Multi-Directional Properties and Hard Coating Development

6/14/2017

Presented by Aaron Nardi

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United Technologies Research Center

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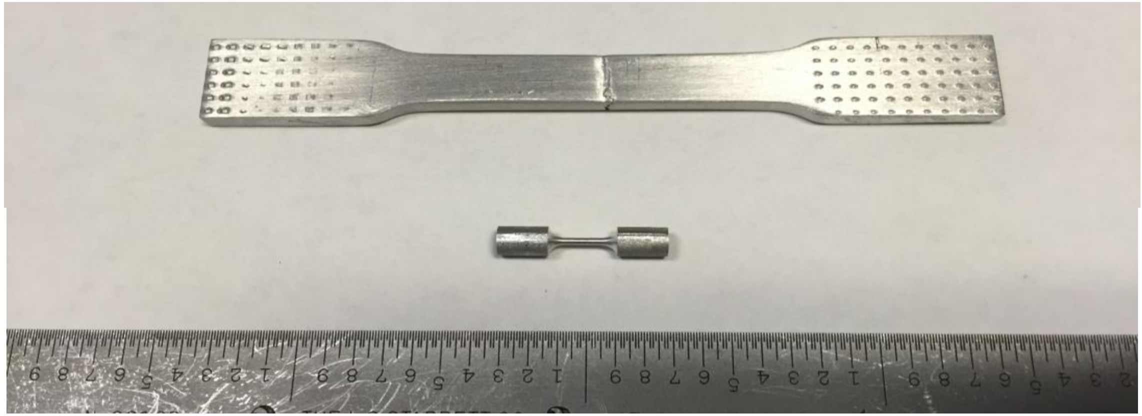
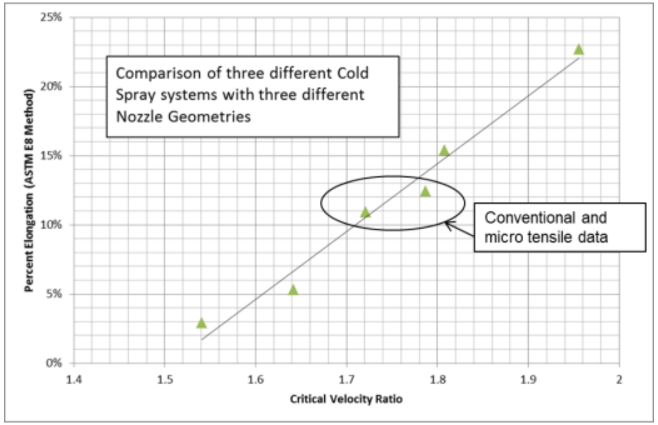
5056 Aluminum Tensile Testing

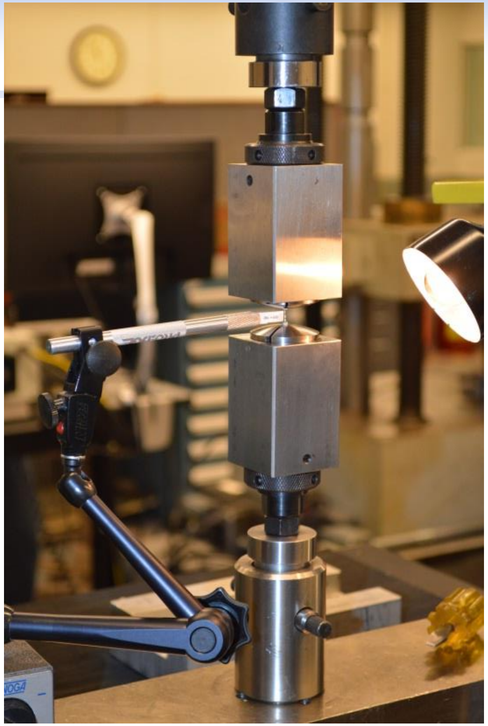
- Tensile testing of 5056 aluminum has consistently provided high strength and good ductility
- Tensile tests are generally performed using ASTM E8 Sub-size flat tensile coupons, but similar results can be obtained from smaller round coupons
- Mini-tensile data follows trend of all previous tensile data with respect to elongation, which is the most sensitive property

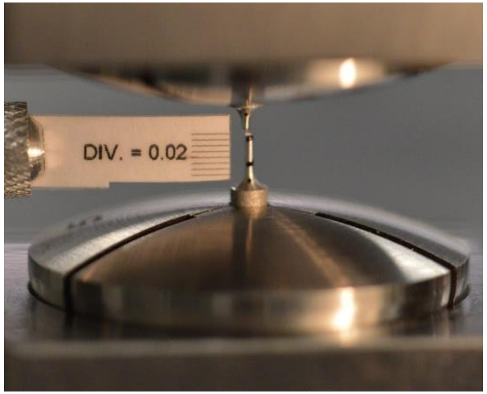


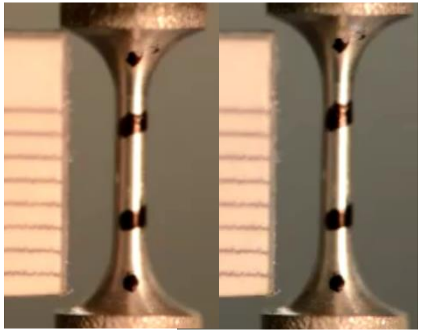


5056 Aluminum Mini-Tensile Testing

- Mechanical collet grips used
- Fixture developed to hold and align mechanical collets for specimen installation in machine
- Load cell zeroed with fixtures installed but lower fixture unpinned
- Mass of lower fixture added to load values during data post-processing
- Attempted to monitor elongation with video did not result in consistent measurements
- Alignment fixture used after testing too measure %elongation by reassembling fracture

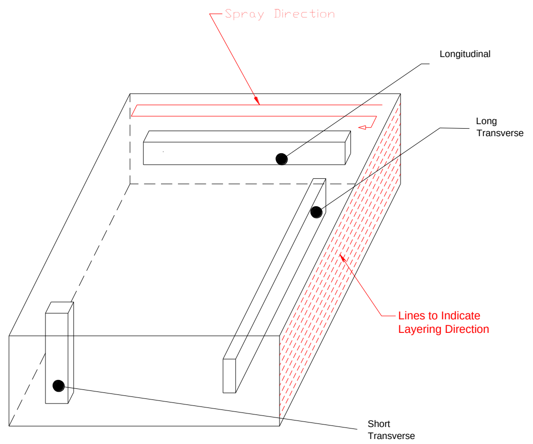




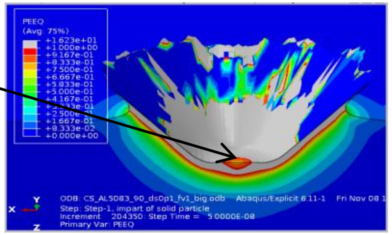


5056 Aluminum Multi-Direction Properties

- Evaluated 5056 mechanical properties in three orientations
  - Longitudinal
  - Long Transverse
  - Short Transverse
- Properties vary depending on orientation
  - Defects aligned with layering direction at the bottom of the impact location
  - Interpass oxidation?
  - Interpass layer/line cooling?



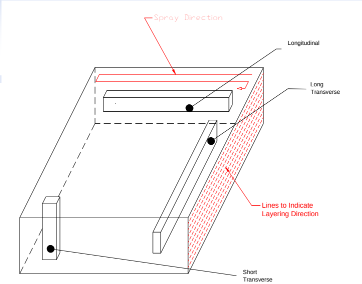
Known potential defect site from models



CS-16-065						
Specimen	Diameter (in)	Initial Mark Length (in)	Final Mark Length (in)	%EL	Peak Load, lbf	UTS, ksi
ST-1	0.03	0.134			33.93	48.00
ST-2	0.0295	0.123	0.130	5.64	36.44	53.31
ST-3	0.0290	0.123	0.127	2.93	35.79	54.18
ST-4	0.0295	0.134	0.136	1.64	34.51	50.49
			Averages	3.40		51.50
LT-1	0.028	0.246	0.261	6.11	34.19	55.53
LT-2	0.028	0.191	0.199	4.19	34.56	56.13
LT-3	Sample broken during set-up					
LT-4	0.029	0.127	0.138	8.93	35.92	54.38
			Averages	6.41		55.34
L-1	0.0275	0.130	0.142	9.17	34.24	57.65
L-2	0.027	0.137	0.150	10.12	33.41	58.35
L-3	0.0290	0.123	0.137	11.38	39.26	59.44
L-4	0.0290	0.110	0.124	12.92	38.53	58.33
			Averages	10.90		58.44

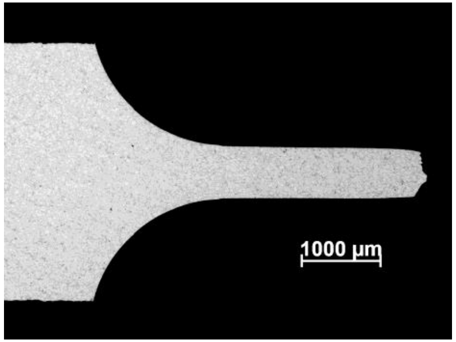
All samples were tested using the same procedure except for elongation measurement. Samples 1 and 2 used a video based measurement initially then just before failure. Samples 3 and 4 used fidutial marks as is typical for ASTM E8. Samples 3 and 4 were used to calculate %el to be consistant with ASTM E8

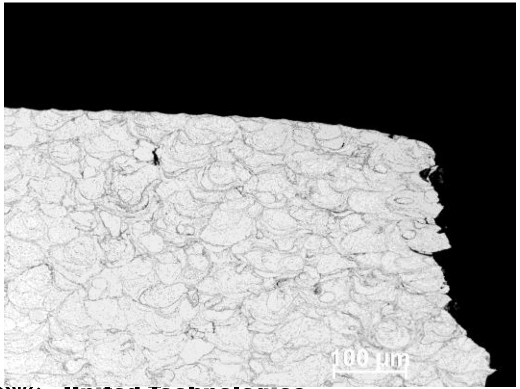
5056 Aluminum Multi-Direction Properties



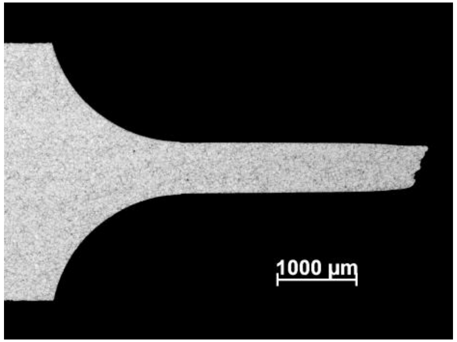
- Evaluation of tensile specimens post-test
  - Micros made from cross sectioning tensile along the length

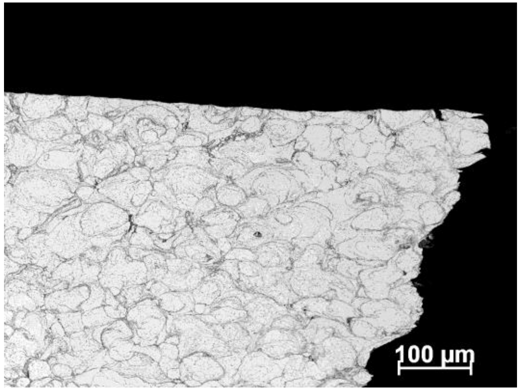
L Direction



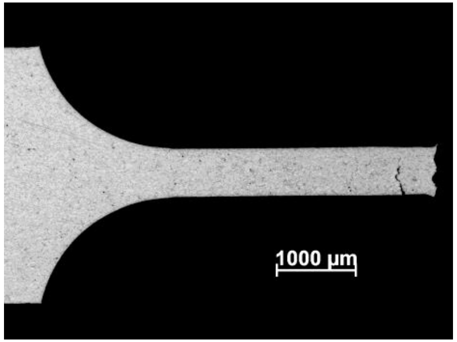


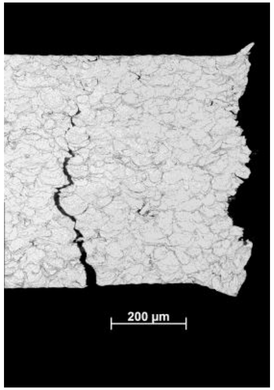
LT Direction

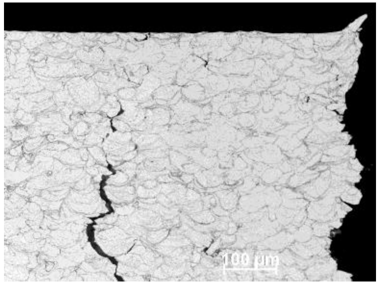




ST Direction





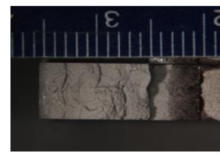


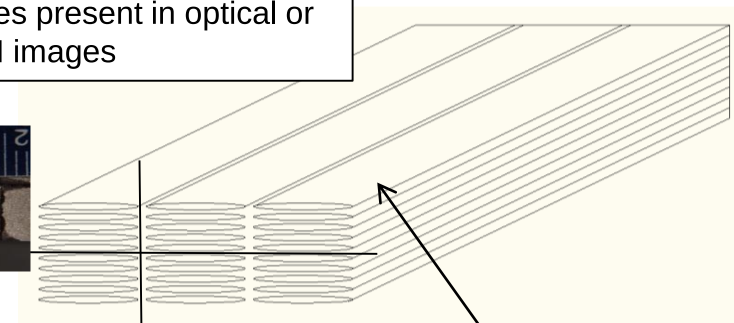
Prior Work with Directional Property Evaluation

Mechanical Property Testing

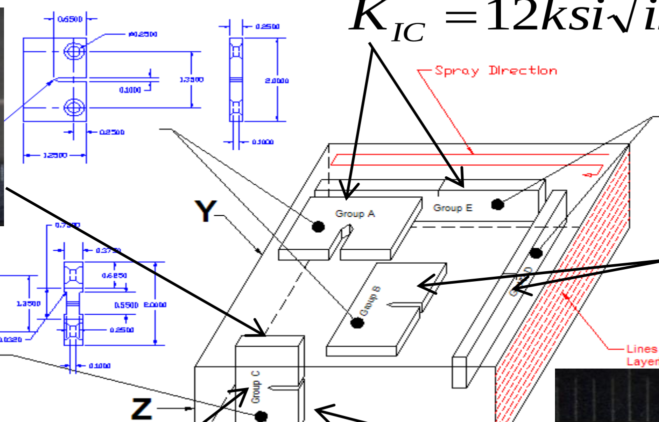
- Fracture toughness experiments in CS CP Aluminum
  - Directional property variation
  - Spray pass interfaces dominate
  - Expect 20 – 40 ksi*sqrt(in)

O2 content measured at 2% even though no obvious oxides present in optical or SEM images





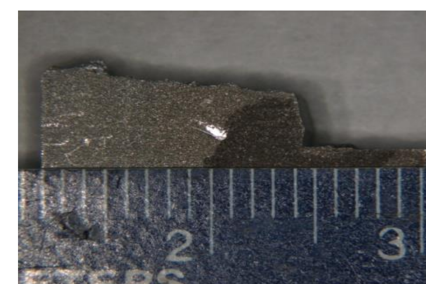
Simplification of Spray Passes



$$K_{IC} = 12 ksi\sqrt{in}$$

$$K_{IC} = 9.8 ksi\sqrt{in}$$

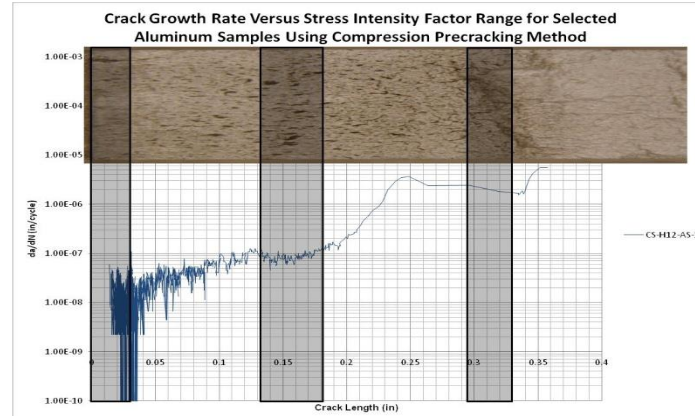
$$K_{IC} = 6.7 ksi\sqrt{in}$$

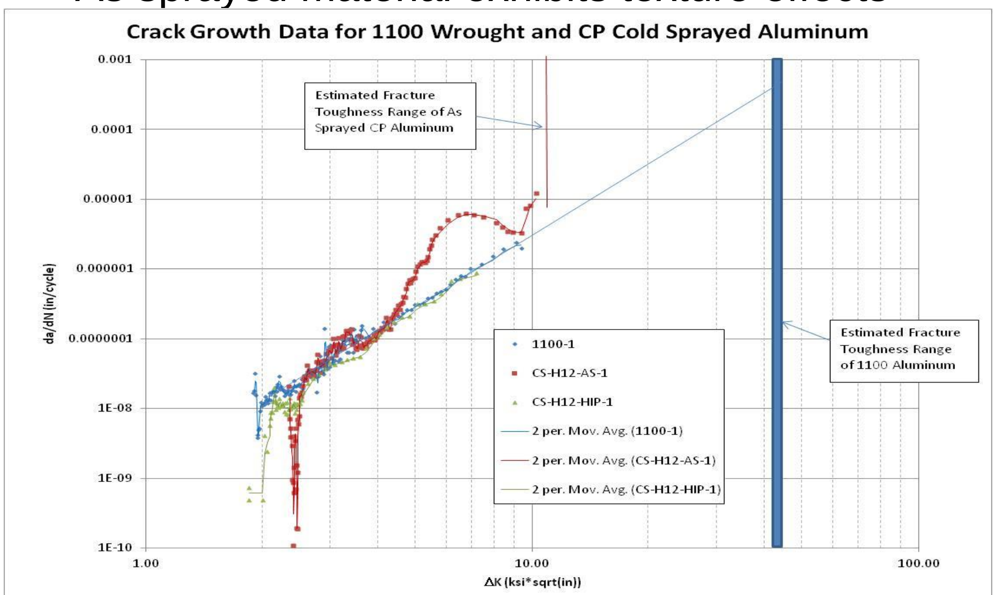


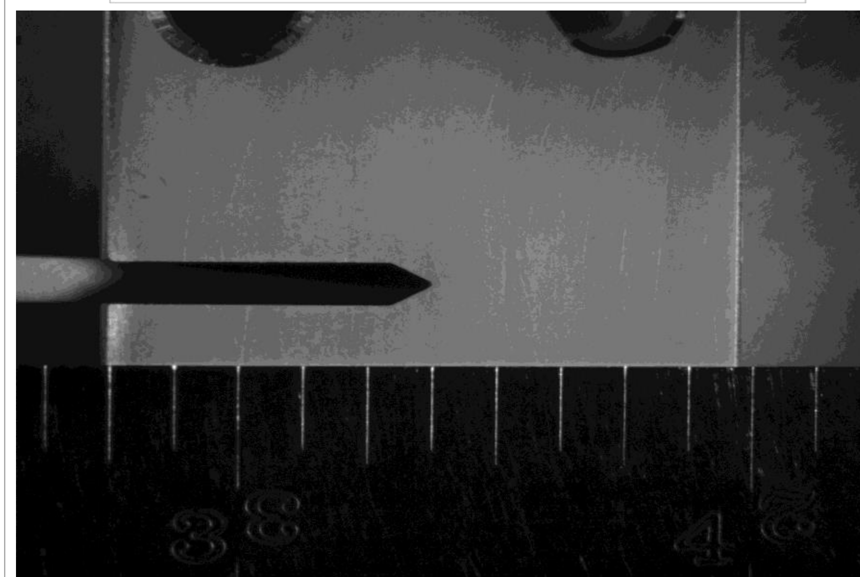
Effect of Directional Artifacts on Crack Growth

Mechanical Property Testing

- Crack propagation testing performed using compressive pre-cracking constant amplitude testing
- HIP'ed material performs similarly to Wrought 1100
- As sprayed material exhibits texture effects







Implications of Multi-Directional Property Variations

- Define the direction of all coupons pulled from deposits
  - Use standard wrought plate stock definitions for simplicity
    - L, LT, ST
- Where structural performance is required, evaluate multi-directional properties
  - Most critical in thick deposits where out-of-plane stresses can be significant
- Choose spray pattern based on design stresses and known best property direction
  - Where possible align “longitudinal” direction with max principal stress direction

Cold Sprayed Hard Coatings Development

- Develop environmentally friendly coatings using Cold Spray which can be used in place of chromium plating and nickel plating
- Identify powder morpologies that might enable Cold Spraying of multiphase composites
- Develop nozzles and processes which enable the deposition of the powders developed

Technical Contributors

ARL

United Technologies Research Center

CORRDESA

Perpetual technologies

WPI

Funding agency:

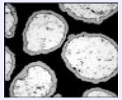
SERDP
DOD ▪ EPA ▪ DOE

Holistic Approach to Coating Development

Powder / Material Selection

- **Environmental Regulations**
- **Composition**
- **Manufacturing process**
- **Compatibility**
- **Health Hazards**

Spray Drying



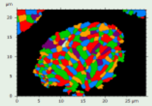
Chemical Clad

Mechanical Clad

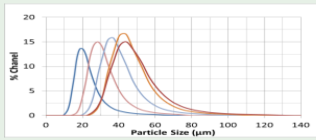
Powder / Material Characterization

Morphology

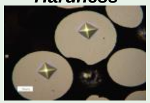
Microstructure

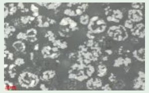


Particle size distribution

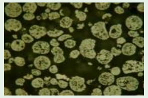


Hardness

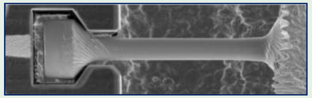




Density

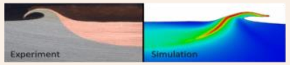


In-situ mechanical tests in SEM

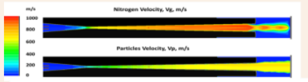


Analytical Tools

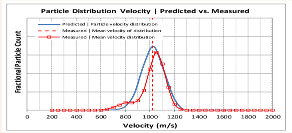
Impact Modeling:
Actual copper CS deposit



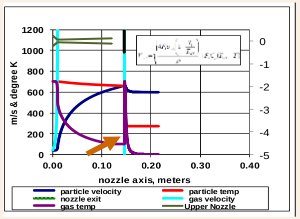
CFD: *Nozzle and Process Modeling*



Validation:
Velocity calculations calibrated with Laser Doppler Velocimeter



CS : *Relative Critical Velocity Ratio Calculations*



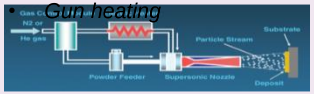
Cold Spray Process

CS Process Conditions

- Pressure
- Temperature
- Accelerating gas

Cold Spray System Design

- Temperature capability
- Powder heating
- Gun heating



Nozzle Design

- Conventional nozzles with varying aspect ratios
- Specialty ID nozzles

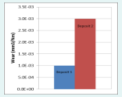
Post-Processing Characterization

Porosity

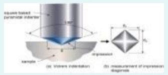
Microstructure

Bond-line

Wear



Hardness



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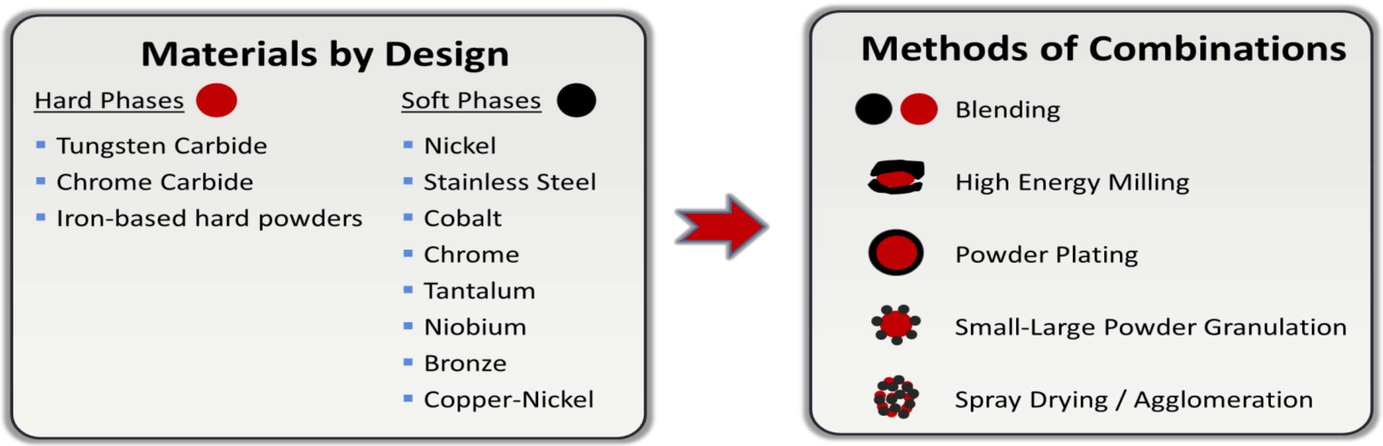
Technical Approach

Synthesis of Cold Spray (CS) powders

- The Cold Spray process achieves particle bonding through a process of high velocity impact and plastic deformation
- Powders used in Cold Spray must contain a “soft” plastic phase in order to properly consolidate
- To create hard coatings, a significant quantity of hard phase is required in the coating

The goal of this project is therefore to:

a. Identify the appropriate types of soft and hard phases
b. Identify the best configuration of these phases within the powder particle
c. Identify the appropriate particle size
d. Develop the spray process parameters required to consolidate this material

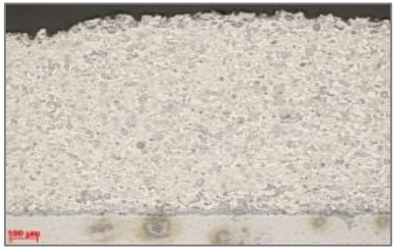


Results

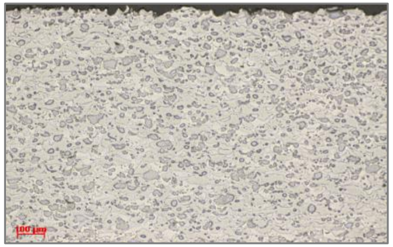
Blending

- Blending of powders can achieve high quality deposits with a variety of combinations of hard and soft phases
- Blending achieves harness limited to approximately 350-500 HV making it a potential solution for nickel plating replacement
- Several potential combinations of hard and soft phases have been successful

Chrome Carbide
Nickel-Chrome



Iron hard face
with Nickel

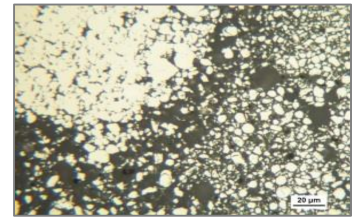


Iron hard face
with Stainless Steel

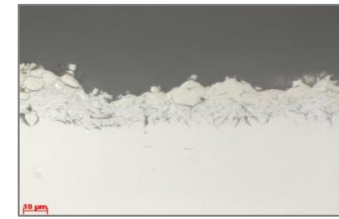
Results

High Energy Milling

- Milling of powder has had limited success to date
- Lack of transfer from soft powder to hard powder during the milling process
- Potential for improvements through the use of finer powders



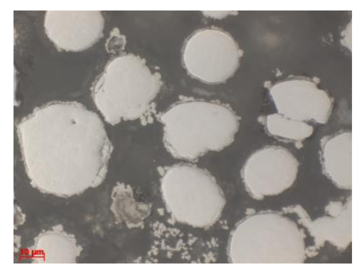
Nanomilled Chrome Carbide powder



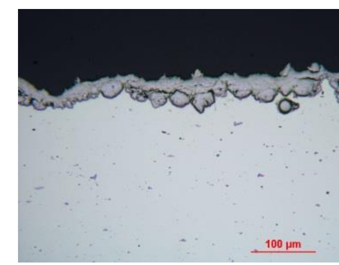
Nanomilled Chrome Carbide deposit

Powder Plating

- Powders have been sent out for plating by nickel
  - Chrome Carbide
  - Tungsten Carbide
- First batch of plated powders received
  - Plating wt% range from 15-36%
  - No significant buildup



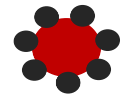
Electrochemically clad powders



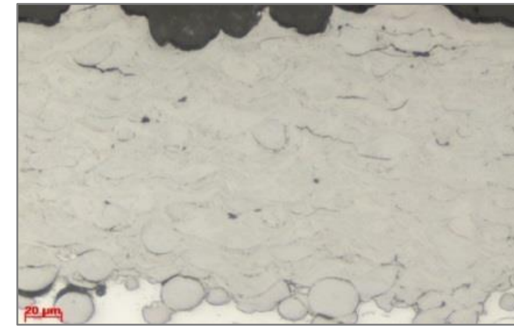
Deposit from clad powder

Results

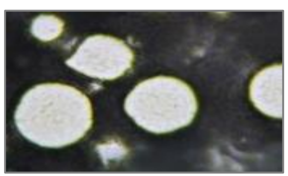
Small-Large Powder Granulation



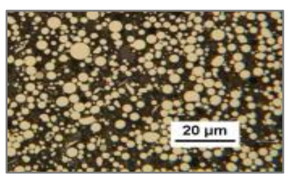
- Large core powders have been granulated with fine metal powders using aqueous PVP solutions
- Powders are then heat treated to sinter the fine powder to the hard core powder
- Fine powders create a coating around the core powder
- Potential for low cost high volume production (commercial process)



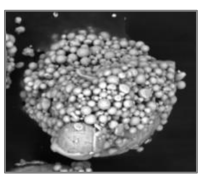
Tribaloy T-400 + Nickel (656 HV)



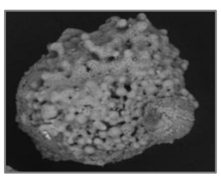
Chrome Carbide powder



Stainless steel powder (1-5um)



Powder particles after granulation



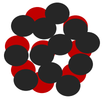
Granulated particles after heat treat

Cold Spray deposit

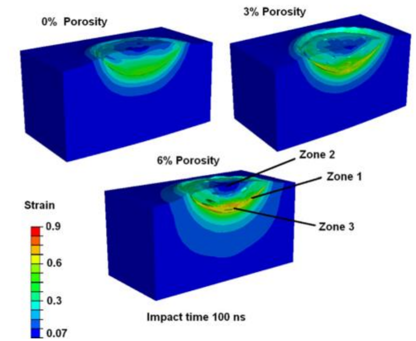
Chrome Carbide with Stainless Steel (430-475 HV)

Results

Spray drying / Agglomeration



- Deposits greater than 850 HV have been achieved
- Both chrome carbide and tungsten carbide based powders were sprayed successfully
- Special nozzle design introduced to improve sprayability
- The following powder characteristics lead to improved outcomes:
  - Finer constituents in agglomerates <2 microns
  - Small agglomerate size <20 microns lower preferred (related to density)
- Other factors that may influence quality
  - Sphericity of agglomerates
  - Homogeneity of agglomerates

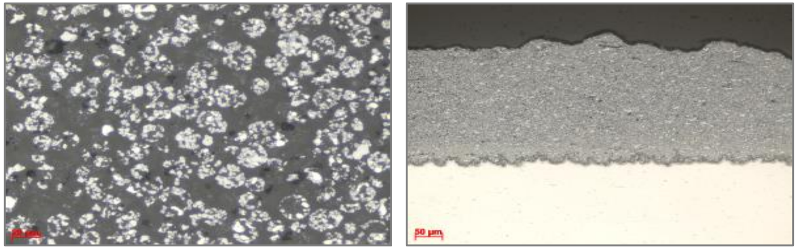


The Influence of Powder Porosity on the Bonding Mechanism at the Impact of Thermally Sprayed Solid Particles

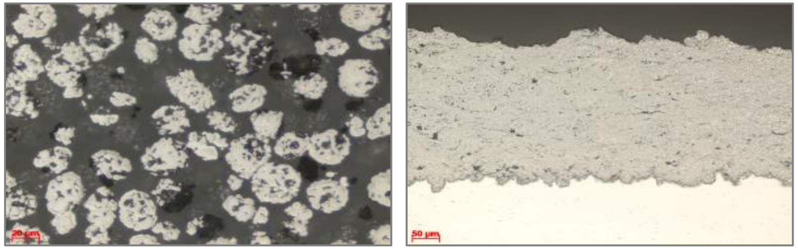
SPYROS KAMNIS, SAI GU, and MICHALIS VARDAVOULIAS

Formulations sprayed successfully
WC-12Co (1300HV)
WC-17Co (900 HV)
WC-17Ni (1150 HV)
WC-25Ni (800 HV)
Cr3C2-35NiCr (850 HV)

Tungsten Carbide (powder and deposit)

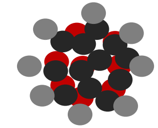


Chrome Carbide (powder and deposit)



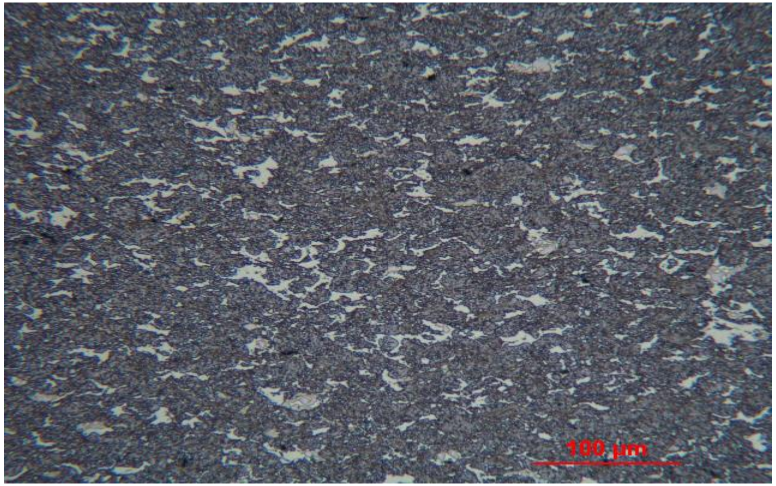
Results

Spray drying / Granulation Combined Benefits

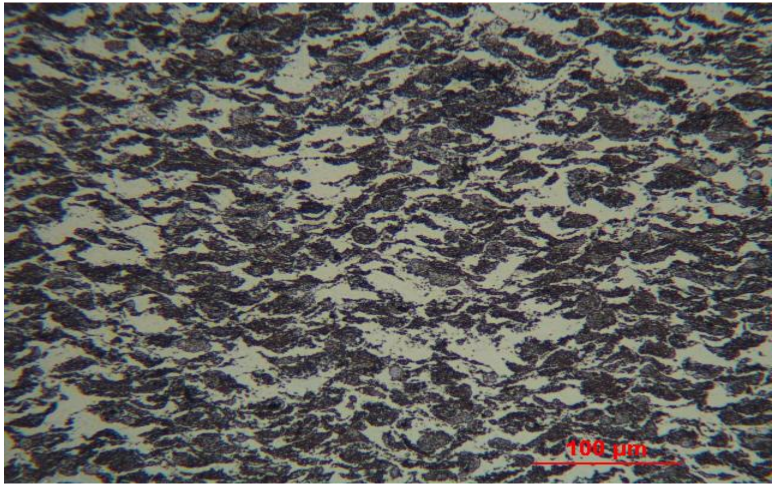


- Using high hardness spray dried powder with addition of soft metal phase to reduce peak hardness but increase DE and spray-ability (combined two processes)
- Deposits in the 650-750 HV range have been achieved using 2 different WC spray dried powders with fine nickel granulation (higher hardness and increased DE)
- DE improved by more than 2x carbide powder alone
- Buildups as thick as 1mm demonstrated with no limits observed (no special nozzles)

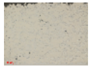
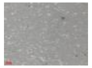
Tungsten Carbide Powder 1



Tungsten Carbide Powder 2



Results

Coating Type	Sample ID	Simple Name	Composition	Gas Used	Nozzle Used	Potential N2 coating	Hardness Range (HV)	Representative Micrographs
Low Hardness Coatings <500 HV	CS-16-093-5	CrC-NiCr-NiCr	Blend, CRC-410-1 + 25% Ni-105-7	N2	Long	yes	400-500	
	CS-16-112	CrC-NiCr +Ni	Blend, CRC-410-1 + 25% Ni-914-3	He	Short	yes	400-500	
	CS-16-133	Fe Hard Phase + Ni	Blend Diamalloy 1008 + 10% Ni-914-3	He	Long	yes	400-500	
	CS-16-134	Fe Hard Phase + 420SS	Blend Diamalloy 1008 + 10% Fe-211 Ar HT	He	Long	yes	400-500	
	CS-16-211	CrC-NiCr +20%Ni	CrC 410-1 -400 mesh granulated with 18% Ni(5 μm)	N2	Long	yes	400-500	
Medium Hardness Coatings 700-800 HV	CS-16-222-3	WC-12Co+18Ni	Amperit 519.059 granulated with 18% Ni(1.5 μm)	He	Medium	yes	700-800	
	CS-16-222-4	WC-17Co+19Ni	Mesocoat Pcomp W611 - 500+635, granulated with 18% Ni(1.5 μm)	He	Medium	yes	700-800	
High Hardness Coatings >800 HV	CS-16-209-5	Cr3C2-35NiCr	Amperit 587 -325/+400	He	Short	?	900	
	CS-16-209-10	WC-12Co	Amperit 519 -635 mesh	He	Short	?	1200-1300	
	CS-17-030-1	WC-17Co	Similar to old Amperit 527-635	He	Short	?	900	
	CS-17-030-2	WC-17Ni	Similar to old Amperit 527-635 but using Ni instead of Co	He	Short	?	1150	
	CS-17-030-3	WC-25Ni	Similar to old Amperit 527-635 but using Ni instead of Co and increasing Ni to 25%	He	Short	?	800	

Thank You