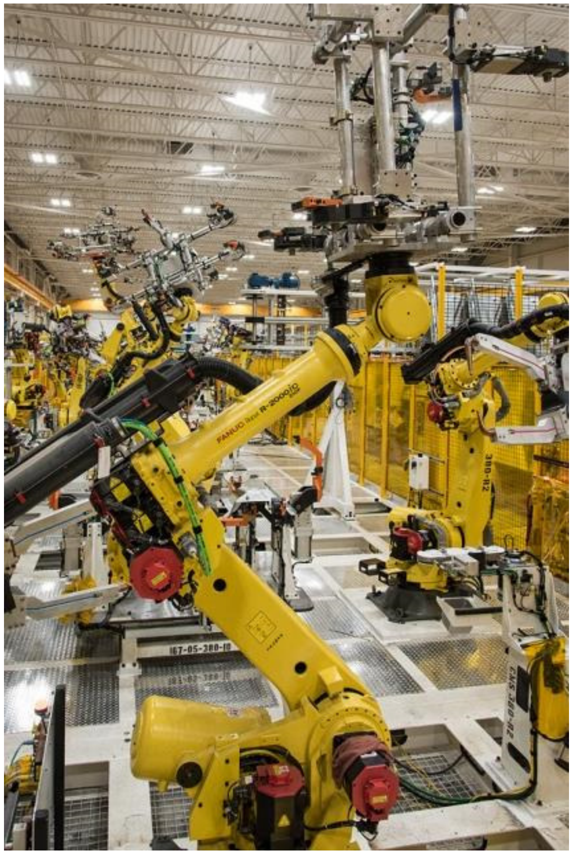
Content

1. **About CenterLine**
2. Review a Mixed Gas study by University of Ottawa
3. Review a Mixed Gas Study by ES3 for the NAVSEA, NAVAIR, USMC Implementation
4. Further savings with a low-pressure N2-He mixing gas management system
5. Summary of Economical advantages of N2-He mixing

CenterLine since 1957

- Design & manufacture of automated welding, metal forming, configured machinery solutions, resistance welding guns, presses, and resistance spot welding consumables for the Auto Industry in the World.





centered on solutions

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Supersonic Spray Technologies (SST) Division since 2003

- Full range of SST patented standard cold spray units
- Turnkey SST Cold Spray Systems
- SST Cold Spray grade Powders
- SST Spare parts, Consumables, and support
- Process development and Qualification
- Job shop services

Helium

- Triple supersonic gas jet velocity compared to Nitrogen due to its lower molecular weight
- Enhance deposition efficiency and overall cold spray deposit properties
- Make it easier to spray hard materials at low pressures and temperatures
- **high cost and limited availability**
- **Helium Recovery: capital-intensive $$$**
- **Helium Recovery: effective if there is at least a 50% helium concentration in the spray Chamber**
- **Helium Recovery: Hard to justify with portable cold spray**

He=4 g/mol

N_2 = 28 g/mol

Helium – Nitrogen Mixing

- ✓ **Does a mixed down He gas perform better than N_2 ?**
- ✓ **Does the mix reflect on real Gas savings?**
- ✓ *Previous gas mixing research, the gas is always premixed in containers at set ratios, thus limiting gas mixing to laboratory scale spray trials and complex mixing operations*

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Mixed Gas Study at University of Ottawa

Peer Reviewed, ASM Springer JTST, vol 28, pages 161–173, (2019)

An Economical Approach to Cold Gas Dynamic Spraying using In-Line Nitrogen-Helium Blending

Daniel MacDonald, S. Rahmati, Bert Jodoin , Wally Birtch

- Developed a method to mix Helium and Nitrogen in-line capable of blending nitrogen and helium at user-defined ratios
- Conducted the study, measuring particle velocity, deposition efficiency, and coating properties
- Developed a preliminary cost model to identify the best nitrogen-helium ratios for specific materials

Mixed Gas Study at University of Ottawa

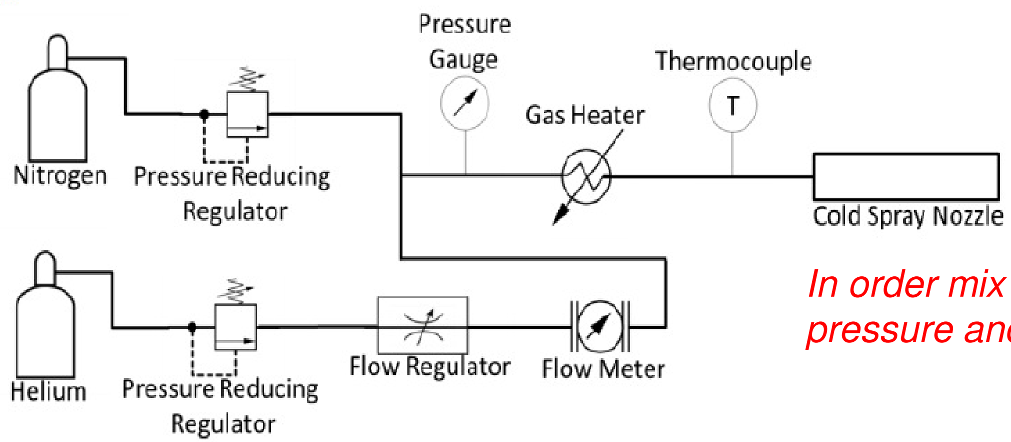
- Throat size: 2.0 mm
- Pressure: 20 to 35 bar*
- Temperature: 550 C
- Powder flow Rate: 31 g/min (15-5 PH SS)
  10 g/min (Al / SST-A5001)
- Standoff Distance 10 mm
- Heater Energy 15 KW
- Tank Min Pressure N_2 48 bar
- Tank Min. Pressure He 52 bar
- Travel speed 5-25 mm/s

* *pressure was varied to maintain constant temperature of 550C at constant 15KW heater power*

35 bar – 15 KW 650C

Particle Velocity: Tecnar ColdSprayMeter eVOLUTION

Mixed Gas Study at U of Ottawa



In order mix in-line at controllable ratios, both the pressure and flow rates were carefully regulated

@ 500 psi / 35 bar

Percentage helium, vol.%	Helium flow rate (SCFM)
0	0
25	8.2
50	19.5
75	37.6
100	80.9

He %	Sonic Velocity (m/s)
0	534
25	852
50	1088
60	1170
75	1286
100	1461

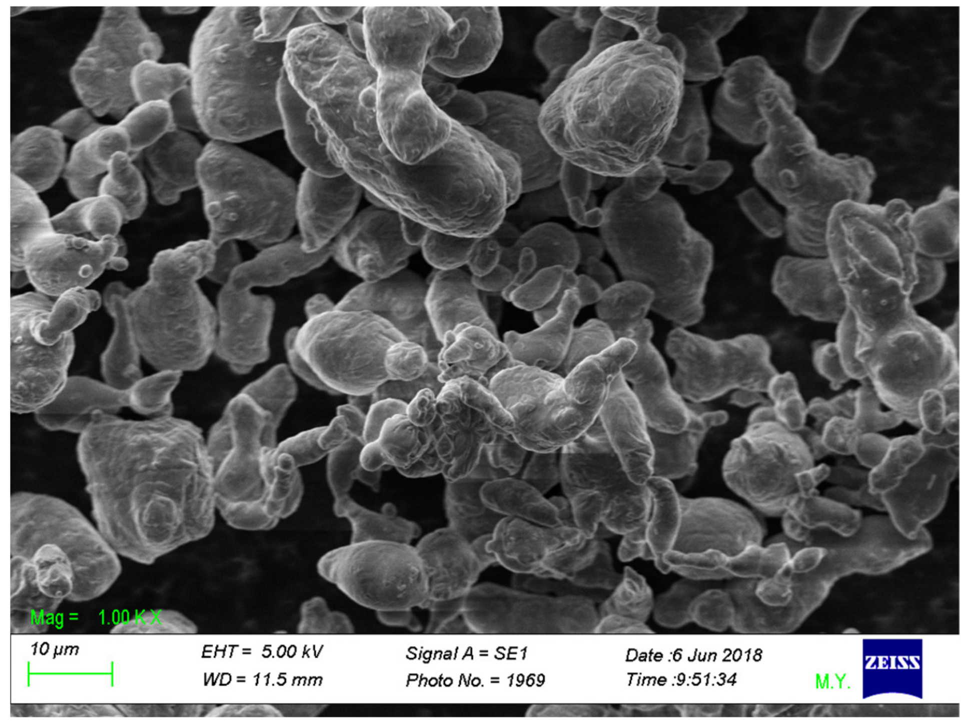
Mixed Gas Study at University of Ottawa

Materials

Powder	Substrate	Surface Prep
Aluminum (SST A5001)	A6061-T6 substrate	Acetone cleaned
15-5 PH Martensitic / Precipitation Hardening SS (Sandvik Osprey®)	AISI1020 substrate	Acetone, Grit blast, scrubbing

Mixed Gas Study at University of Ottawa

- **SST-A5001** (Al 99.5%) (CenterLine, Canada)
- The particle size distribution (by sieving): -45µm to +5µm
- Cost $35.00/lb



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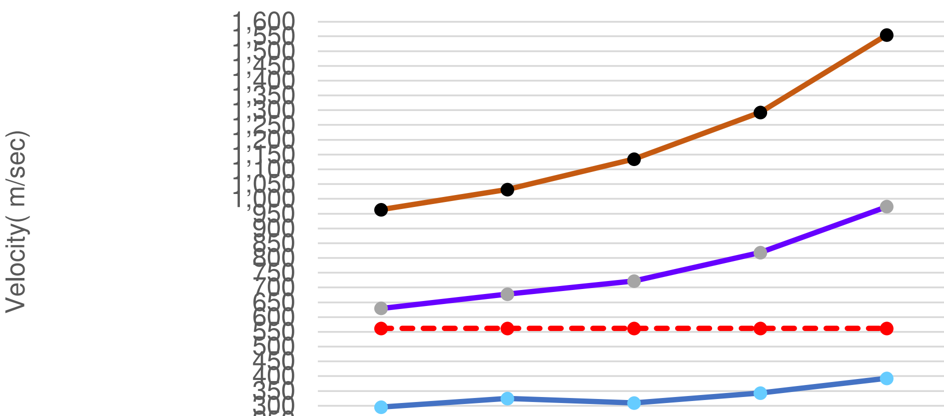
Mixed Gas Study at University of Ottawa

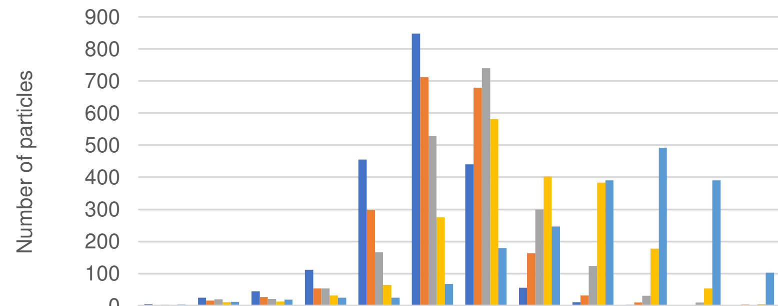
Particle Velocity Measurements – 99.5% Al

SST-A5001 Pure Al Particle Velocity



	0% He	25% He	50% He	75% He	100% He
+ 3 Sigma	963	1,032	1,135	1,293	1,555
Mean	629	678	722	818	974
- 3 Sigma	295	324	310	343	393
Approximate Critcal Velocity	562	562	562	562	562

SST-A5001 Pure Al Distribution by Velocity



	# particles 100's M/sec	# particles 200's M/sec	# particles 300's M/sec	# particles 400's M/sec	# particles 500's M/sec	# particles 600's M/sec	# particles 700's M/sec	# particles 800's M/sec	# particles 900's M/sec	# particles 1000's M/sec	# particles 1100's M/sec	# particles 1200's M/sec
0% He	5	25	45	112	455	848	440	56	11	3	0	0
25% He	0	16	27	54	299	712	679	164	32	10	2	4
50% He	3	20	21	54	167	528	740	300	124	31	10	2
75% He	0	11	13	32	65	276	581	402	383	178	54	5
100% He	4	12	19	25	25	68	180	247	390	492	390	103

Particle Velocity

The Mean and the Standard of Deviation was calculated based on 2000 particles measured

Mixed Gas Study at University of Ottawa

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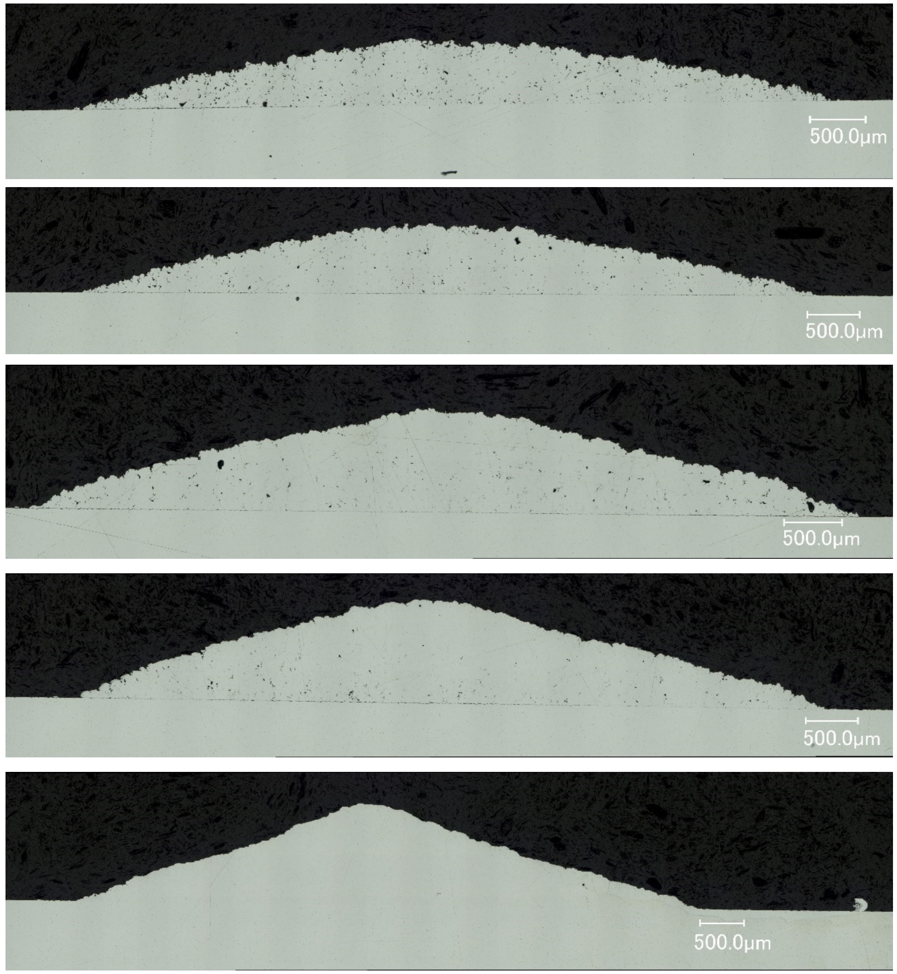
Al (SST-A5001)



% Porosity

0 % He 1.85%

25 % He 1.32 %

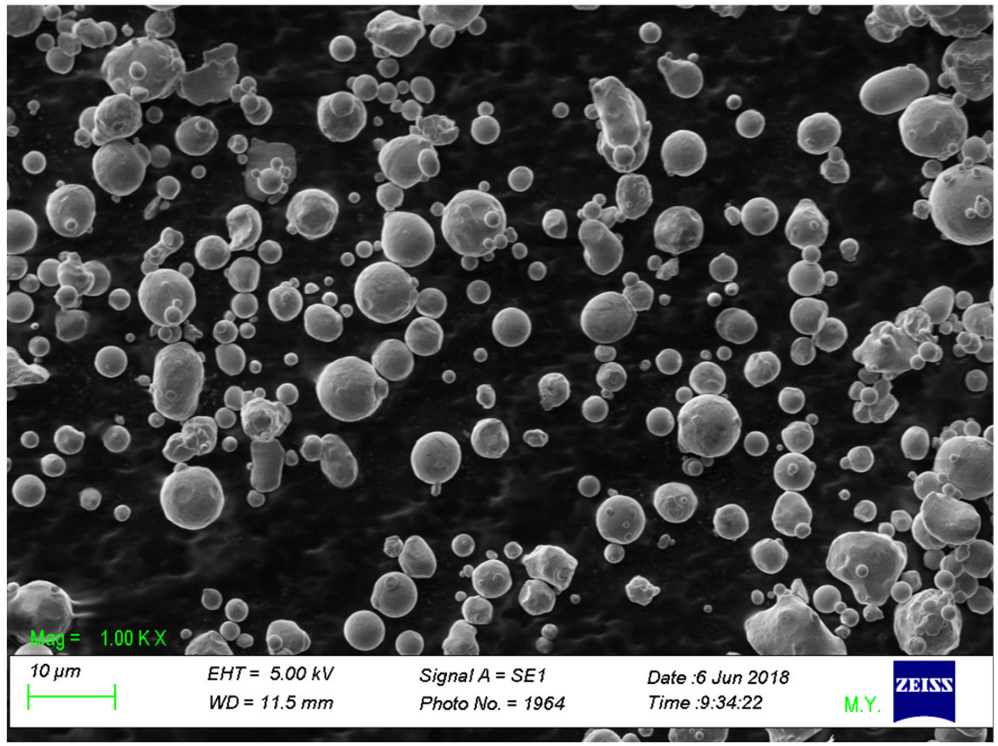
50 % He 0.55 %

75 % He 0.22 %

100 % He 0.00 %

Mixed Gas Study at University of Ottawa

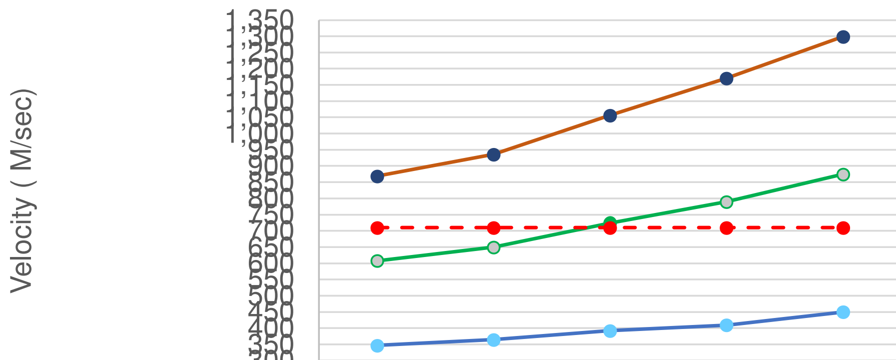
- **15-5PH Precipitation Hardening SS** (16.18%Cr - 4.45%Cu - 3.66%Ni - 1.47%Si) (Sandvik Osprey®, UK)
- The particle size distribution: (by laser diffraction):
  - d10=3.2µm
  - d50=5.7µm
  - d90=9.7µm
- Cost : $95.00/lb



Mixed Gas Study at University of Ottawa

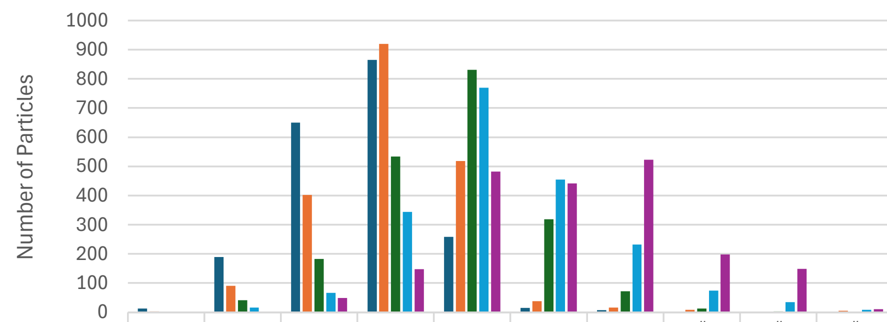
Particle Velocity Measurements – 15-5 PH SS

15-5 SS Particle Velocity



	0% He	25% He	50% He	75% He	100% He
Mean	608	650	724	790	875
+ 3 Sigma	869	936	1,056	1,171	1,299
- 3 Sigma	347	364	392	410	450
Aprox. Calculated Critcal Velocity	710	710	710	710	710

15-5 SS Particle Distribution by Velocity

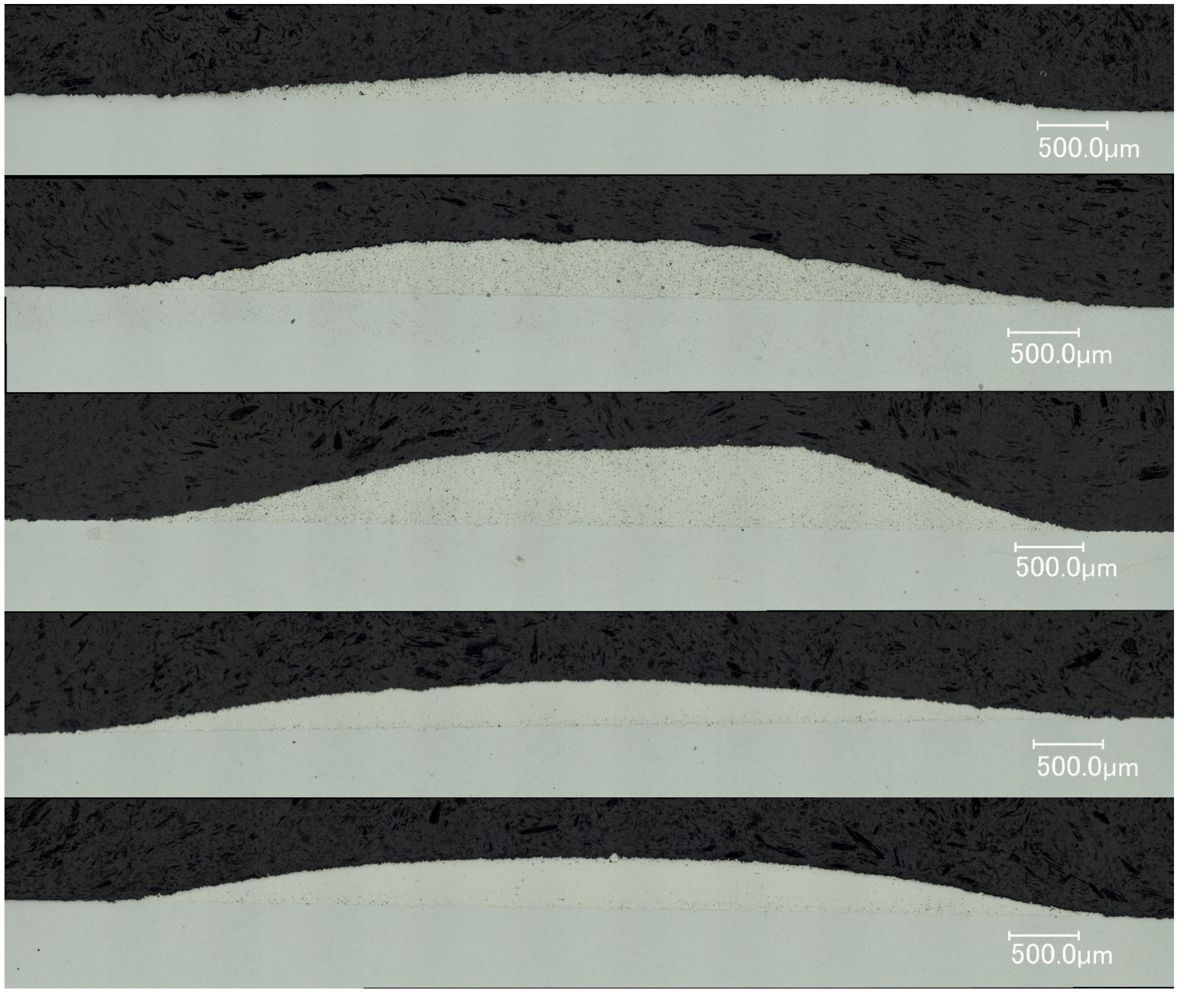


	# particles 300's M/sec	# particles 400's M/sec	# particles 500's M/sec	# particles 600's M/sec	# particles 700's M/sec	# particles 800's M/sec	# particles 900's M/sec	# particles 1000's M/sec	# particles 1100's M/sec	# particles 1200's M/sec
0 % He	13	189	650	865	258	15	7	2	0	0
25 % He	3	90	402	920	518	38	16	8	0	5
50% He	0	41	183	534	831	319	72	13	3	0
75% He	0	16	66	344	770	455	232	74	34	8
100% He	0	0	49	147	482	441	523	198	149	10

Particle Velocity

The Mean and the Standard of Deviation was calculated based on 2000 particles measured

15-5PH SS



% Porosity

0 % He 1.52 %

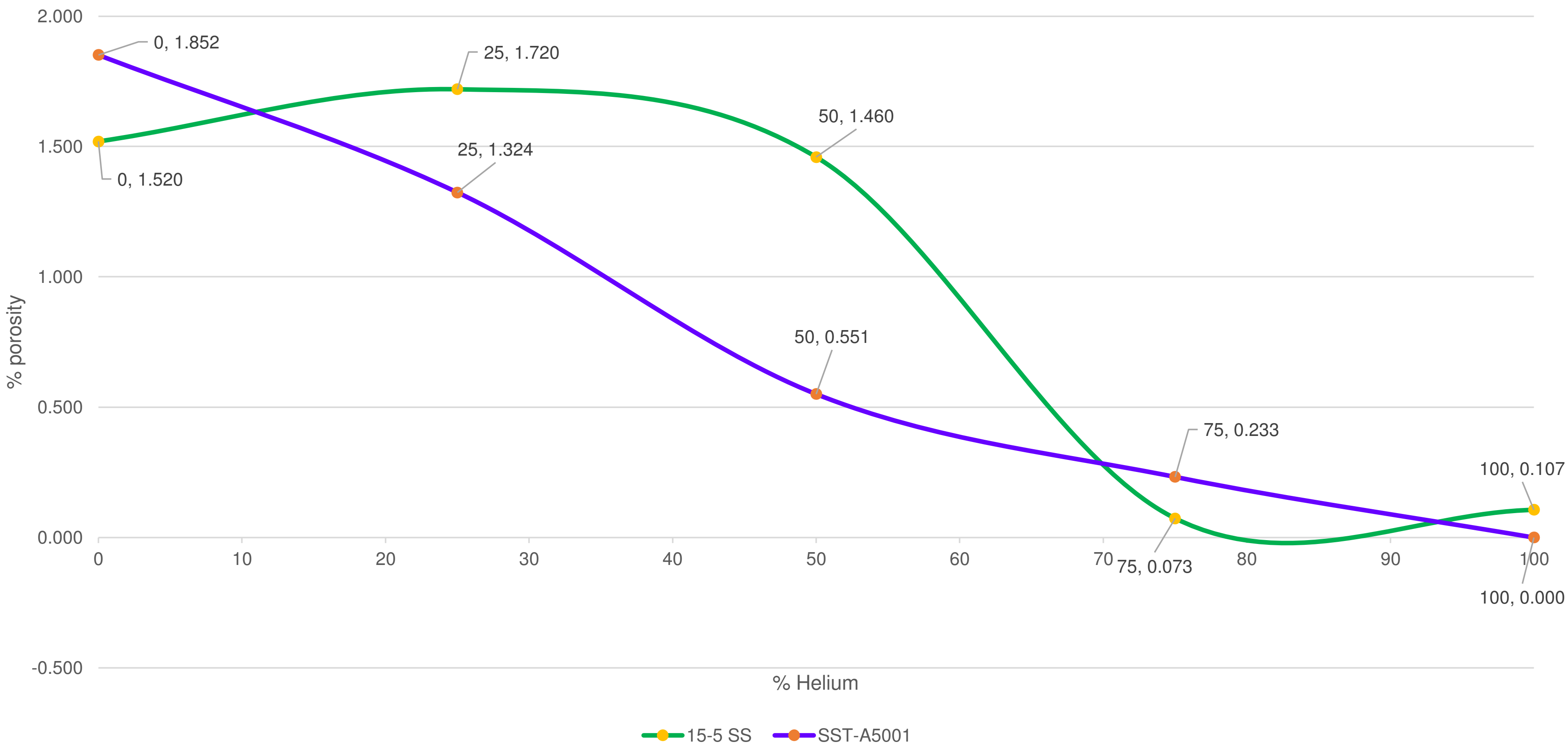
25 % He 1.72 %

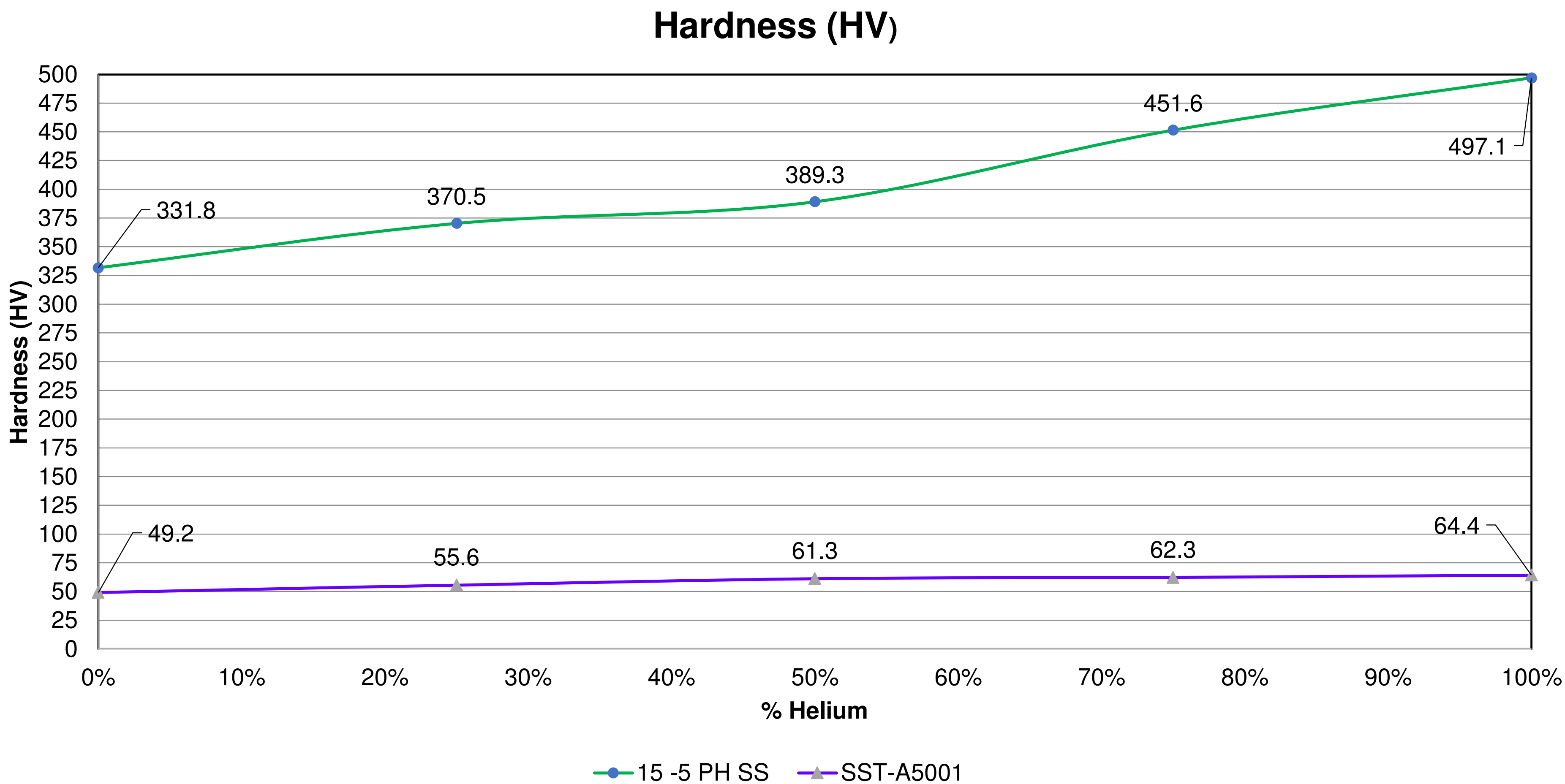
50 % He 1.46 %

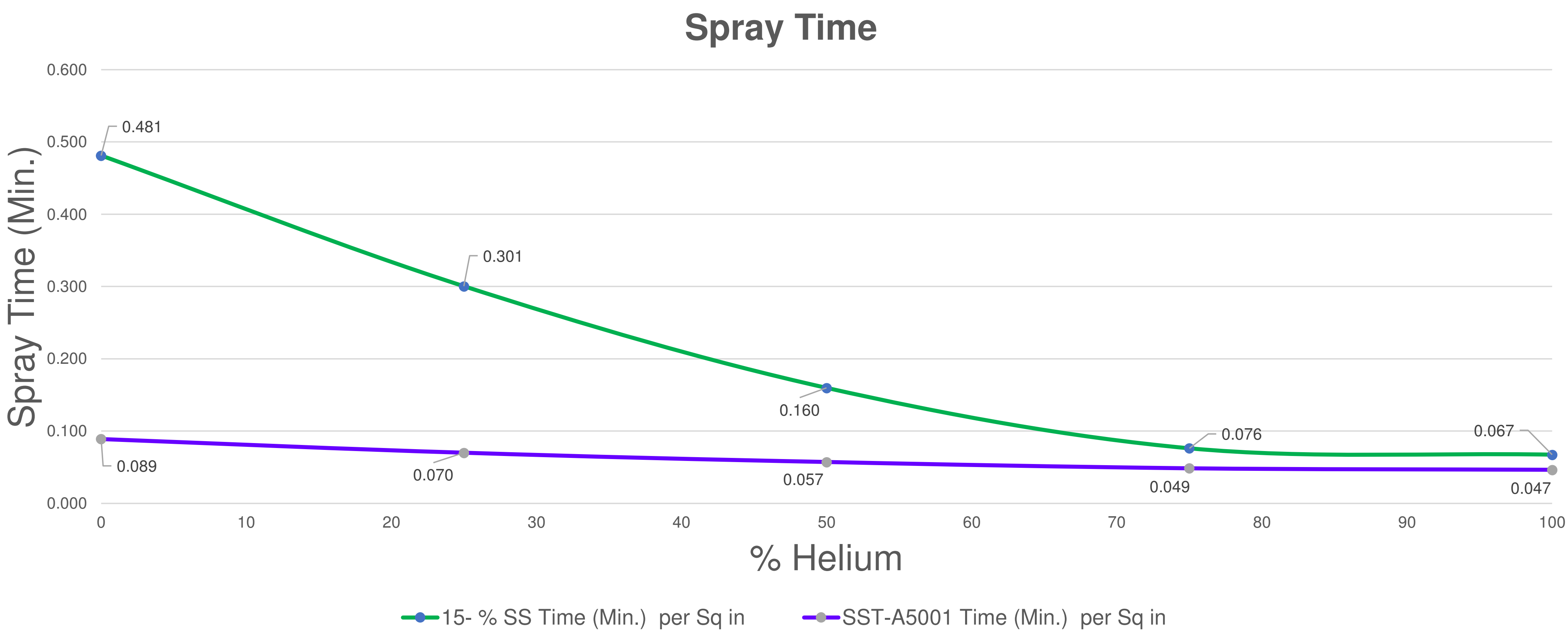
75 % He 0.07 %

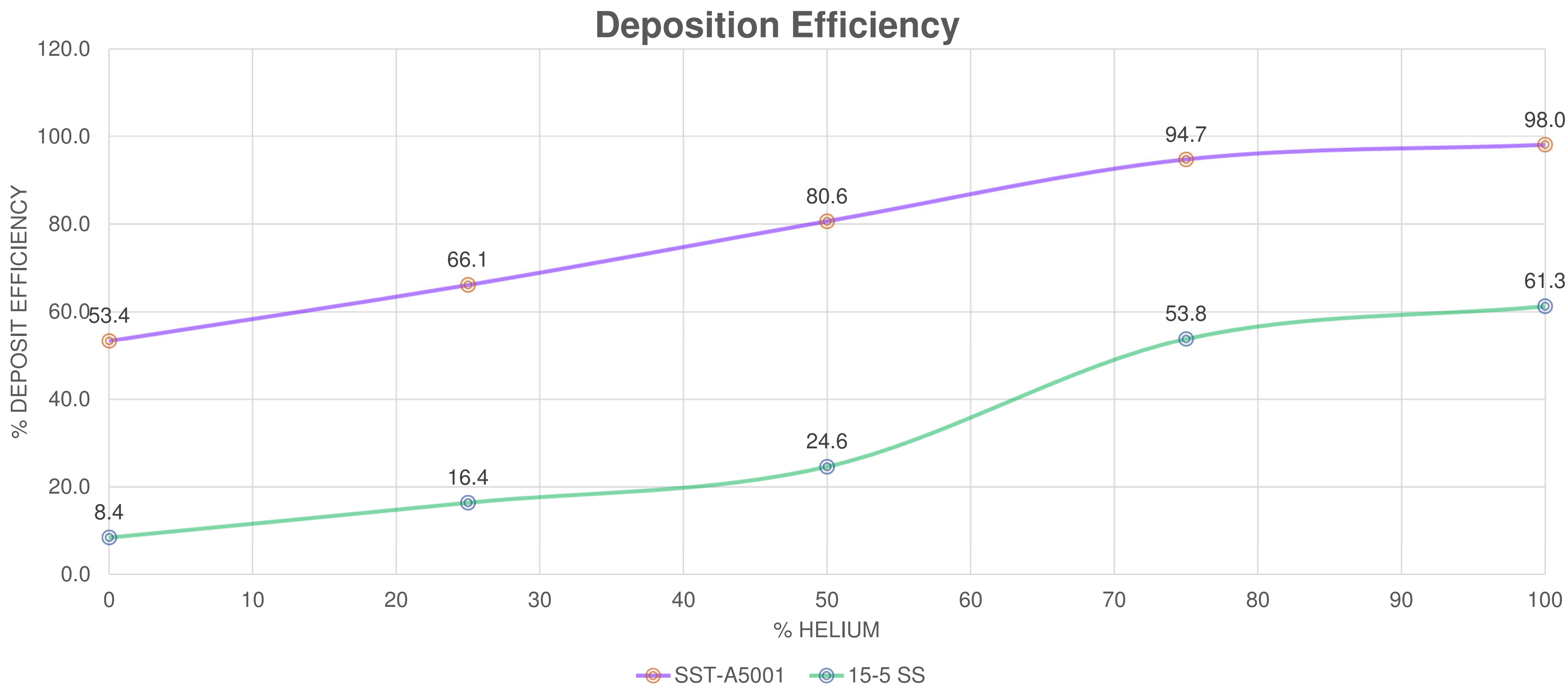
100 % He 0.11 %

Optical Porosity % from Coating Cross sections




Hardness (HV)
Hardness (HV)
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Helium
331.8
370.5
389.3
451.6
497.1
49.2
55.6
61.3
62.3
64.4
15 -5 PH SS
SST-A5001


Spray Time
Spray Time (Min.)
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.481
0.301
0.160
0.076
0.067
0.089
0.070
0.057
0.049
0.047
0
10
20
30
40
50
60
70
80
90
100
% Helium
15- % SS Time (Min.) per Sq in
SST-A5001 Time (Min.) per Sq in


Deposition Efficiency
% DEPOSIT EFFICIENCY
% HELIUM
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
10
20
30
40
50
60
70
80
90
100
53.4
66.1
80.6
94.7
98.0
8.4
16.4
24.6
53.8
61.3
SST-A5001
15-5 SS

Initial Cost Model

Assumption: coating quality attributed (porosity and hardness) are adequate for the specific application under all deposition conditions

The cost of the deposited powders is calculated if the DE as a function of helium percentage is known

C = P + HC + NC + LC + EC

C is the cost per Sq In/.010” Thickness of coating deposited

PC is the total cost of powder used

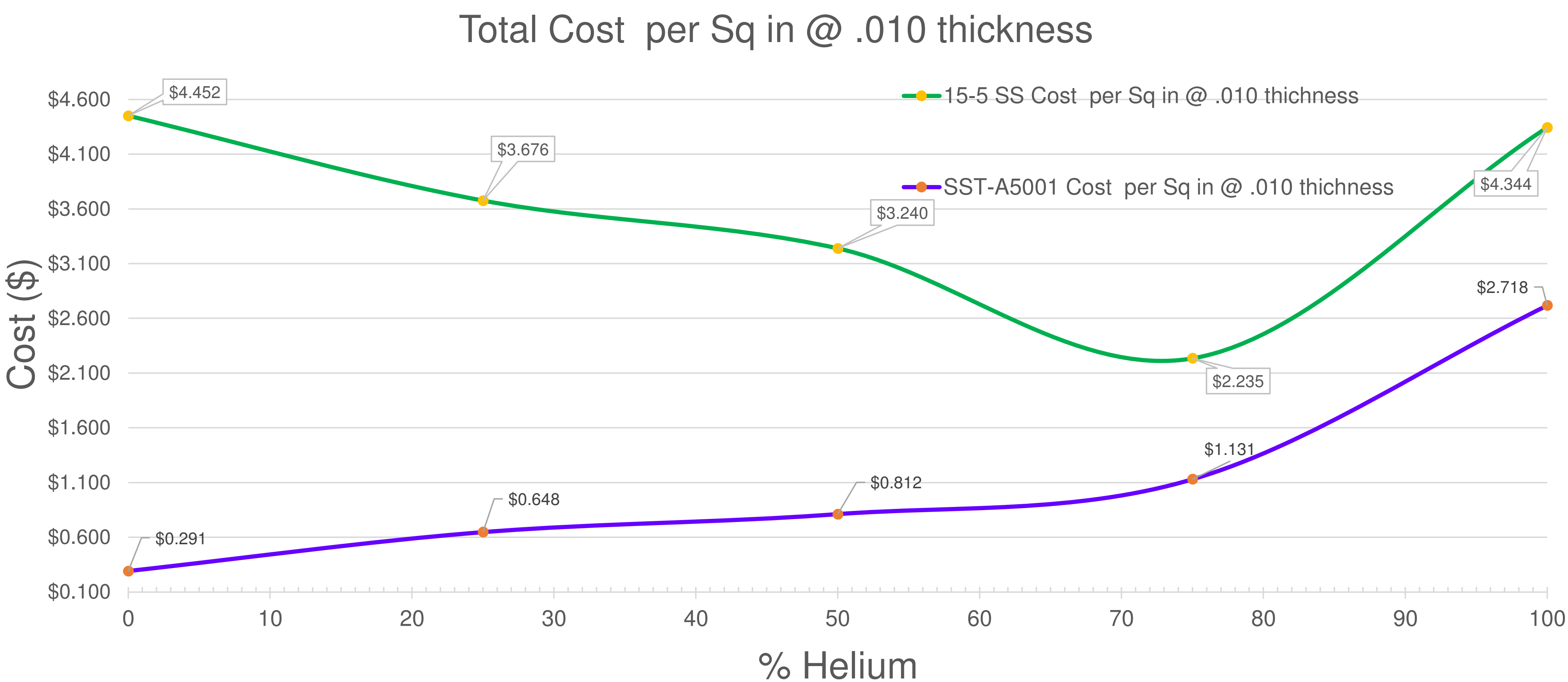
HC total cost of Helium used

NC total cost of Nitrogen used

LC total labor cost

EC total electricity cost

Symbol	Descrip	Cost
HC	Helium	$0.92/cuft
NC	Nitrogen	$0.04/cuft
P	Aluminum	$35/lb
P	15-5PH SS	$95/lb
LR	Labour rate	$75/hr
ER	Electricity rate	$0.20/KWHr


Total Cost per Sq in @ .010 thickness
15-5 SS Cost per Sq in @ .010 thichness
SST-A5001 Cost per Sq in @ .010 thichness
Cost ($)
% Helium
$4.600
$4.100
$3.600
$3.100
$2.600
$2.100
$1.600
$1.100
$0.600
$0.100
0
10
20
30
40
50
60
70
80
90
100
$4.452
$3.676
$3.240
$2.235
$4.344
$0.291
$0.648
$0.812
$1.131
$2.718

U Ottawa Summary

Justification for Using Nitrogen/He Mixture, when:

✓Powder Material costs are high
✓Nitrogen Deposition Efficiency is low

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ES3 Study for NAVSEA, NAVAIR, USMC Implementation

- Improvements made to the mixing delivery system hardware to:
  - (a) increase volume mixing flexibility between He and N_2
  - (b) increase flow capacity, and
  - (c) implement more automation
- Validated cold spray coatings for nitrogen/mixes on multiple substrates using three commercial cold spray systems – this report only contemplates results with the VRC Gen III system
- Coatings must meet fit, form, and function requirements to restore parts for routine operation, including corrosion and wear resistance

ES3 Study for NAVSEA, NAVAIR, USMC Implementation

Increased Flow Meter Capacity:

- **Two separate outlet ports: one at 700 PSI and one at 200 PSI.**
- **Human-Machine Interface (HMI) & Fully Automated Controls**

Gas Mixing Delivery System Flow Rates:

- **Designed around unique spray characteristics of**
  - **VRC (high pressure),**
  - **Centerline (mid and low pressure)**
  - **Inovati Cold Spray Systems (low pressure)**

ES3 Study for NAVSEA, NAVAIR, USMC Implementation

VRC Gen III

- The baseline tests for the SAAM-AL7075- G1H1 powder with 100% helium

ES3 Study for NAVSEA, NAVAIR, USMC Implementation

Materials

Powder	Substrate	Surface Prep
Solvus SAAM-7075AL-G1H1	A7075-T6 substrate	Grit blasted and Alcohol Wipe
Solvus SAAM-7075AL-G1H1	A6061-T6 substrate	Grit blasted and Alcohol Wipe

ES3 Study for NAVSEA, NAVAIR, USMC Implementation

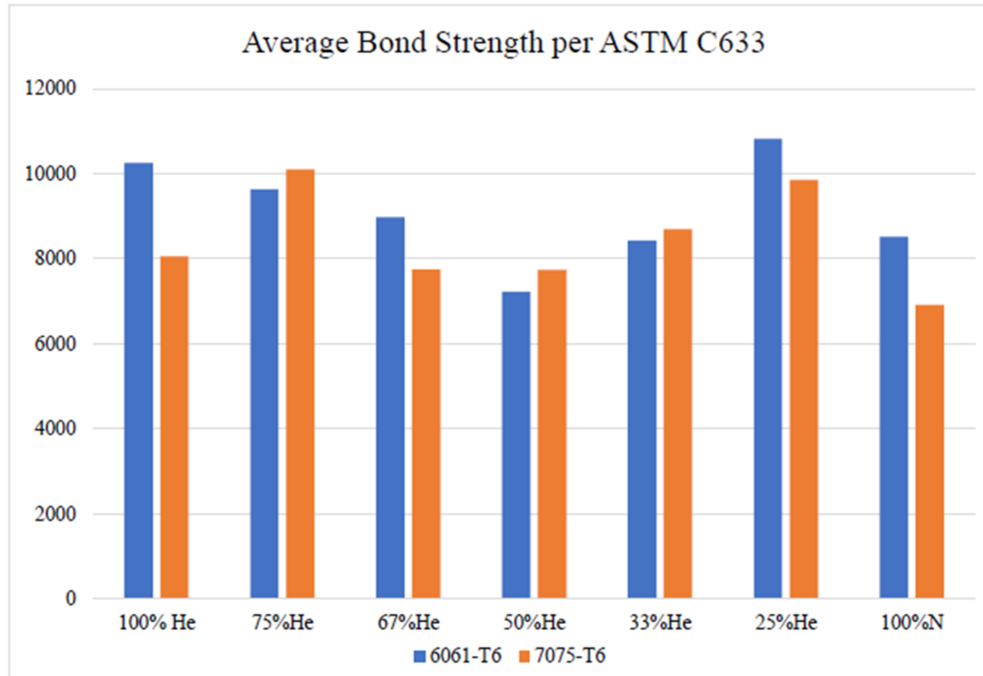
For the materials tested, a mixture of Helium and Nitrogen may achieve equivalent coating performance characteristics as 100% He

Overall Best Mixes for all categories:

- 25% N_2 - 75% He
- 33% N_2 – 67% He

Overall Worst Mixes:

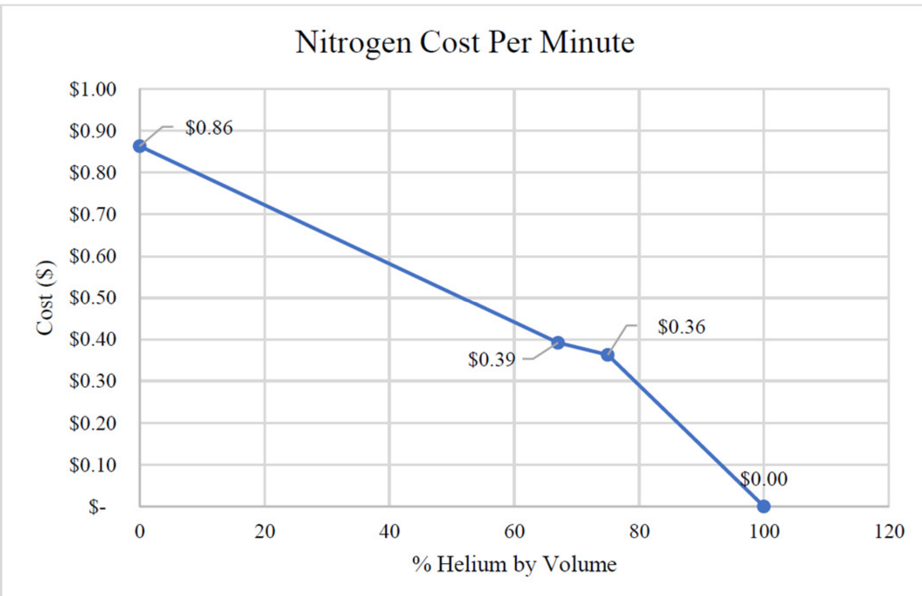
- 50%N_2-50%He
- worse than 25%N_2/75%He
- varied significantly from each spray run

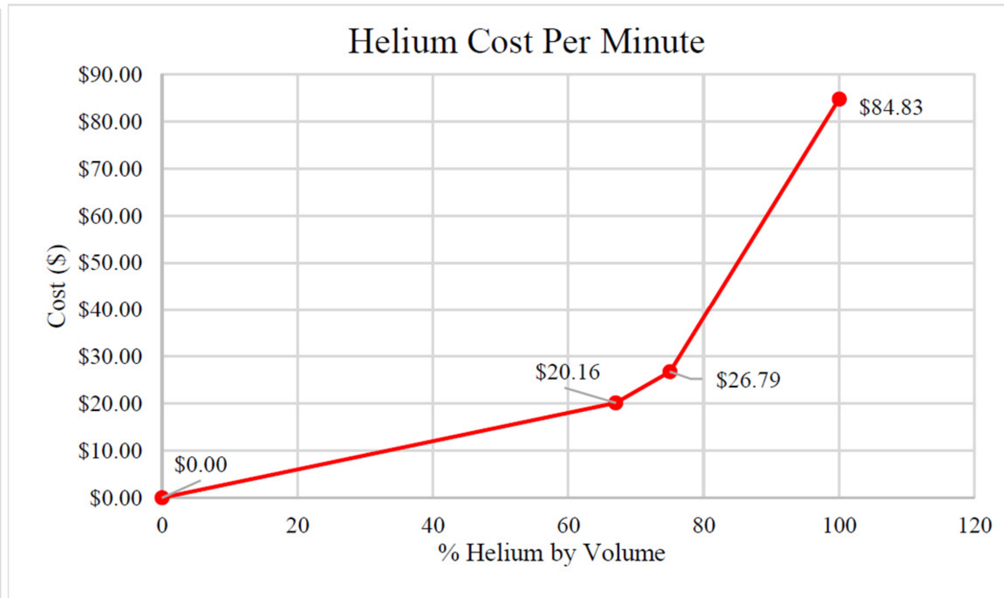


ES3 Cost Analysis

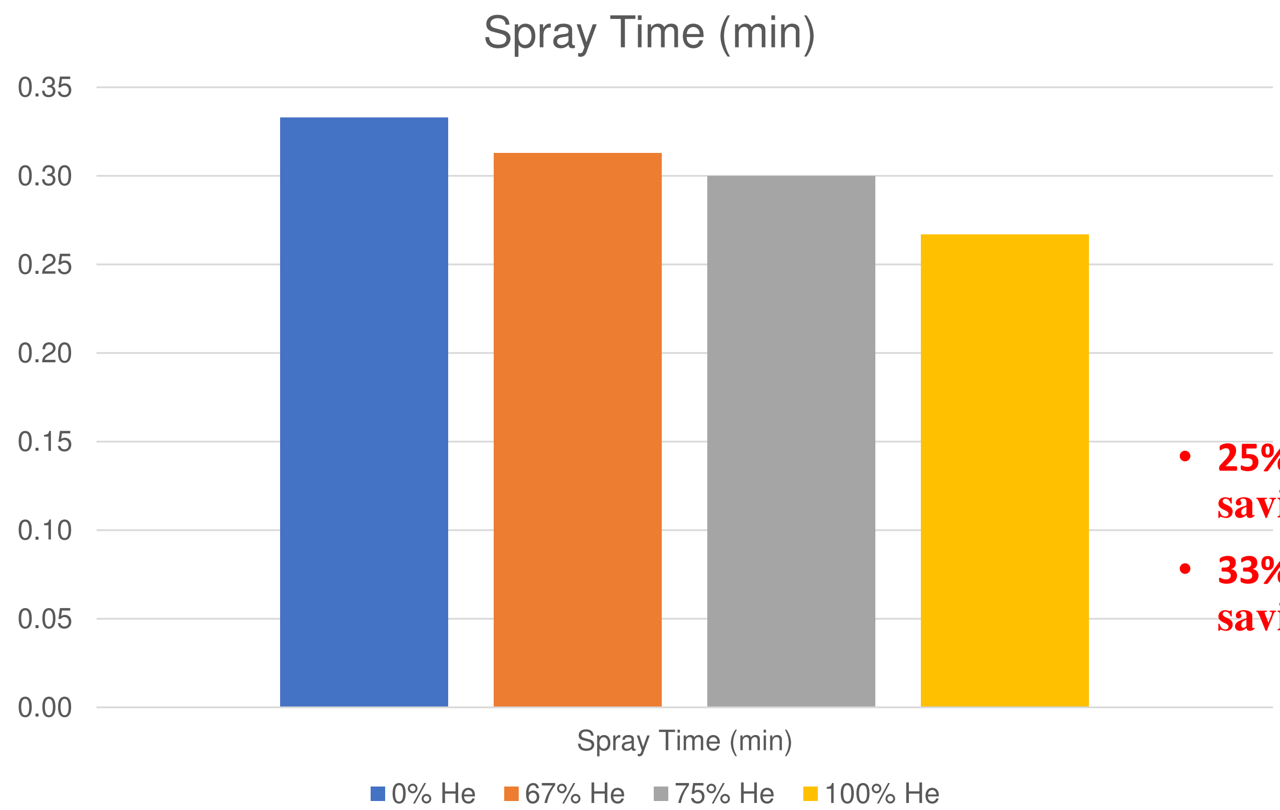
Gas Cost per Minute

VRC Gen III
12-pack cost
nozzle characteristics
Spray parameters
Gas flow rate
gas cost per CF





ES3 Cost Analysis



Spray time : to deposit a 0.015-0.018-inch-thick coating with the Solvus SAAM-7075AL-G1H1 aluminum powder on a square-inch area

- **25%N_2-75%He provides 68% cost savings compared with 100% He**
- **33%N_2-67%He provides 76% cost savings compared with 100% He**

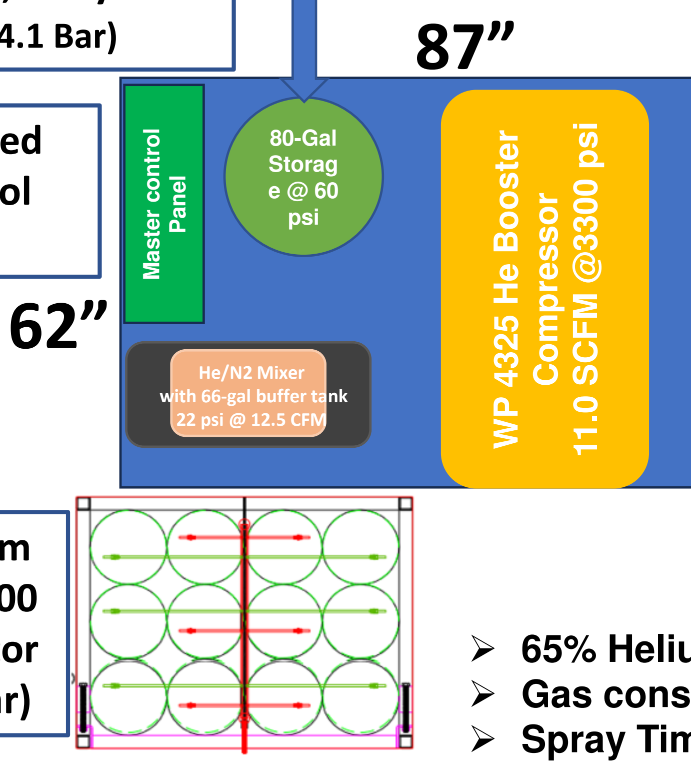
Content

Proposed Layout for N_2 and He/N_2 Supply

Nitrogen Source Whether it be Nitrogen Generator , Tube Truck, Liquid to Gas, or Cylinder packs set at 60 psi (4.1 Bar)

This process allow you to use 97.5% of the gas in the Supply containers at 2400 psi (166 Bar)

Gas Analyzer included in the Master Control panel



12 or 16 pack Helium Tanks @ 2400 to 2600 psi with exit regulator set to 60 psi (4.1 Bar)

3300 psi 16 pack of cylinders with 7570 CF of usable N2 at 625 psi(43 Bar) → To Cold Spray Equipment

3300 psi 16 pack of cylinders with 7,570 CF of usable N2/He at 625 psi(43 Bar) → To Cold Spray Equipment

- 65% Helium /35% Nitrogen
- Gas consumption 22.17 SCFM of N2 65% He /35% N_2
- Spray Time per fill with out the compressor running (7,637/22.17)/60=5.75Hrs

Cost Analysis of 15-5 PH SS Based on U of Ottawa Data with Low-Pressure Mixer

The Chart below is utilizing the Max. Heater capacity of 15 Kw to maintain 550 °C

At 60 PSI Helium Min Tank Pressure

Gas	Gas Pressure (psi)	Sonic Velocity (m/s)	Flow rate SCFM	Gas Cost/ min. @60 psi tank supply	% cost savings to He cost	% Velocity to He Velocity	Measured 15-5 PH SS Mean Particle Velocity (m/s)	% Particle Velocity to He Particle Velocity	Gas Saving per Hr. versus 100% He	Gas & Powder Cost per Sq in @ .010 thichness	% cost savings to He cost	DE	Time (Min.) per Sq in @ .010 thichness	Burdened Labor@ $75/hr. Cost per Sq in @ .010 thichness	Total Cost per Sq in @ .010 thichness	% cost savings to He cost
He 100%	370	1,461	60.24	$56.35			875			$4.26		62.0%	0.067	$0.084	$4.344	
He 75% N_2 25 %	290	1,286	29.71	$21.14	62.48%	88.02%	790	90.29%	$2,112.48	$2.14	49.77%	53.0%	0.076	$0.095	$2.235	58.79%
He 50% N_2 50 %	310	1,088	24.67	$12.03	78.65%	74.47%	724	82.74%	$2,659.08	$3.04	28.64%	25.0%	0.160	$0.200	$3.240	40.27%
He 25% $N_2$75 %	405	852	26.79	$7.07	87.46%	58.32%	650	74.29%	$2,956.92	$3.30	22.54%	16.4%	0.301	$0.376	$3.676	32.24%
N_2 100%	500	534	28.67	$1.15	97.96%	36.55%	608	69.49%	$3,312.24	$3.85	9.62%	8.4%	0.481	$0.602	$4.452	17.93%

At 625 PSI Helium Min Tank Pressure

Gas	Gas Pressure (psi)	Sonic Velocity (m/s)	Flow rate SCFM	Gas Cost/ min. @625 psi tank supply	% cost savings to He cost	% Velocity to He Velocity	Measured 15-5 PH SS Mean Particle Velocity (m/s)	% Particle Velocity to He Particle Velocity	Gas Saving per Hr. versus 100% He	Gas & Powder Cost per Sq in @ .010 thichness	% cost savings to He cost	DE	Time (Min.) per Sq in @ .010 thichness	Burdened Labor@ $75/hor. Cost per Sq in @ .010 thichness	Total Cost per Sq in @ .010 thichness	% cost savings to He cost
He	370	1,461	60.24	$80.44			1007			$5.34		60%	0.067	$0.084	$5.424	

This further reduces the Total cost from $2.97 to $2.24per sq in for an additional 10.5%

Economical Advantages of Low-Pressure Mixing System
Savings and Return on Investment

Cost of Nitrogen/Helium Booster with the capability of Mixing Heluim & Nitrogen at 60 psi	$332,000

	625 psi pure He	60 psi75% He 25% N2			Savings	Capital Cost	Pay Back Period				
$ per min of spray	$80.44	-	$21.14	=	$59.30	$332,000	/	$59.30	=	5,599	min. of Spray
$ per Hour of spray	$4,826.40	-	$1,268.58	=	$3,557.82	$332,000	/	$3,557.82	=	93	Hours. of Spray

With the Gas Management System It will allow you to Start up and Cool down with Nitrogen if you are using Helium or He/N2 mixture

	Time (Min.)	Cost with He @ 625 psi	Cost with75%He/25% N2 @ 60 psi	Cost with N_2 @ 625 psi	Savings from He @ 625 psi	Savings from 75%He/25% N2 @ 60 psi
Cost of Gun Start up to Temperature	1.25	$100.55	$26.43	$1.43	$99.12	$25.00
Cost of Cool Down to 150 °C	2.50	$201.10	$52.86	$2.87	$198.23	$49.99
Total	3.75	$301.65	$79.29	$4.30	$297.35	$74.99

	48	Working Weeks/yr
	5	Days/week
	240	Days /year
93 Hrs of spray/240 Days=	0.389	Hours per Day

60 psi(4.1Bar) tank pressure savings are $59.30/min.
Capital investment is approximately $332,000 needing 93 hrs, for a return

Content

- Not all powders can take advantage of N_2-He Mixing depending on the cost of the powders and Nitrogen Deposition Efficiency
- 15-5 SS: 25%N2–75%He particle velocity about 90% of particle velocity with 100% He
- 15-5 SS: 25%N2–75%He provided 48% cost savings compared with 100% He
- 15-5 SS: 25%N2–75%He savings can provide savings to pay back an investment on a complete gas mixing system in about 68 spray hours
- For the Materials tested, there appear to be a range from 50% to 75% He that gives the best economical advantage without giving up deposit performance.
- With a low Supply Pressure of 60 psi (4.1 Bar) it is possible to utilize up to 97.5% of the He gas in a Cylinder, compared to 74% at 625psi (43 Bar) providing additional net savings of about 30% in gas costs

THANK YOU

Julio Villafuerte
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