



HARD CHROME ALTERNATIVES and REPAIRS

C-17 POLLUTION PREVENTION SUB.IPT

HARD CHROME ALTERNATIVES and REPAIRS on C-17 LANDING GEAR

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Boeing C-17 Pollution Prevention

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HAZMAT ISSUES

- **Hard chrome plating baths contains hexavalent chromium**
 - Carcinogenic and toxic compound readily absorbed through gastrointestinal system, lungs, and skin
- **Hard chrome plating used on components for wear protection**
 - Generates significant amounts of hazardous dust and waste from plating and maintenance operations

REGULATORY DRIVERS

- HAZMATS regulated as Hazardous Air Pollutants (HAP) and Toxic Release Inventory (TRI) chemicals
- HAZMATS targeted for reduction as EPA 17 Industrial Toxics and C-17 Chemicals of Concern (COC)
- Disposal of the HAZMATS regulated by the Resource Conservation and Recovery Act (RCRA)
- Worker safety is regulated by OSHA Expanded Standard for hexavalent chromium



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HVOF COATING TECHNOLOGY

- Selected by Hard Chrome Alternatives Team (HCAT)
- Extensive laboratory testing and commercial field usage
- ALCs/Depots already have HVOF coating equipment in place
- Hill AFB continues to test and qualify their HVOF equipment

BENEFITS OF HVOF COATINGS

- Materials and coating process are more environmentally friendly
- High hardness and adhesive strength
- Improves wear and corrosion resistance properties
Compressive residual stress improves fatigue properties
- High density and low porosity
- Non-embrittling, hydrogen embrittlement bake not required
- Not overheat or affect structural integrity of substrate



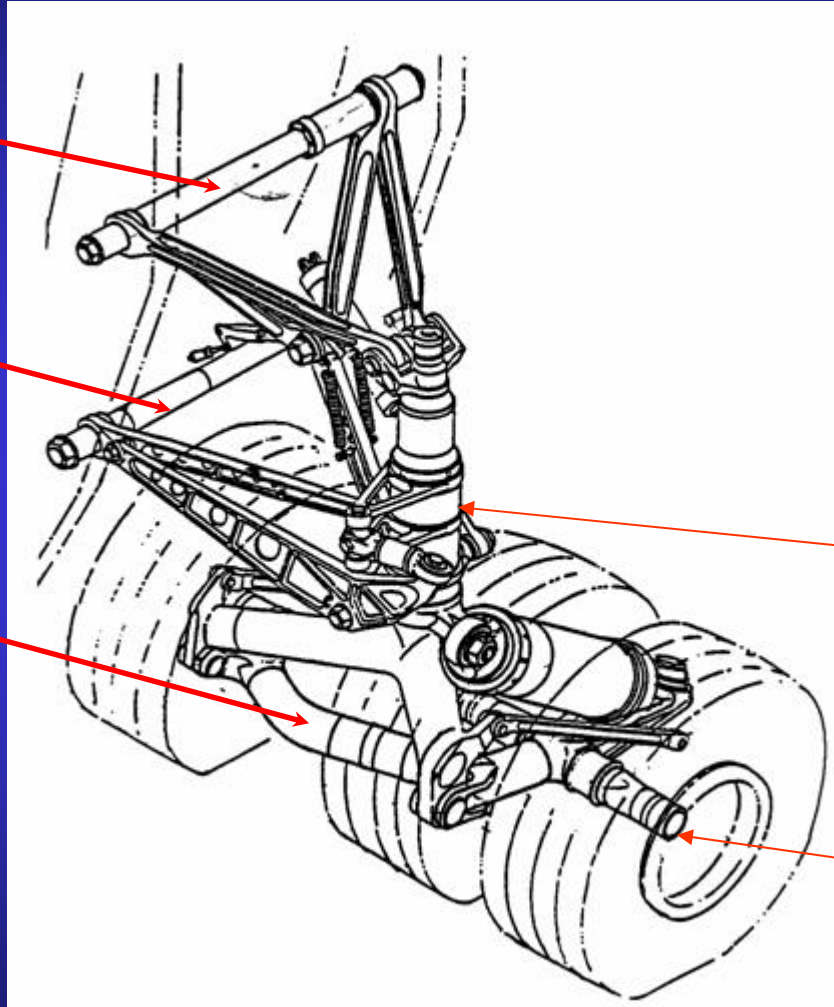
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Upper
Cross Shaft

Lower
Cross Shaft

Axle Beam



Post

Axle

C-17 L/H AFT MLG



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PREVIOUS DURABILITY TESTING C-17 MLG PARTS

- 300M HSS pins/bolts HVOF coated with WC/CoCr
- Successfully completed C-17 MLG durability rig and bench testing
- HVOF coating was exposed to severe loading environment that simulated any problems that might occur in service
- Visual and NDI results give confidence that these HVOF coated parts will survive their expected life
- Concluded HVOF coating performed as well as chrome plating and compatible with mating parts



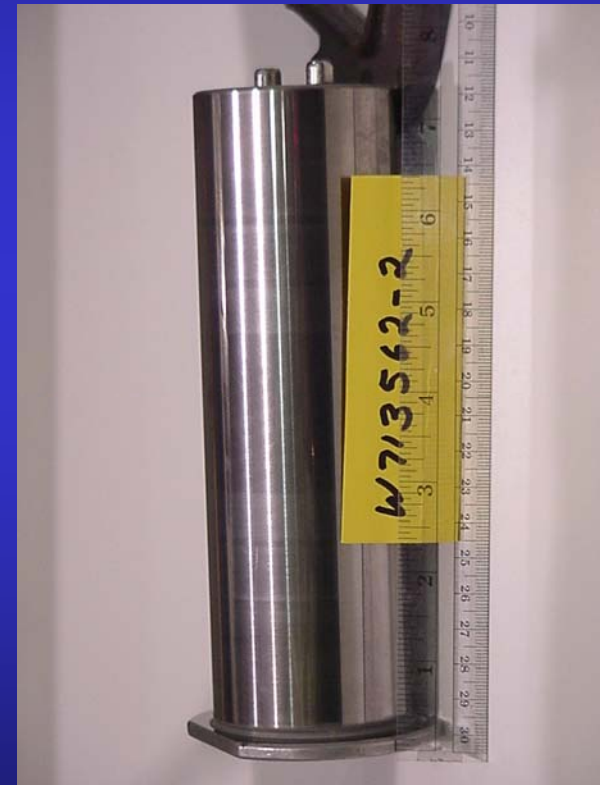
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Chrome plated pin



HVOF coated pin



C-17 LG Pins After Test



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PREVIOUS DEMONSTRATION on C-17 MLG WHEEL AXLE

- Hill AFB applied HVOF coating on OD of single axle
- Initiated Boeing Quality survey / audit of Hill AFB to become approved supplier to process C-17 axles
- Developed proposal for implementation in production and overhaul
- Recommended change drawing notes on 32 selected landing gear parts
 - Outer surface of post, axles, braces, pins, and bolts
- Expect to improve component durability and performance
- Expect to reduce frequency of maintenance and overhaul operations



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Galling/Chipping Chrome Plate and Base Metal



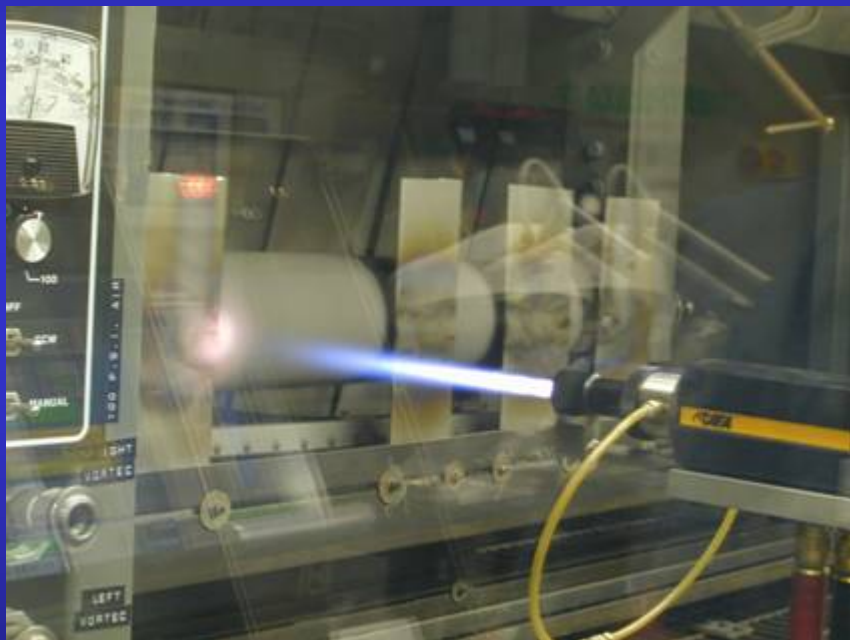
C-17 AXLE Returned From Field



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HVOF Coating



Hill AFB HVOF Coating C-17 MLG Wheel Axle



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Burning/Cracking
Chrome Plate on Shelf

C-17 MLG POST Returned From Field



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PREVIOUS LABORATORY TESTING for THERMAL PROPERTIES

- Implemented WC/CoCr HVOF coating on post shelf
 - Had experienced burning and cracking in service
- Performed testing to measure transient heating of HVOF coating compared to baseline chrome plating and bare 300M
- Expected HVOF to have better thermal barrier properties than chrome, will spread heat and reduce transfer to base metal
- Results indicate no statistically significant difference in average temperature change between samples
- Conclude that HVOF, at the applied thickness, did not provide any thermal resistance or barrier protection



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PREVIOUS LABORATORY TESTING for FATIGUE PROPERTIES

- Evaluated fatigue properties on high strength steel (HSS) Boeing smooth, big bars at R = 0.2 and -0.3
- Compared HVOF / thermal spray coated to hard chrome plated and bare specimens
- As expected, bare specimens performed best
- In general, HVOF / thermal spray coating performed better than chrome plating
- Similar results but some variation between three Boeing approved suppliers



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PREVIOUS EVALUATION of REPAIR METHODS

- **Laboratory testing of brush plating repair for hard chrome plating and HVOF coating on high strength steel**
 - Evaluated six no-bake nickel-based brush plating candidates
 - Completed screening tests for adhesion, metallurgy, and hydrogen embrittlement
 - All somewhat softer and more flexible, compatible with hard chrome as repair
 - All non-embrittling, hydrogen embrittlement bake not required



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CURRENT QUALIFICATION of REPAIR METHODS

- Qualify and demonstrate permanent repair for LG components
- Added tri-chrome (Tri Cr) brush plating as new candidate
- Perform further testing for adhesion, metallurgy, corrosion, fluid immersion, fatigue, and static and dynamic loads
- Conduct demonstration and assess maintenance impact
- Prepare Douglas Process Standard (DPS) for repair materials and processes for C-17 program
- Involve Boeing – Long Beach, Mesa & St. Louis, Suppliers, Aircraft Maintainers, and C-17 Systems Group



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Brush Plate Flow Process with D.C. Power Supply (A), Panel Holder (B) and Brush Plate Tool/Anode (C).



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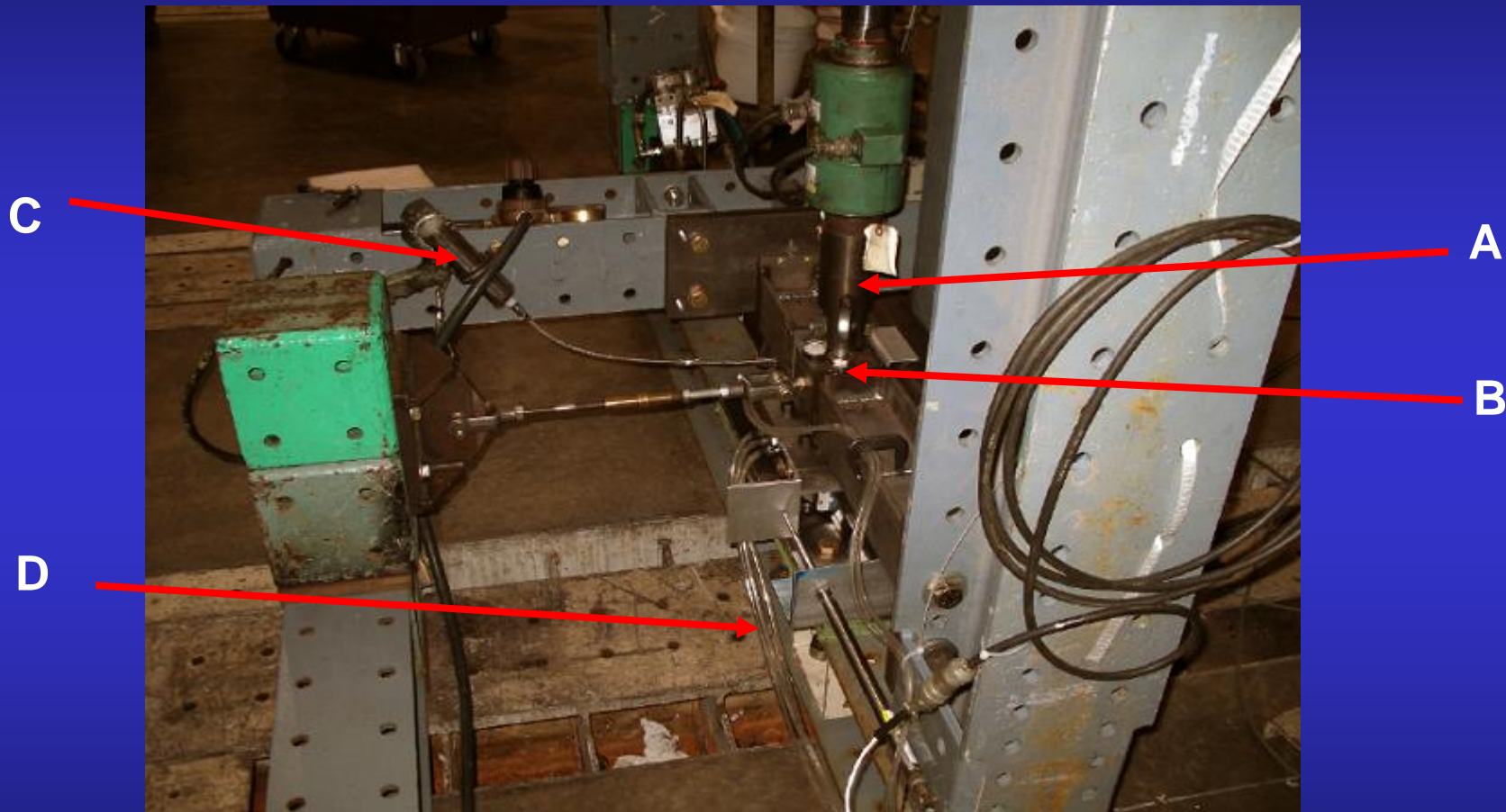
STATUS / RESULTS of LOADS TESTING for CHROME REPAIR

- **Performed reduced dynamic loads testing on first set of specimens with 3 mil coatings**
 - Hard Chrome baseline performed best
 - Two candidate repairs Ni Hi Build and Ni Hi Speed
 - Performed nearly as well as Hard Cr, showed minimal wear and low lateral load/friction
 - Two candidate repairs Ni-W and Tri Cr
 - Not perform as well as Hard Cr, broke down/peeled off
 - HVOF baseline showed high lateral load and galled/wore off the Cu-Be load block
- **Completed all static testing on 3 and 10 mil coatings as specified by Landing Gear IPT**
 - Showed no damage, only slight indentation on load area



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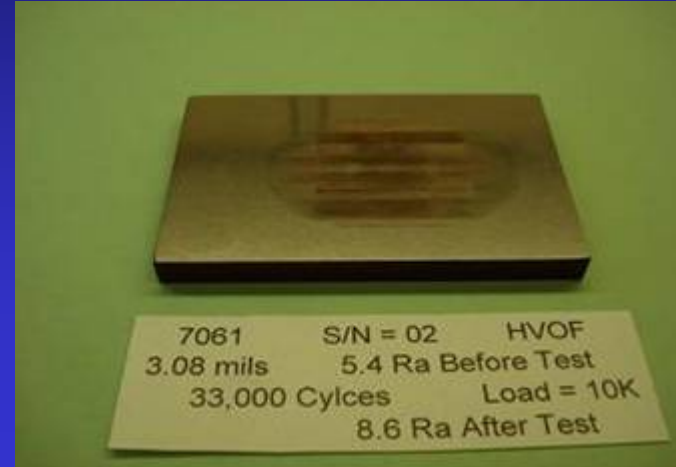


**Dynamic Loads Test Fixture with Load (A), Specimen (B),
Lubrication (C), and Cooling (D)**



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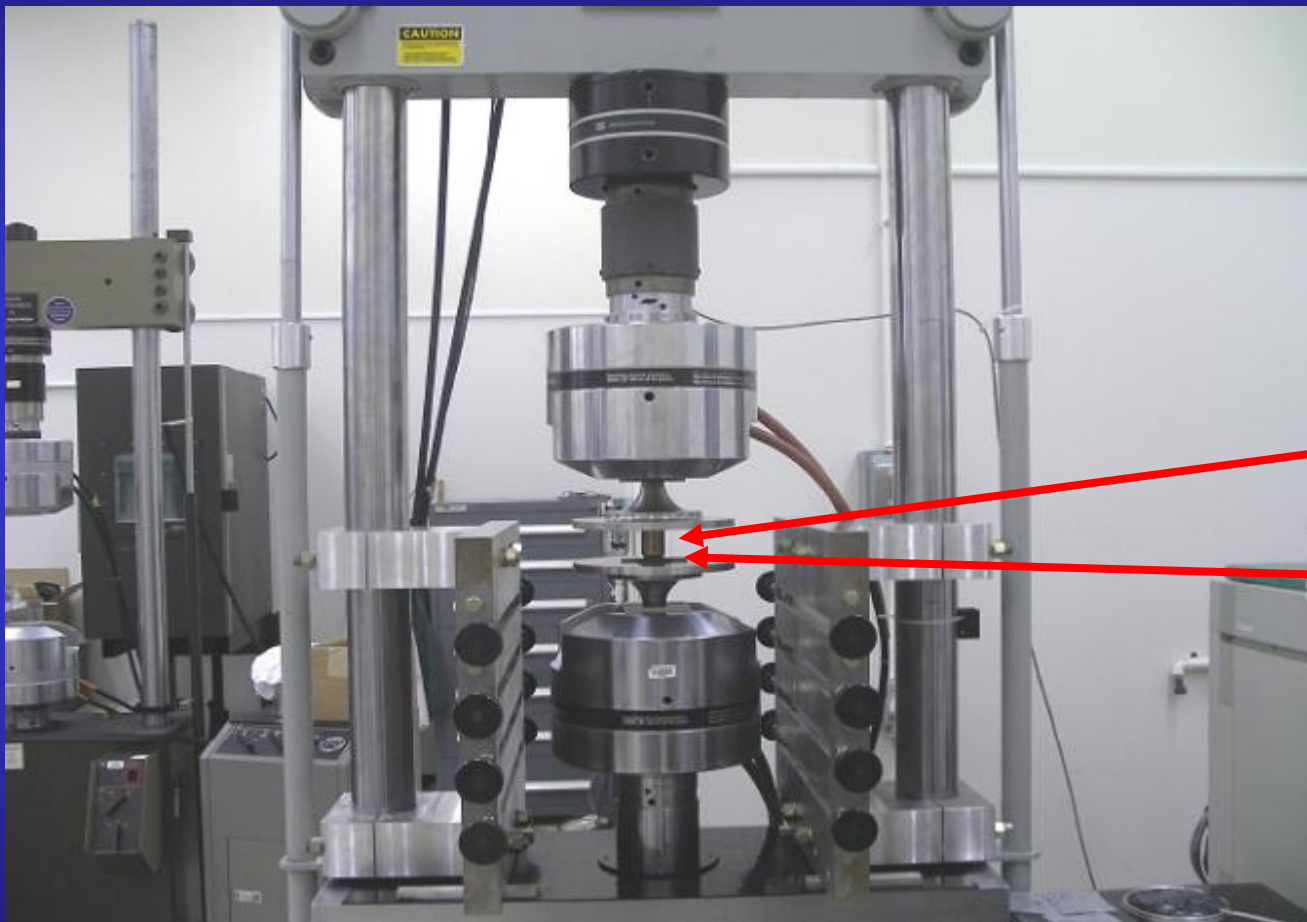


Dynamic Loads Specimens After Test



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A

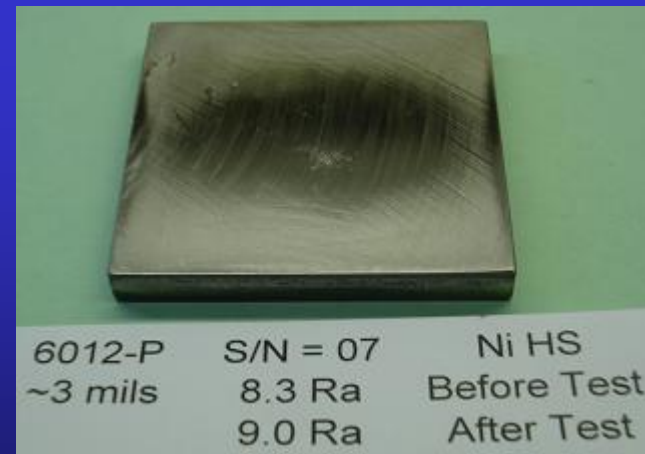
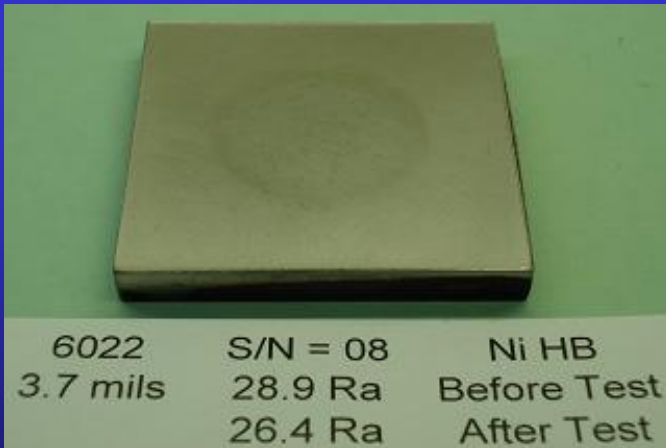
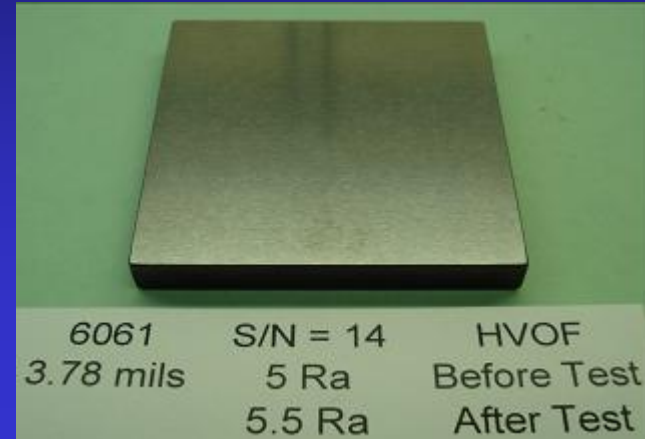
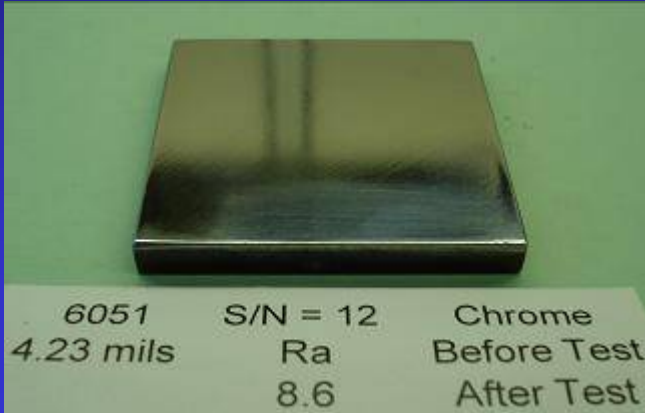
B

Static Loads Test Fixture with Load Block (A) and Specimen (B)



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Static Loads Specimens After Test



LANDING GEAR COMMENTS on LOADS TESTING

- **Repair candidates that passed the static test will be viable for brush repair for our largest expected usage**
 - Majority of expected uses of these chrome repairs will be at overhaul on lug bores/faces, which are static applications
- **Dynamic repair applications will probably be limited to a far smaller number of repairs at overhaul**
 - Covers the cross shafts and (depending on what you estimate as affective bearing area) the post shelf



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BASELINE / REPAIR MATERIAL PROPERTIES

- **Ni Hi Build and Ni Hi Speed repair candidates**
 - Somewhat softer than Hard Cr and more flexible
 - Can be deposited to 3 mils and 10 mils thick
- **Ni-W and Tri Cr repair candidates**
 - Somewhat harder than Ni candidates and less flexible
 - Can only be deposited to 3 mils, not 10 mils, thick
 - Slower or more difficult to apply
- **HVOF coating baseline**
 - Considerably harder than Hard Cr and repair candidates
 - Low porosity and no micro cracks, does not hold grease as well as other coatings



REVISED TEST PLAN for CHROME REPAIR

- Drop Ni-W and Tri Cr as candidate repairs because they have no advantages and are more difficult to plate
- Perform dynamic loads testing on second set of six specimens of 10 mil coatings
 - One Hard Chrome and one HVOF applied by outside supplier
 - Two Hi Build and Two Hi Speed
 - One each applied by Boeing Mesa and St. Louis facilities to demonstrate that process and test can be reproduced



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AGREED PATH FORWARD for CHROME REPAIR

- **Revise and approve TW/R to reflect reduced loads test**
- **Revise test and project plan and estimate the additional budget and schedule to complete project**
- **Proceed to plate and test the second and final set of dynamic specimens**
- **Proceed to plate and test the specimens for other tests**
 - Adhesion, metallurgy, corrosion, fluid immersion, hydrogen embrittlement, and fatigue
 - Passed bend adhesion and hydrogen embrittlement
 - Other plating and testing underway