Bronze Powder Research and Development for Cold Spray Repair

June 23, 2015
Cold Spray Action Team Meeting

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Center for Cold Spray

Outline

- Cold spray test plan
  - Material & testing requirements
  - Geometry and thickness considerations
- Bronze powder specification comparison
- Cold spray testing results
  - He process gas
  - N_2 process gas if possible
  - Mechanical testing
  - Corrosion performance
- Powder investigation conclusions
- Future work

Cold Spray Test Plan/Requirements

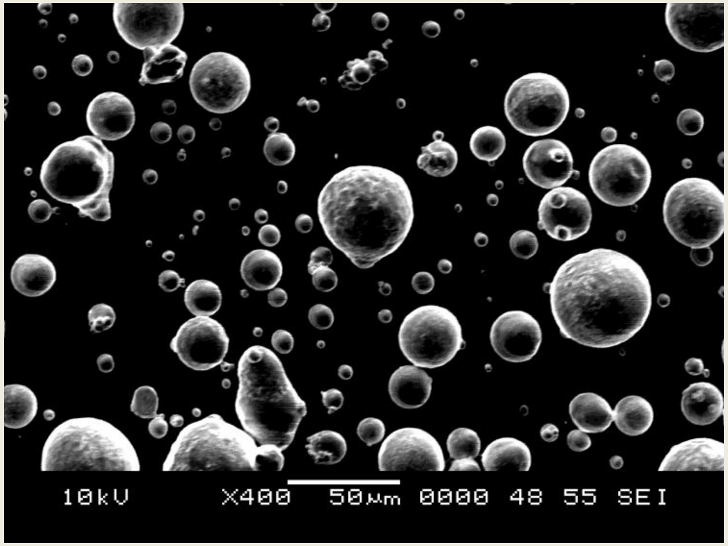
- Substrate: tin bronze
  - Wt. Cu 86-89%, Sn 7.5-9%, Zn 3-5%, P 1.5%, Ni 1%
  - 70 HRB (125 HV)
  - Density 8.75 g/cc
- Application requirements
  - Thickness required for repair 0.25”
  - Total deposit volume for repair approximately 400 in^3
  - Match substrate composition/properties as best as possible
- Testing requirements
  - Porosity < 2.0%
  - Adhesion ASTM C633 > 10 ksi
  - Galvanic Corrosion ASTM G71

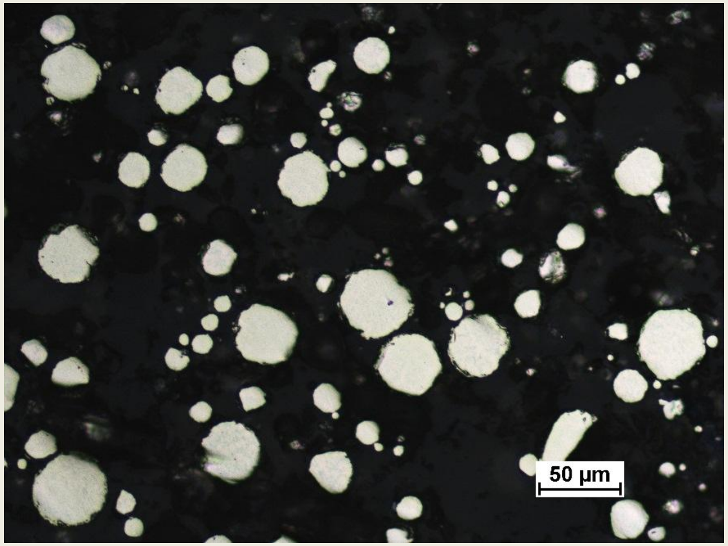
Bronze Powder Survey

Powder Supplier	Powder Name	Production Method	Listing Form/Size	Density g/cc	Cu	Sn	Pb	Zn	Fe	Ni	Sb	P
ACuPowder	5657C	Air gas atomized from alloy melt	Spherical, 90% -325 mesh	5.0	89.6	10						0.4
ACuPowder	DT-31	Water atomized Cu, diffusion alloyed	Irregular, -400 mesh	3.4	89	9		2				
ACuPowder	5631D	Air gas atomized from alloy melt	Spherical, 98.4% -325 mesh	4.1	90.6	8.1		1.3				
F.J. Brodmann & Co.	Tin Bronze Alloy	Air gas atomized from alloy melt	Spherical, -325 mesh	Not listed	87.5-91	8-10		1-2.5				

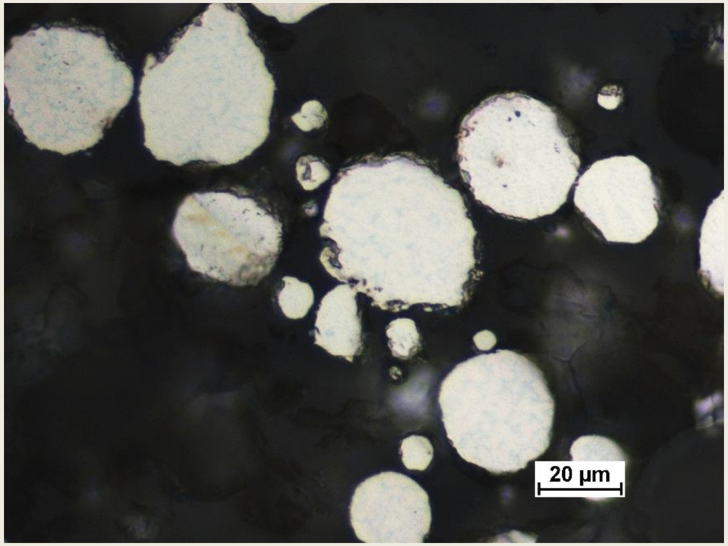
	Density g/cc	Cu	Sn	Pb	Zn	Fe	Ni	Sb	P
Substrate Tin Bronze	8.75	86-89	7.5-9	0.3	3-5	0.2	1	0	1.5

5657C Powder



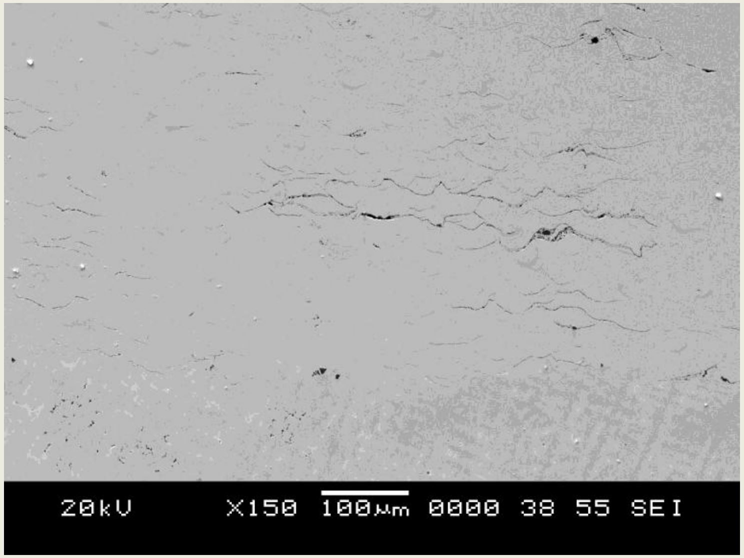


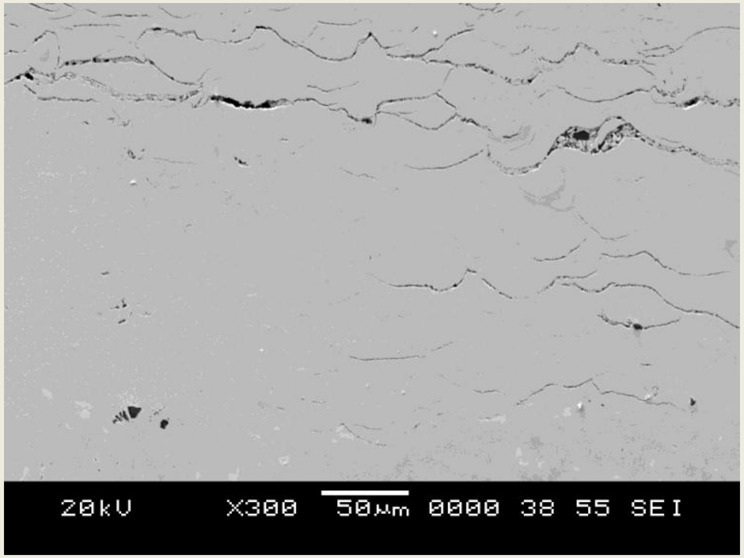
- **Listed as wt. Cu 89.6%, Sn 10%, P 0.4%, air gas atomized from alloy melt, spherical, 90% -325 mesh**
- **Horiba LA-910 laser scattering particle size distribution analysis**
  - **Mean particle diameter 16.9 µm**
  - **Standard deviation 8.6 µm**
- **Microhardness 157.7 HV25**



5657C Spray Testing

- 5657C powder as received
- Ktech cold spray system employed to provide powder preheating, mirror final repair on VRC Metal Systems Gen 3 system being installed
  - 450 psi He
  - 400 °C main gas, 400 °C powder gas
- Deposition efficiency
  - 23.2% on 6061 Al plate w/ grit blast
- Deposit microhardness: 274.0 HV500 avg.
- Microstructure observations on bronze substrate w/ grit blast
  - Dense deposit, evidence of incomplete particle-particle bonding
  - Good substrate interface
- Conclusion: DE too low with helium





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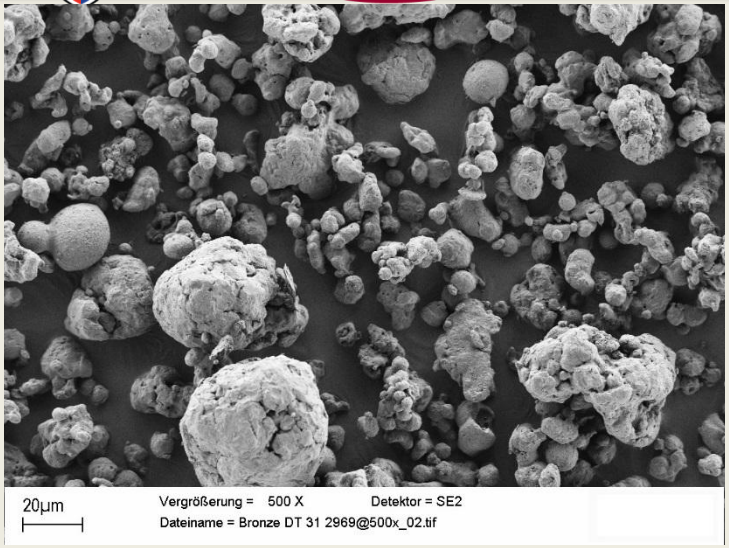
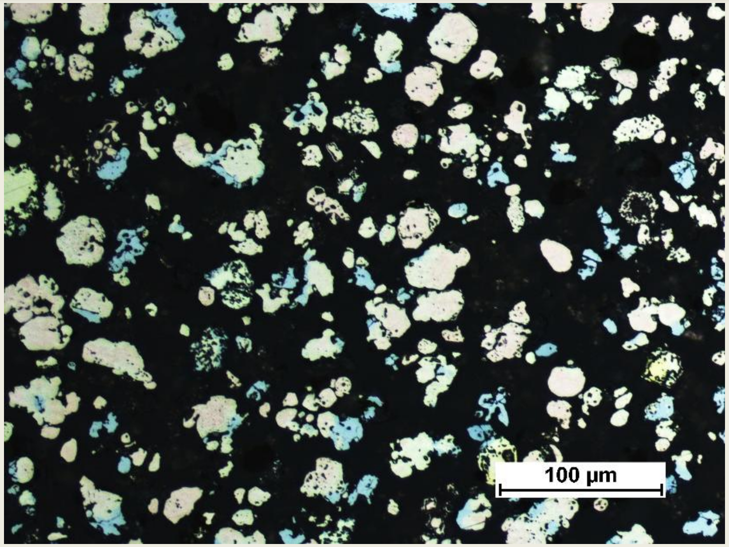
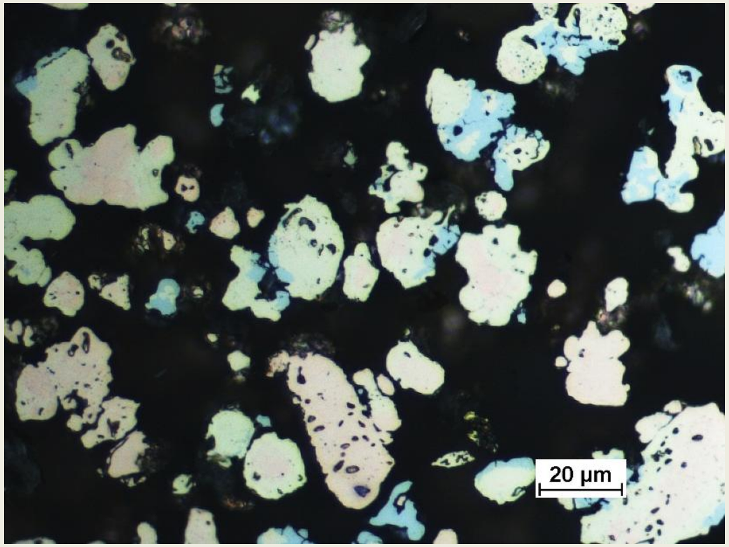
DT-31 Powder



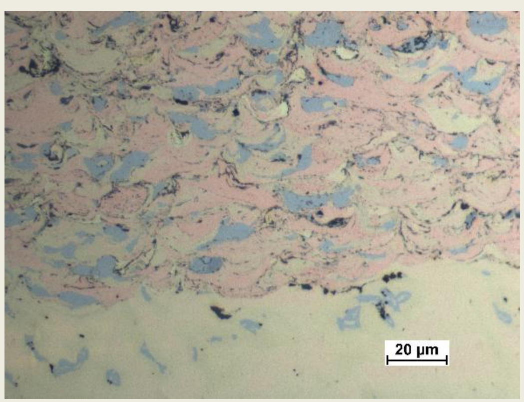


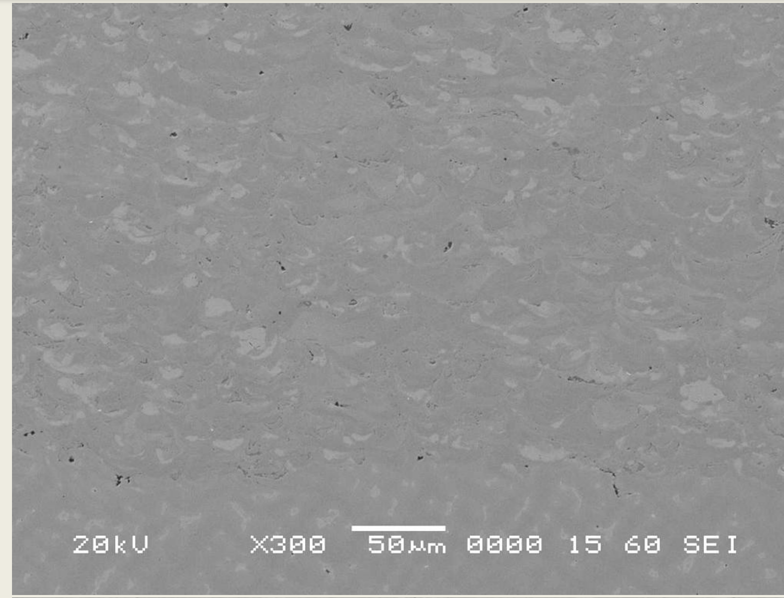


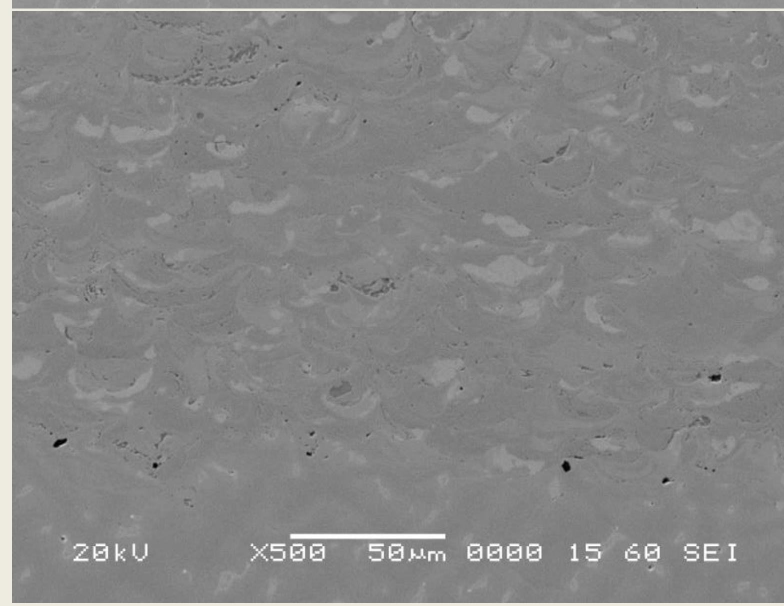
- Listed as wt. Cu 89%, Sn 9%, Zn 2%, water atomized Cu and diffusion alloyed with Sn, irregular -400 mesh
- Segregated areas of high tin content from diffusion alloying
- Horiba LA-910 laser scattering particle size distribution analysis
  - Mean particle diameter 22.4 µm
  - Standard deviation 14.0 µm
- Microhardness 68.7 HV25

DT-31 Spray Testing

- **DT-31 powder as received**
- **Ktech cold spray system**
  - **450 psi He**
  - **375 °C main gas, 300 °C powder gas**
- **Deposition efficiency**
  - **65.8% avg. on 6061 Al plate w/ grit blast**
- **Microstructure observations on bronze substrate w/ grit blast**
  - **Dense deposit, porosity from image analysis 0.432% avg.**
  - **Good interface and particle bonding**
  - **Segregated areas with higher tin content**



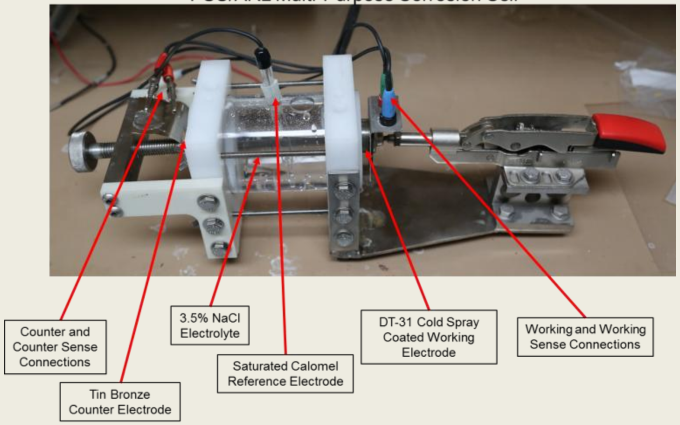




DT-31 Deposit Performance

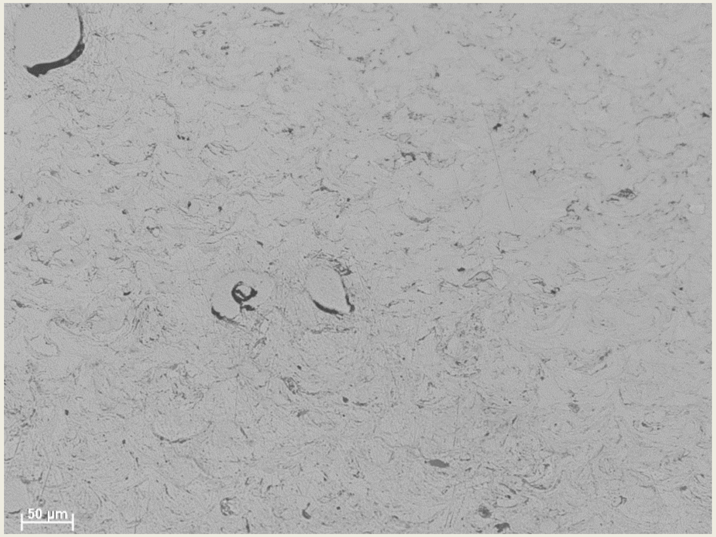
- **Deposit microhardness: 272.2 HV500 avg.**
- **ASTM C633 bond bar adhesion on tin bronze substrate w/ grit blast**
  - **UTS: 11.3, 11.7, 10.6, 10.6 ksi**
  - **Failure mech: all glue failures**
- **Corrosion testing at PSU Applied Research Laboratory**
  - **ASTM G71: 0.0002 inch/year, very small galvanic effect**
  - **Separate areas of high tin do not cause any corrosion concerns**
- **ARL spray tested to full thickness 0.25” to ensure proper quality**
  - **No cracking or delamination**

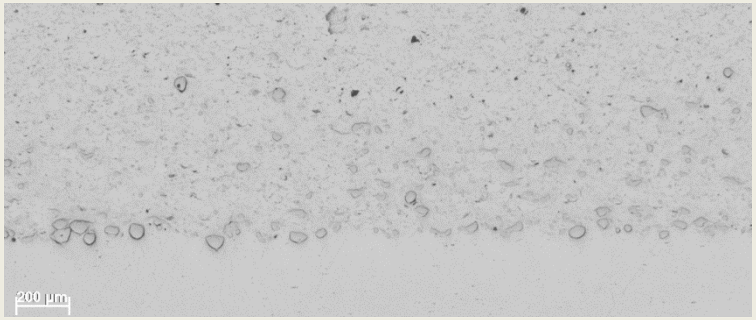
PSU/ARL Multi-Purpose Corrosion Cell

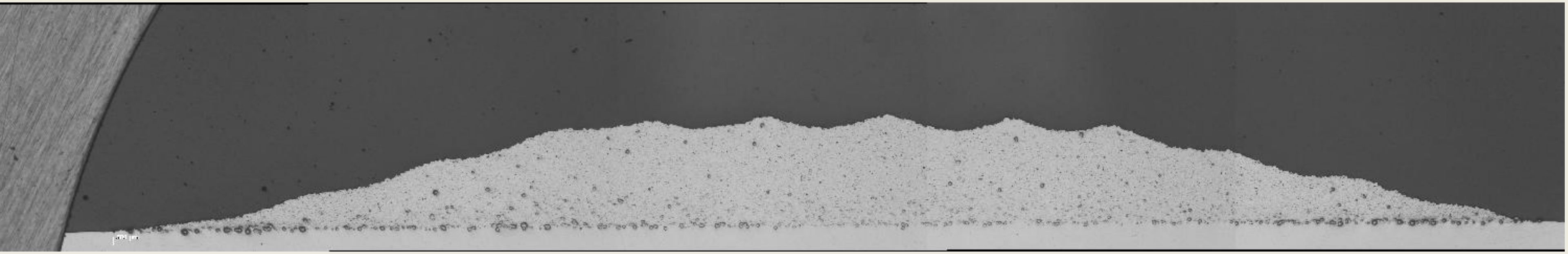


DT-31 w/ N_2 (UTRC)

- DT-31 sprayed with N_2 on UTRC cold spray system
- Cold spray system parameters
  - 580 psi N_2
  - 521 °C gun inlet temperature
- Deposition efficiency 68%
- Microstructure observations on bronze substrate w/ grit blast
  - Dense deposit consolidation
  - Good interface
- ASTM C633 bond bar adhesion on tin bronze substrate w/ grit blast
  - UTS: 9.6, 9.5, 11.6 ksi
  - Failure mech: all glue failures



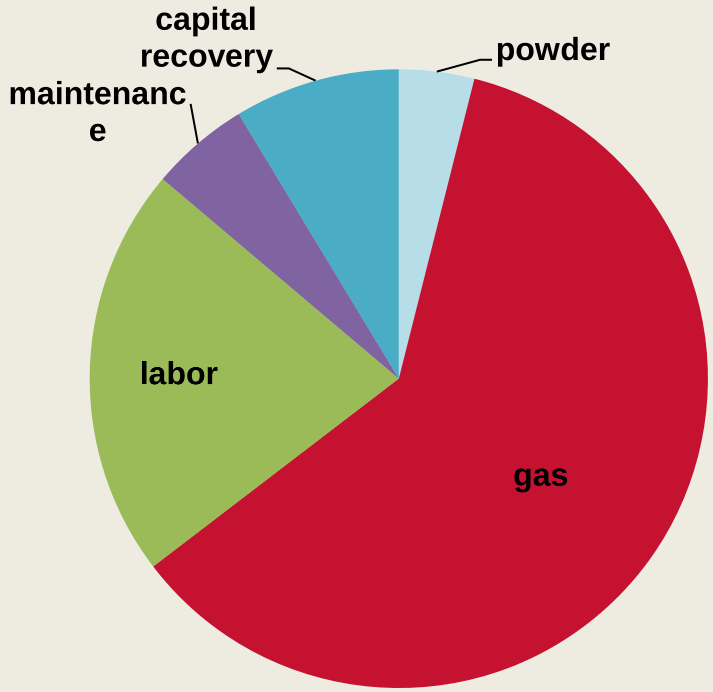




DT-31 He vs. N_2 Cost Comparison

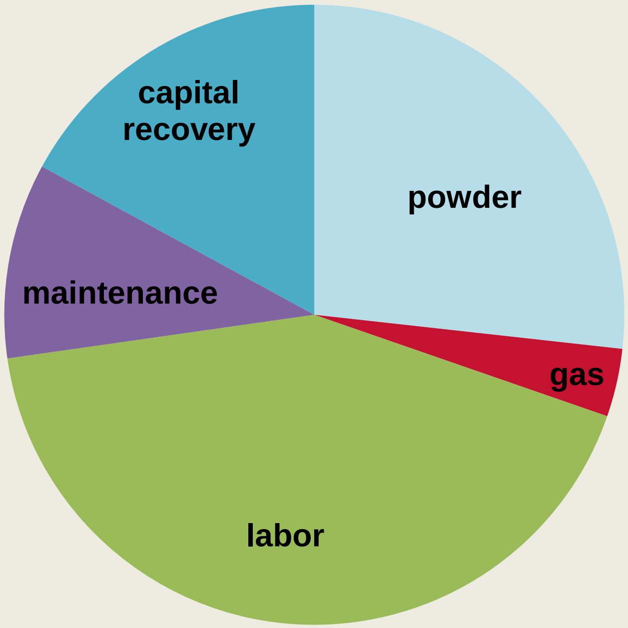
Helium

Gas temperature (°C)	**375**
Compressed gas pressure (psi)	**450**
Deposition efficiency (%)	**65.8**
Powder cost	**$904**
Gas cost	**$13,947**
Electricity cost	**$132**
Labor cost	**$4,954**
Maintenance	**$1,189**
Capital recovery cost	**$1,992**
Total cost	**$23,118**

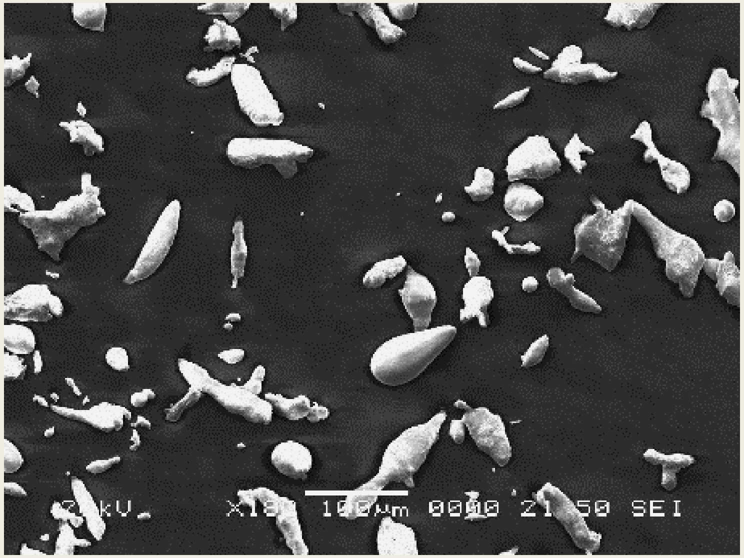


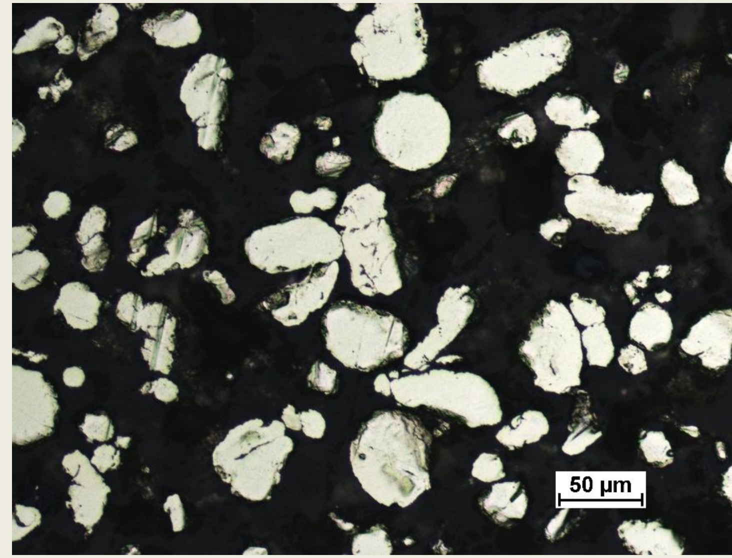
Nitrogen

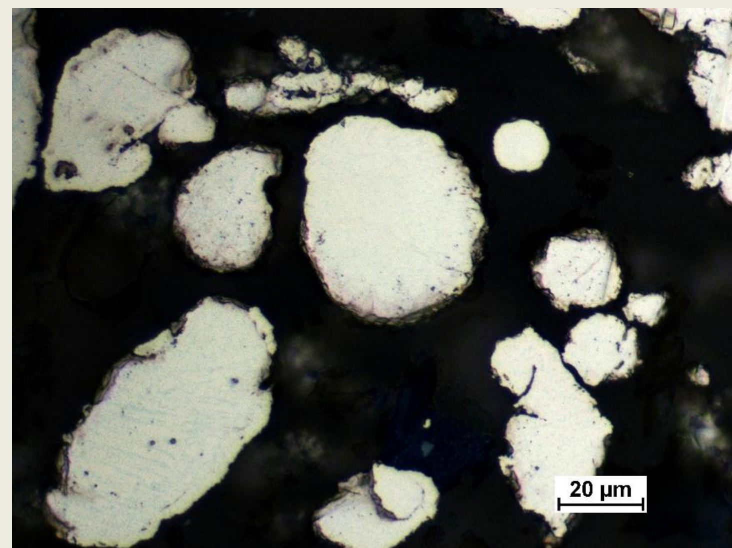
Gas temperature (°C)	**521**
Compressed gas pressure (psi)	**580**
Deposition efficiency (%)	**68**
Powder cost	**$875**
Gas cost	**$116**
Electricity cost	**$39**
Labor cost	**$1,388**
Maintenance	**$333**
Capital recovery cost	**$558**
Total cost	**$3,309**



5631D Powder



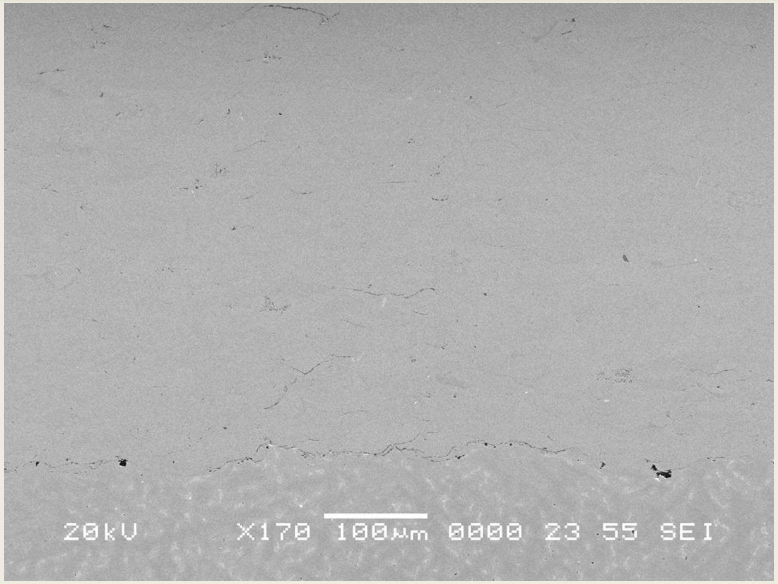


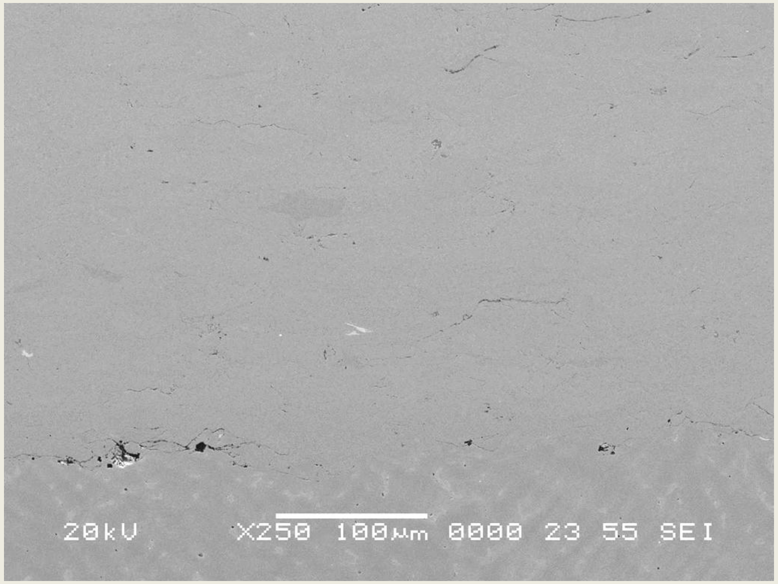


- **Listed as wt. Cu 90.6%, Sn 8.1%, Zn 1.3%, air gas atomized from alloy melt, spherical 98.4% -325 mesh**
- **Horiba LA-910 laser scattering particle size distribution analysis**
  - **Mean particle diameter 20.5 µm**
  - **Standard deviation 13.8 µm**
- **Microhardness 131.1 HV25**

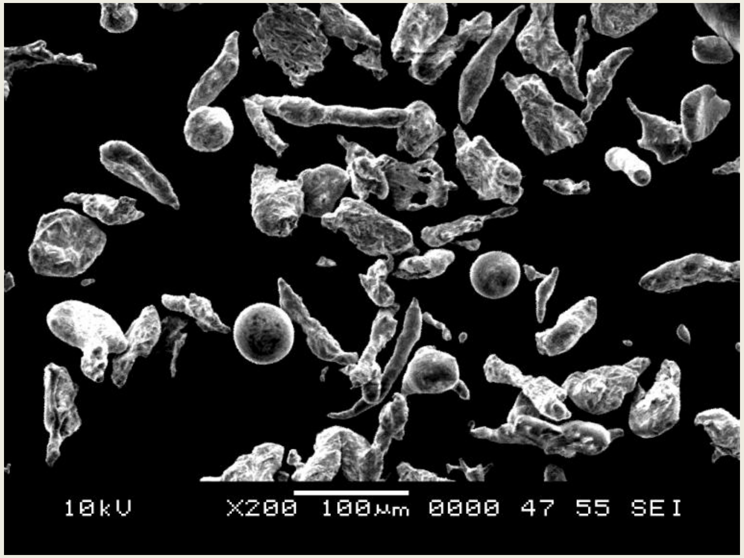
5631D Spray Testing

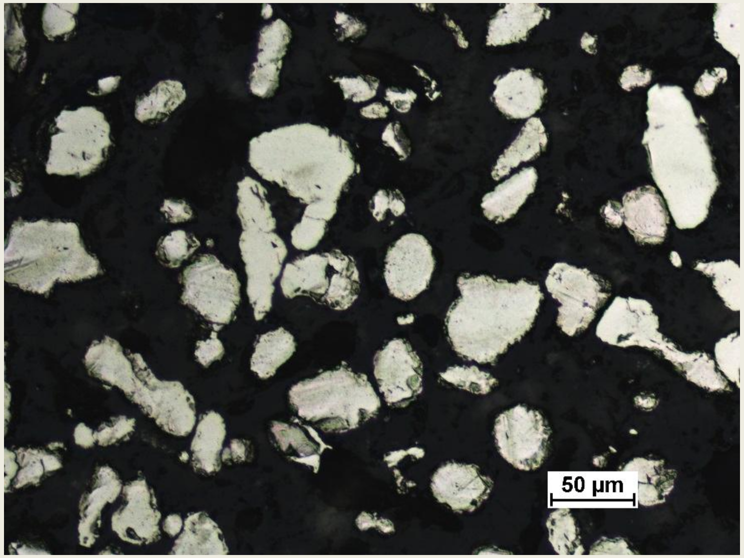
- **5631D powder as received**
- **Ktech cold spray system**
  - **375 psi He**
  - **375 °C main gas**
  - **300 °C powder gas**
- **Deposition efficiency**
  - **63.2% avg. on 6061 Al plate w/ grit blast**
- **Microstructure observations on bronze substrate w/ grit blast**
  - **Dense deposit consolidation**
  - **Good interface quality**
- **Deposit microhardness: 280.0 HV500 avg.**
- **ASTM C633 bond bar adhesion on tin bronze substrate w/ grit blast**
  - **UTS: 7.1, 9.5, 9.8 ksi**
  - **Failure mech: all cohesive failures**
  - **Future testing with increased pressure should increase adhesion**



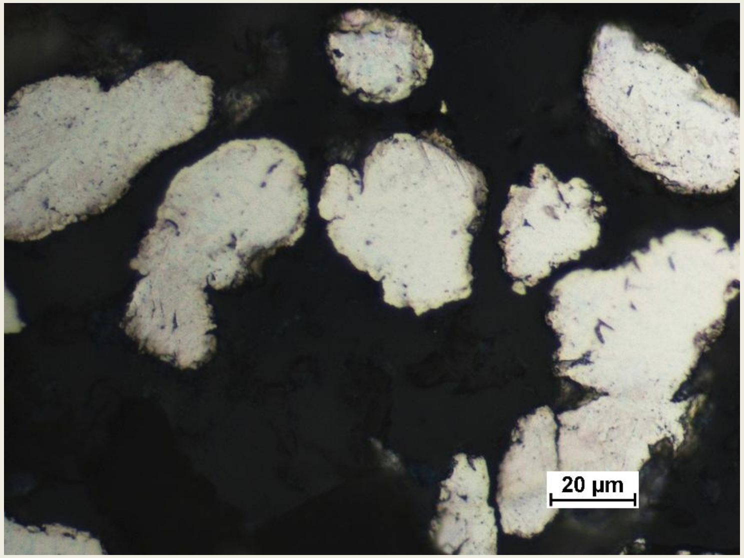


FJ Brodmann Powder



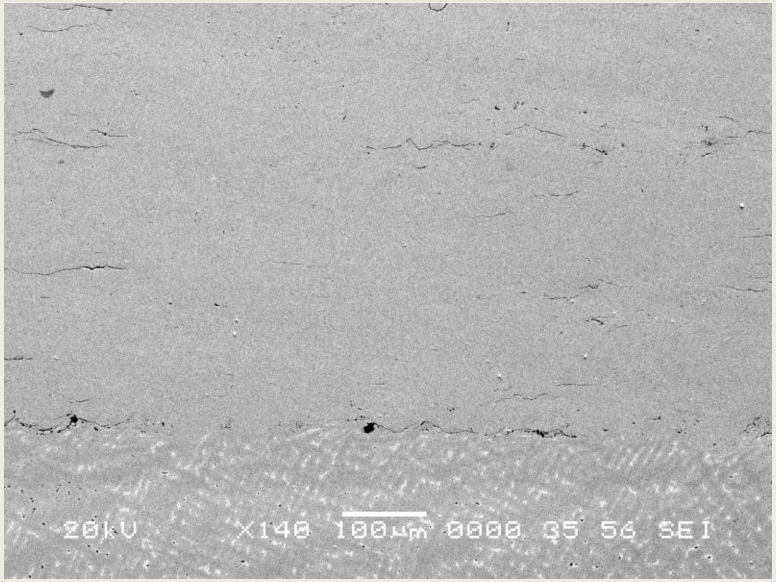


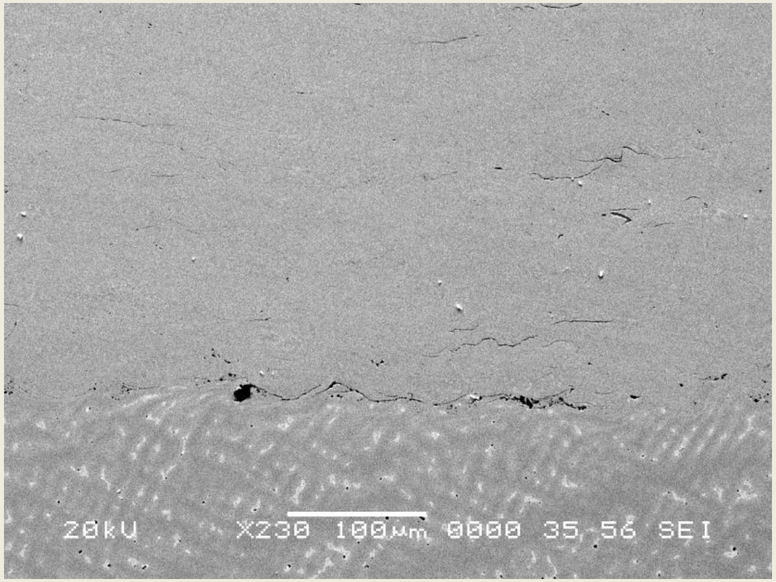
- **Listed as wt. Cu 87.5-91%, Sn 8-10%, Zn 1-2.5%, air gas atomized from alloy melt, spherical -325 mesh**
- **Horiba LA-910 laser scattering particle size distribution analysis**
  - **Mean particle diameter 24.5 µm**
  - **Standard deviation 11.2 µm**
- **Microhardness 156.7 HV25**



FJ Brodmann Tin Bronze Spray Testing

- FJ Brodmann tin bronze powder as received
- CGT4000 cold spray system
  - 508 psi He
  - 400 °C gun temperature
- Deposition efficiency
  - 52.1% avg. on 6061 Al plate w/ grit blast
- Microstructure observations on bronze substrate w/ grit blast
  - Dense deposit consolidation with evidence of poor particle-particle bonding
  - Substrate interface shows evidence of poor bonding
- Deposit microhardness: 282.5 HV500 avg.
- ASTM C633 bond bar adhesion on tin bronze substrate w/ grit blast
  - UTS: 6.3, 4.7, 6.5, 3.5 ksi
  - Failure mech: all adhesion to substrate





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Bronze Deposits Test Results Summary

ARL

Powder	Powder Microhardness (avg. HV25)	Powder Mean Diam. (µm)	Process Gas	Deposition Efficiency (avg. %)	Deposit Microhardness (avg. HV500)	Bond Bar Adhesion UTS (avg. ksi)	Bond Bar Failure Mechanism	Porosity (avg. %)	Galvanic Corrosion ASTM G71
AcuPowder DT-31	68.7	22.4	He	65.8	272.2	11.1	Glue	0.432	Passed
			N_2	68.0	TBD	10.2	Glue	TBD	TBD
AcuPowder 5631D	131.1	20.5	He	63.2	280.0	8.8	Cohesion	-	-
FJ Brodmann Tin Bronze	156.7	24.5	He	52.1	282.5	5.3	Substrate Adhesion	-	-
AcuPowder 5657C	157.7	16.9	He	23.2	274.0	-	-	-	-

Conclusions and Future Work

Powder Investigation Conclusions

- 5657C not a practical candidate for repair
- DT-31 yields the highest quality deposit
  - Composition segregation does not cause mechanical or corrosion issues
- DT-31 shows most viability with N_2 to significantly reduce cost
- 5631D is the best alternative option for a fully alloyed powder

Future Work

- Transfer spray testing DT-31 w/ N_2 to VRC Metal Systems Gen 3 system for final repair conditions
- Angled spray testing to confirm deposit quality and performance
  - Some sections of the repair can only be accessed at 70-80° angle
- Hammer peen test to evaluate ductility / resistance to impact
- Final component repair

Acknowledgements

- United Technologies Research Center
- Penn State University Applied Research Laboratory
- VRC Metal Systems

Thank You