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U.S. Air Force Reduction of Hexavalent Chromium on Landing Gear Components via Implementation of HVOF Tungsten Carbide Coatings

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Report Documentation Page

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Overview



- **HVOF Implementation process**
 - **HVOF Implementation progress**
 - **Other engineering services**
-



HVOF Implementation Process



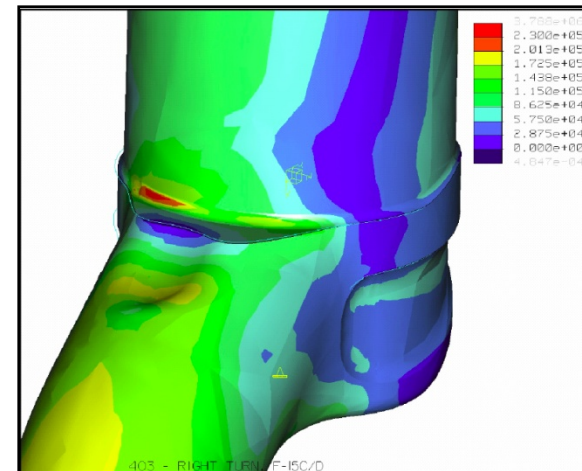
- **All line-of-site Chrome plated high strength steel components are targeted**
 - **3-Step Component Approval:**
 - 3D Modeling
 - Stress Analysis
 - System Safety Evaluation (SSE)
 - **6-Step Part Conversion:**
 - HVOF Fixture Design
 - HVOF Fixture Fabrication
 - HVOF Spray prototype
 - Grind Prototype
 - Process Order Digital Display System (PODDS)
 - Technical Documentation:
 - Technical Order Update
 - Engineering Change Orders (ECO)
-



HVOF Implementation Process



- **Step 1 of 3 - 3D Modeling:**
 - Used for component stress analysis (later used for fixture design)
 - Generated from original prints
 - Pro-E or Solidworks
- **Step 2 of 3 - Stress Analysis:**
 - Each component must go through a stress analysis at coating location
 - Performed using limit loads to ensure function under normal stress conditions
 - Not all components identified are suitable for HVOF conversion
 - High stress thin walled (spallation)





HVOF Implementation Process



- **Step 3 of 3 - System Safety Evaluation (SSE):**
 - An SSE must be performed on each component
 - Formal review of safety related changes to original part configuration
 - Separated into two separate cases:
 - General case SSE:
 - Limit stress are below material yield or 226 KSI and at least one of the following:
 - HVOF and EHC finished thickness are equal
 - HVOF is replacing an existing flame spray repair
 - HVOF is specified by the OEM
 - Special case SSE:
 - All others not defined by the General case

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HVOF IMPLEMENTATION

GROUP 1

GENERAL PURPOSE (DIRECT CHROME REPLACEMENT WITH HVOF) SYSTEM SAFETY EVALUATION (SSE)

REGARDING THE USE OF HVOF COATINGS ON GENERAL LANDING GEAR COMPONENTS

REVISION A

DISTRIBUTION STATEMENT D. Distribution authorized to the Department of Defense and U.S. DoD contractors only (Operational Use), July 2005. Other requests shall be referred to 417 SCMS/GUEB, Landing Gear Engineering, Hill AFB, Utah.

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POC: Richard Vander Straten
Prepared for OPR: 417 SCMS/GUEB

Reference: MIL-STD-882D Standard Practice For System Safety

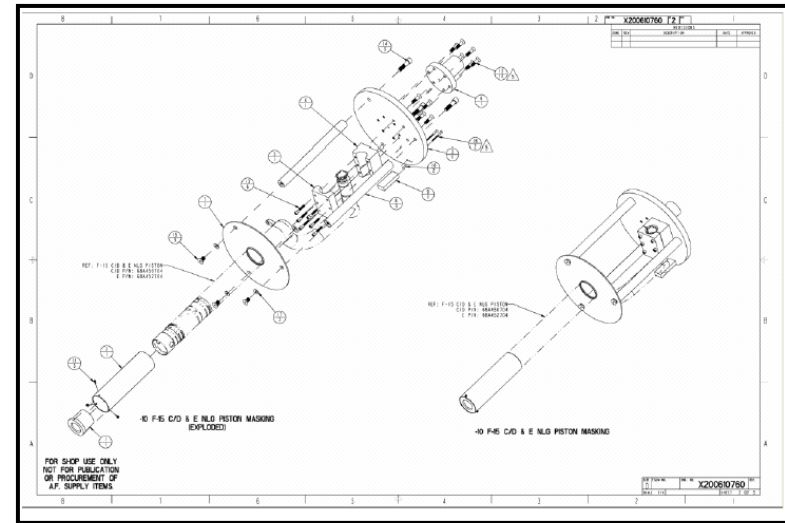
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HVOF Implementation Process



- **Step 1 of 6 - HVOF Fixture Design:**
 - Uses previously generated 3D model
 - Fixtures are designed with consideration of booth(s) to be used including:
 - Movement restrictions and limitations.
 - Cost effective manufacturing methods
 - Ease of overspray stripping
 - Ease of operator use
- **Step 2 of 6 - HVOF Fixture Fabrication:**
 - Fixture validation:
 - Dimensional inspection
 - Fit check on actual component
 - Fixture delivery:
 - Custom container including all hardware, fixture blueprints, tolerance stack and run out sheets
 - Recommended spare parts lists
 - Instruction manual

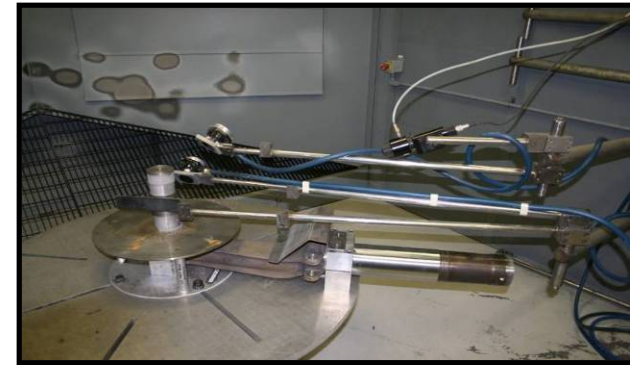




HVOF Implementation Process



- **Step 3 of 6 - HVOF Spray Prototype:**
 - Prototyping ensures:
 - Application program incorporates all optimized coating methods
 - Ensures part cooling cycles are correct
 - Verifies actual part processing times
 - Verifies tolerances
- **Step 4 of 6 - HVOF Grind Prototype:**
 - Prototyped component is diamond ground
 - Ensures final dimensional and surface finish attributes are achievable within optimized grinding parameters
 - Grinding accomplished per Air Force drawing 200310642

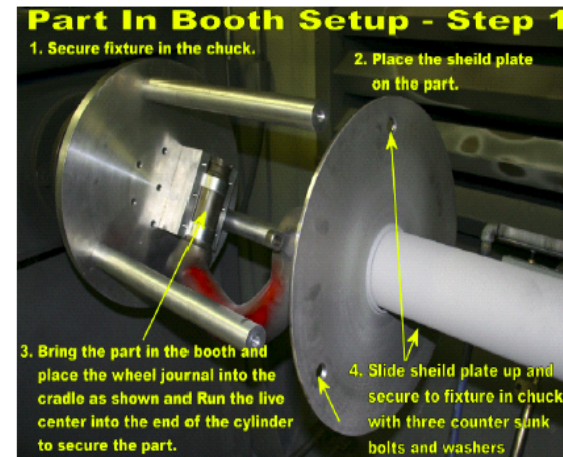




HVOF Implementation Process



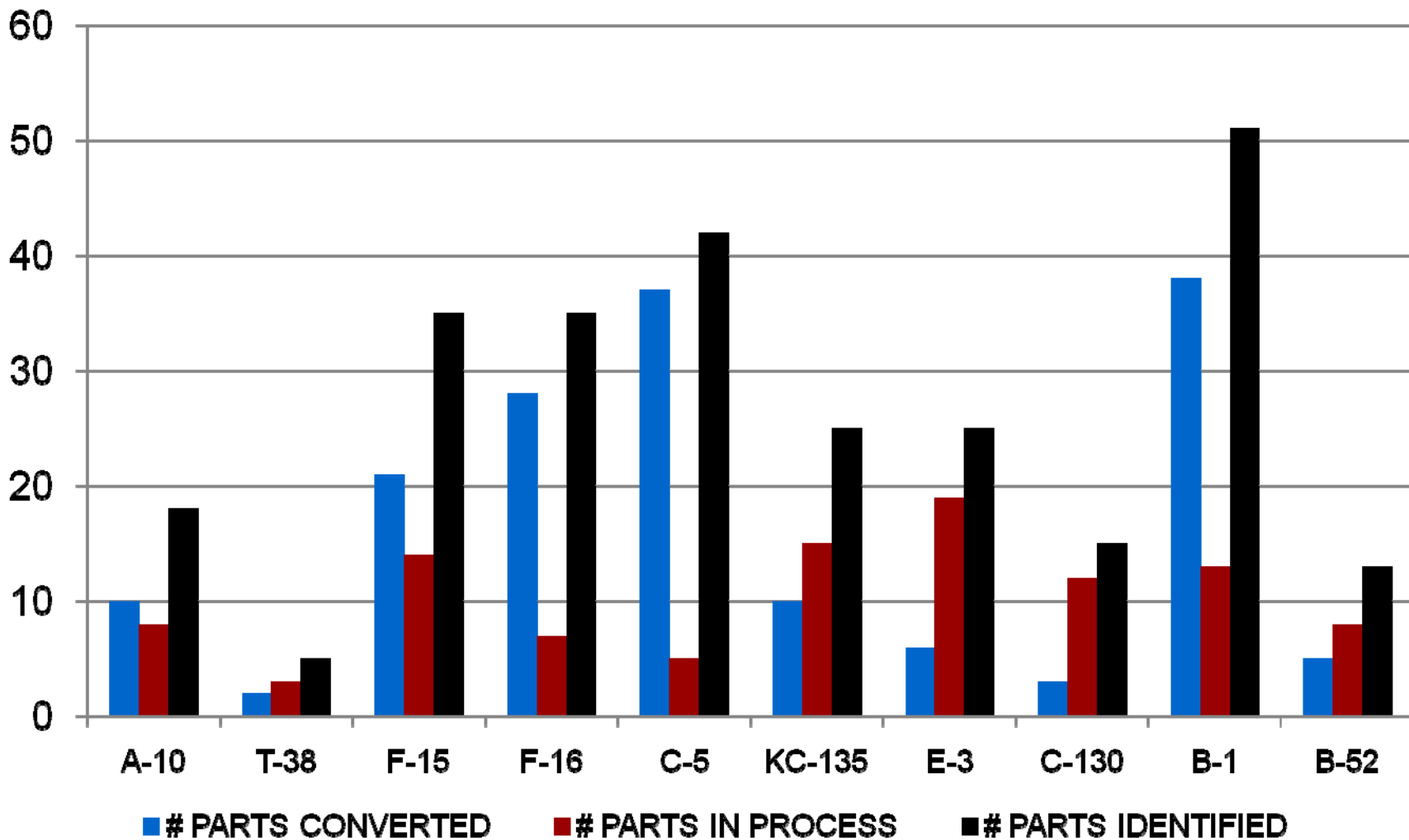
- **Step 5 of 6 - Process Order Digital Display System (PODDS):**
 - Process Orders are the detailed, step-by-step instructions for operators to use to ensure process repeatability
 - The digital instruction database is available on line for all operators
- **Step 6 of 6 – Technical Documentation:**
 - Technical Orders updated
 - Engineering Change Orders:
 - Ensures new procurement using HVOF WC/Co in lieu of EHC
 - Converting components ensures future use of EHC will be reduced, thus lowering hexavalent chrome volume and related exposure issues



ENGINEERING ORDER (Continuation Sheet)				PAGE 3 OF 6 PAGES	
1. ENGINEERING ORDER NO.	1. TITLE	1. CASE CODE	4. ORDER NO.		
	AXLE ASSY-MLG	17576	2006035		
REVISIONS OF THIS ORDER					
Ref sheet 1 zone 7A					
Note: UNAFFECTED DIMENSIONS AND FEATURES OMITTED FOR CLARITY. CAD MODEL MAY HAVE SOME VISUAL VARIATIONS FROM ORIGINAL DRAWING.					
What:					
Is:					
ACTION PLAN IS PASSED PERIODIC					
PARTS LIST CHANGE(S)					
AF FORM 2601, 19940701 (EF-V2) PREVIOUS EDITION IS OBSOLETE					



HVOF Implementation Progress





Other Engineering Services



- **Duplex Coating**
 - **Finishing Methods:**
 - Diamond Grinding
 - Superfinishing
 - Diamond Belt Finishing
 - **Stripping Methods:**
 - Rochelle Salt
 - Pulsed Water Jet
 - **WC/Co Alternatives**
 - **WC/Co & WC/Co/Cr Qualification**
-



Duplex Coating

- Duplex Coating:**

- The optimized HVOF WC/Co coatings are currently limited to 0.003”-0.015”
- Coatings thicker than 0.015” are periodically needed
- Duplex coating enables application up to 0.030” while maintaining all mechanical properties
- Phase I complete and working on Phase II

Table 5: Experiment Design Candidates Summary

		Experiment Design Candidates			
		Replicated Mixed 5-Factor Full Factorial	Replicated 5X 4-Factor Full Factorial	Replicated 5X 4-Factor Half Fraction Fractional	5X 4-Factor Central Composite
Experiment Design Characteristics	Powder Types studied	4	4	4	4
	Runs	128	136	72	124
	Included replications	2	2	2	1*
	Detect/quantify linear first-order effects?	Y	Y	Y	Y
	Highest order interactions able to detect/quantify	4	4	3	4
	Detect system curvature (non-linearity)?	N	Y	Y	Y
	Quantify/model system curvature?	N	N	N	Y
	Quantify inherent system variation/repeatability?	Y	Y	Y	Y
	Generate mathematical system model?	Y	Y	Y	Y
	Predict multi-output optimal response?	Y	Y	Y	Y
	DOE mitigates influence of unknown extraneous factors?	Y	N	N	N
	Study-length control of extraneous factors required?	N	Y	Y	Y
Total change-over time (minutes)	1,920	72	72	72	

* No replicates on corner and axial points. Multiple replicates, however, placed on center point.



Duplex Coating (Phase I)



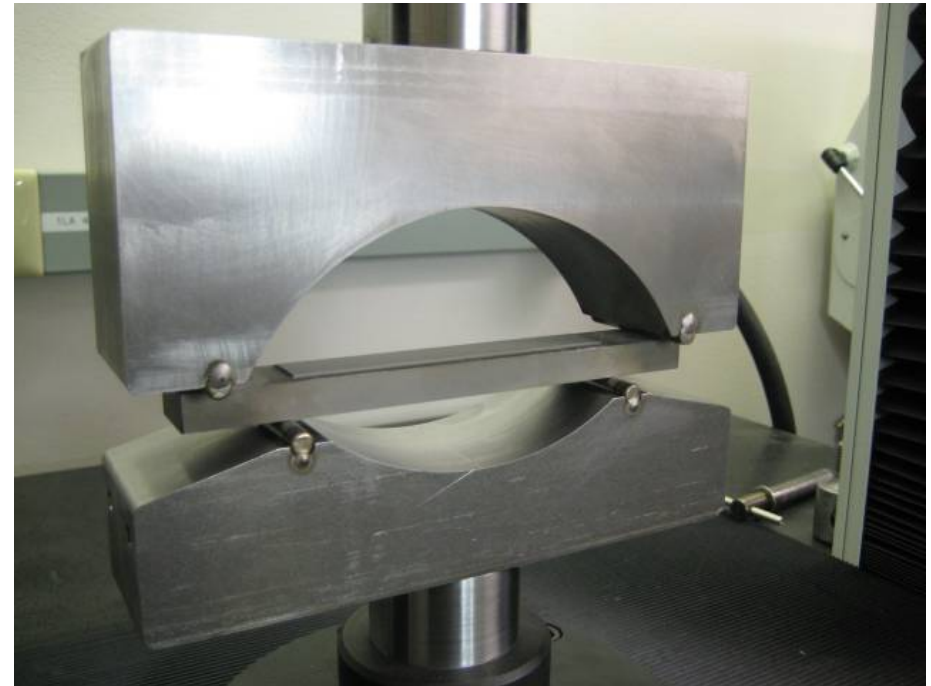
- **Phase I:**
 - Identified initial group of coating chemistries
 - Tested per Air Force drawing 200310641
 - Down-selected to 4 chemistries
 - Generated a coating model tool using a Design of Experiment (DOE) method
 - DOE input parameters:
 - Oxygen Flow Rate
 - Fuel Flow Rate
 - Powder Flow Rate
 - Stand-off Distance
 - Coating model tool predicts coating bond strength, ductility, porosity and hardness given changes in the input variables
 - Significantly reduces Phase II testing
-



Duplex Coating (Phase II)



- **Phase II:**
 - 4-point bend integrity testing:
 - 0.020" and 0.030" total coating thickness with 0.003" inch WC-Co cap
 - 0.017" and 0.027" total coating thickness without WC-Co cap
 - 5 cycles at 190ksi, 210ksi and 230ksi stress levels or until failure (spallation)
 - Corrosion testing of duplex system to chrome and WC-Co
 - Per ASTM B117
 - Coating integrity (large bar) testing of 2 best chemistries



4-Point Bend Integrity Testing

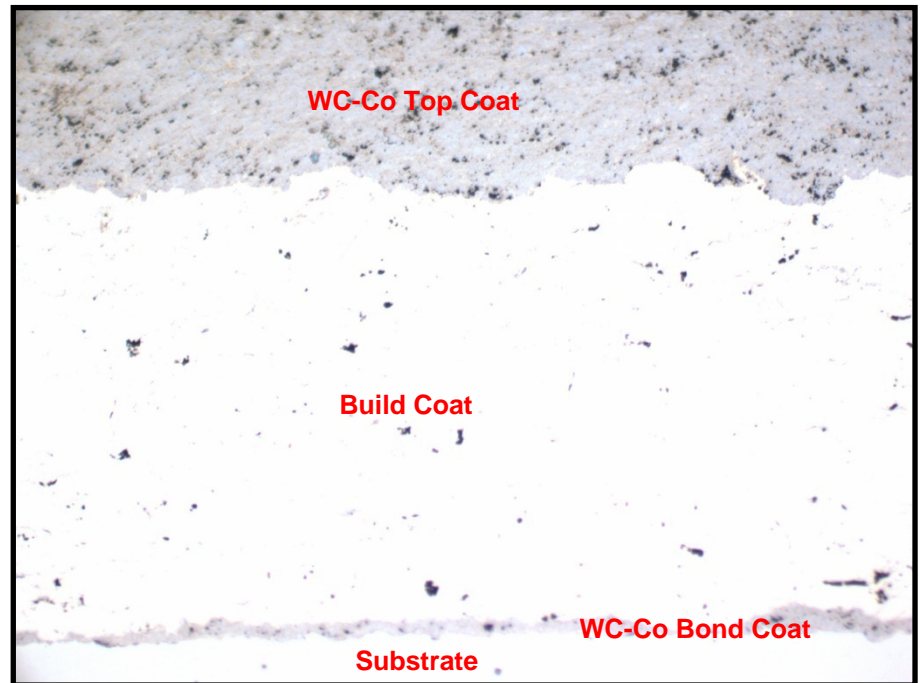


Duplex Coating (Phase II)



- **Phase II Coating Integrity Testing Results:**

- The optimized build coat performed worse than expected
- Adding WC-Co cap to build coat failed coupons at lower than predicted stress levels
- Important observations:
 - The bond strength of WC-Co to build coat was very high
 - The bond strength of build coat to substrate was low
 - Possibly WC-Co bond coat followed by build coat could improve overall bond
- Integrity testing with WC-Co bond coat:
 - Much better results (at 230 ksi):
 - **No spallation** at 0.027 without WC-Co top coat
 - **No spallation** at 0.030 from 3 of 4 chemistries with WC-Co top coat

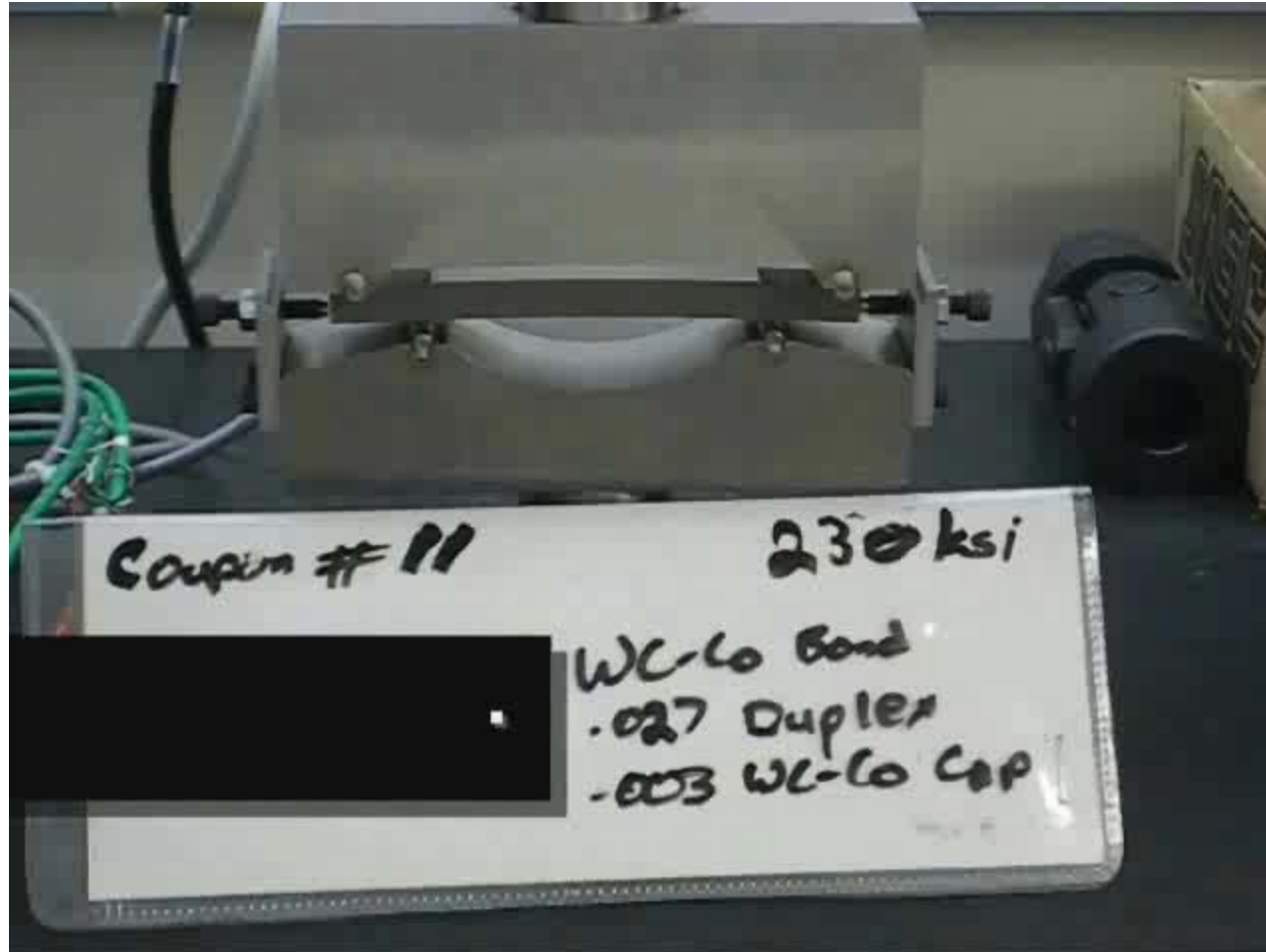




Duplex Coating (Phase II)



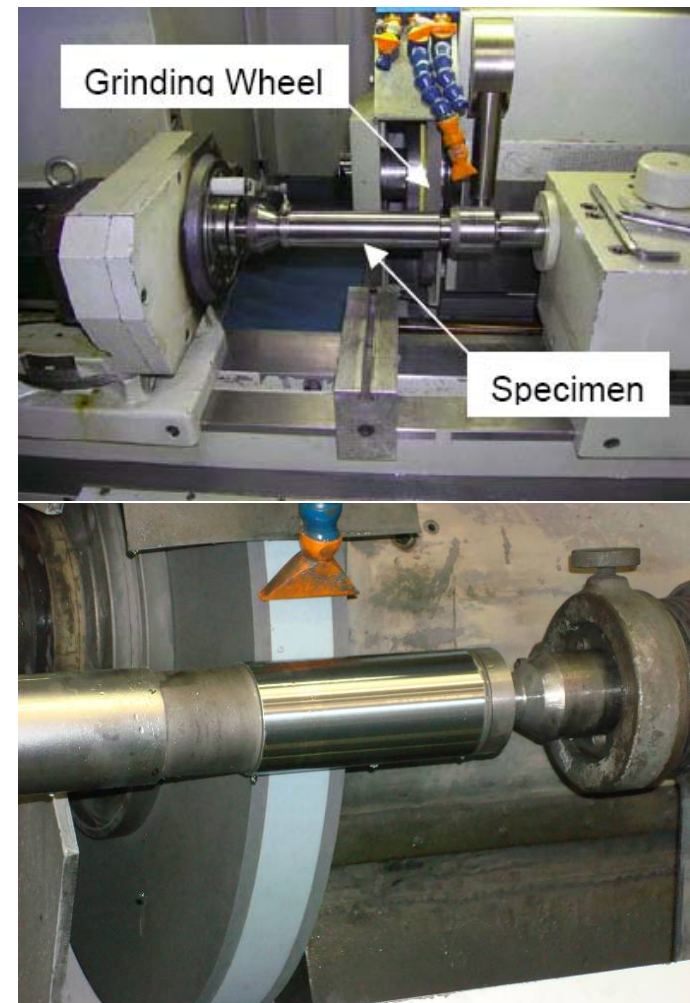
WC/Co Bond-0.027 Build-0.003 WC/Co Top @ 230 ksi





Finishing Methods

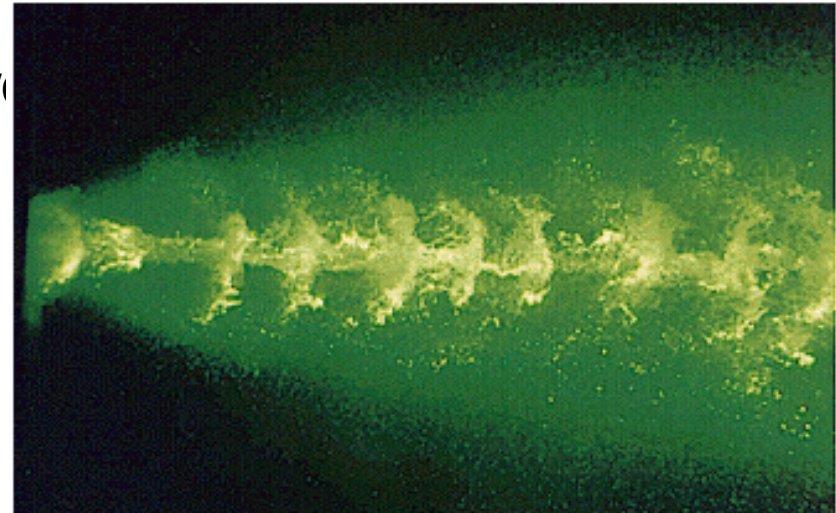
- **Diamond Grinding of 300M:**
 - Air Force drawing 200310642:
 - Cylindrical, Face (contoured) and Surface grinding techniques were optimized to reduce/eliminate grinding burns
- **Superfinishing:**
 - Seal surfaces containing HVOF applied WC/Co coatings must be Superfinished after diamond grinding has been completed
 - Superfinishing methods were optimized and written into AF Drawing 200310642
- **Diamond Belt Finishing:**
 - The initial results of testing indicate an increase of processing efficiency by 3-5 times over standard diamond wheel grinding
 - HAFB long bed grinder has been retrofitted with belt attachment
 - Optimization testing will begin this year, specification to follow.





Stripping Methods

- **Rochelle Salt Stripping:**
 - Industry standard for removing HVOF applied WC/Co materials
 - Electrolytic method under controlled temperature and ph to break down the binder (Co) in the HVOF applied coating
 - Parameters identified within Air Force HVOF application specification-200310641
- **Forced Pulse Water Jet:**
 - Optimized for HVOF WC/Co and WC/Co/ stripping
 - Environmentally friendly
 - Fast, very efficient





WC-Co Alternatives

- **WC/Co Alternatives:**

- Currently, HVOF WC/Co & WC/Co/Cr is the only approved Landing Gear coating
- These coating are expensive and have fatigue and spallation concerns
- It is desirable to qualify alternative coatings which provide:
 - As good as or better than chrome performance characteristics
 - More cost effective
 - Conventionally finished
- Landing Gear Thermal Spray Specification
 - Requirements which will enable the Air Force to qualify other thermal spray chemistries
 - Modeled after the Landing Gear HCAT JTP





WC/Co & WC/Co/Cr Qualification



- **WC/Co & WC/Co/Cr Qualification:**
 - Enables the USAF to qualify vendors for HVOF WC application on OEM components
 - Qualification based on coatings passing standard metallurgical and performance baselines
 - Specification completed and signed off on 28 July 2009 (200925098)
 - Located at www.fbo.gov

APPLICATION		REVISIONS																					
REV	NEXT ASSY	USED ON	REV	DESCRIPTION	DATE	APPROVED																	
	✓	AF ACFT LDG																					
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UNLESS OTHERWISE SPECIFIED		DFTSMN	510 CBSS/GBAC		DATE	U.S. AIR FORCE																	
DIMENSIONS ARE IN INCHES		RODNEY GOULD			09/05/18																		
TOLERANCE OR FRACTIONS DECIMALS ANGLES		CHECKER	510 CBSS/GBAC		09/07/17	TITLE																	
± .XX ± .XXX ± °		BEN DUNKLEY				Qualification Requirements for																	
		MATL ENGR	809A/SSA/DEA		09/07/17	High Velocity Oxygen Fuel WC-Co, WC-Co-Cr Coatings																	
		WELDON BETTS				On High Strength Steel Substrate (>180 KSI)																	
		PROJ ENGR	417 SCMS/GUEB		15JUL09	Landing Gear Components																	
		BRAD MARTIN																					
		PROJ CT AUTH	417 SCMS/GUEB		15JUL09	SIZE	CAGE CODE	DWG NO.	REV														
CURRENT CAGE CODE		RELEASE	510 CBSS/GBAC			A	98747			200925098													
		RICK HARRISON			090723	SCALE	NONE	SHEET	1 of 28														



Conclusion

- **Benefits:**
 - Improved wear performance
 - Removing a known embrittling process
 - Component longevity
 - Reduction in hexavalent chrome waste stream
 - Greatly reduced rework
 - Faster processing of parts
 - **Issues:**
 - Solid infrastructure for EHC
 - Momentum change
-