CORROSION TESTING OF ADVANCED COATINGS IN ACCORDANCE WITH HARD CHROME ALTERNATIVES TEAM ACTUATOR JOINT TEST PROTOCOL

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Hard Chrome Alternatives Team Meeting
San Diego, CA – January 24, 2006

CTC Concurrent Technologies Corporation

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **24 JAN 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Corrosion Testing of Advanced Coatings in Accordance with Hard Chrome Alternatives Team Actuator Joint Test Protocol**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Concurrent Technologies Corporation,100 CTC Drive,Johnstown,PA,15904**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **26th Replacement of Hard Chrome and Cadmium Plating Program Review Meeting, January 24-26, 2006, San Diego, CA. Sponsored by SERDP/ESTCP.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**46**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Outline

- Introduction
- Summary of Efforts
  - Actuator Coating Research
    - Field/Depot Assessments
    - Alternatives
  - Corrosion Testing
  - Corrosion Test Results
- Summary

Introduction - U.S. Army Efforts

- "Validation of Corrosion Protection of Hydraulic Systems"
  - Multi-year task initiated under U.S. Army Corrosion Measurement and Control (CM&C) Program in FY02
  - Continuing under U.S. Army Technology Demonstration for Prevention of Material Degradation (TDPMD) Program
- Objectives:
  - Assess impact of corrosion on U.S. Army hydraulic-based assets
  - Identify and validate technologies to mitigate most critical corrosion problems

Introduction - U.S. Army Efforts (cont.)

- PHASE 1 – Identify affected Army assets, and assess impact of hydraulic corrosion/degradation
- PHASE 2 – Identify hydraulic components, and impact of corrosion
- PHASE 3 – Identify candidate advanced coatings and technologies for problem mitigation
- **PHASE 4 – *Test candidate technologies identified***

PHASES 1 – 3 complete, PHASE 4 underway

Introduction – Critical Military Hydraulic Assets

M9 Armored Combat Earthmover (ACE)

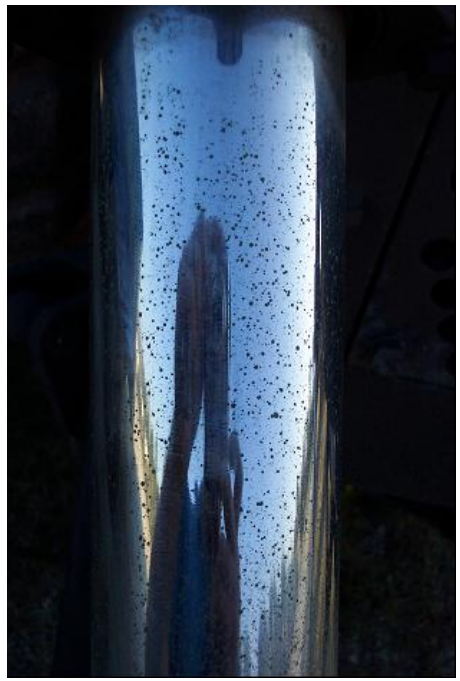
Palletized Load System (PLS)

(truck (M1074 (older), M1075 (newer)), trailer (M1076), cargo beds (M1077))

Introduction – Most Critical Hydraulic Components

Hoses

Hose-End Fittings



Actuators

Actuator Coating Research

- Actuator – "receives pressure energy and converts it to mechanical force and motion" (*source: FM 5-499, Hydraulics*)
- Low alloy carbon steel substrates
  - Stainless in commercial, but not military
- Conventionally coated with electrolytic hard chrome (EHC)
  - Wear resistance
  - Anti-galling
  - Low coefficient of friction

Actuator Coating Research – Alternatives

- Most promising alternative coatings for actuators identified from literature, past work, etc.
- EHC Repair technologies
  - Thermal Spray (TS) Coatings
    - Tungsten Carbide alloys
    - Chromium Carbide alloys
    - Proprietary TS coatings
    - Electrospark deposition
- EHC Enhancement technologies
  - Proprietary surface treatments

Actuator Coating Research – Alternatives (cont.)

- EHC Replacement technologies
  - Electroless plated nickel (EN), and electroplated coatings
  - Surface modification technologies
  - Trivalent chrome plating baths
  - TS coatings
  - And many more
- Downselected promising product/technology from each category
  - Potential military utilization
  - Not studied previously

Corrosion Testing

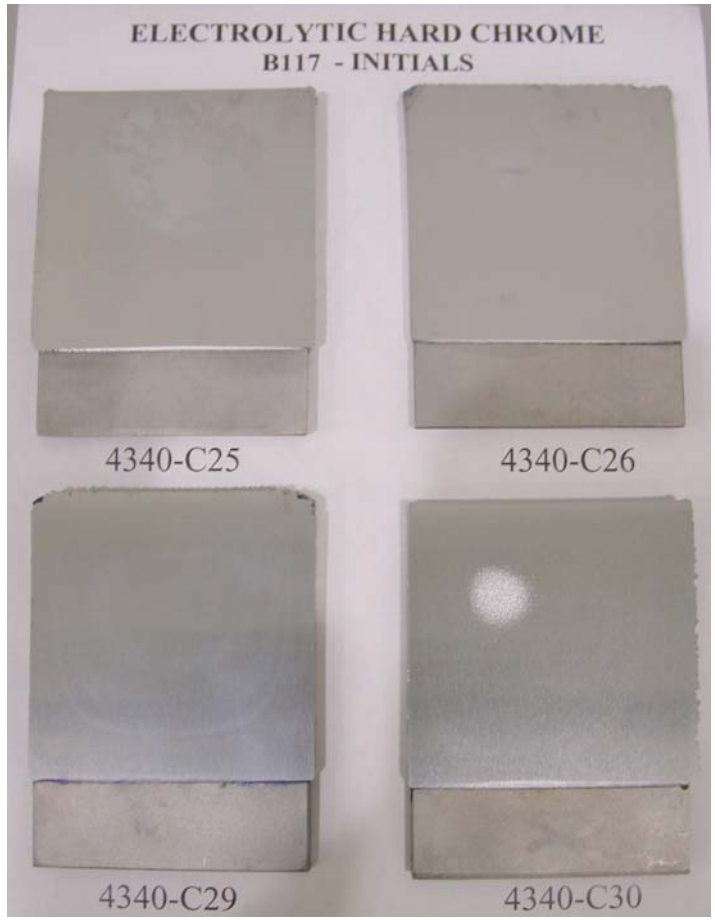
- Three sets of test specimens
  - TDPMD Shaft Specimens
    - Designed to simulate actuators used in military ground vehicles
    - Test data gap matrix completed
    - Test plan finalized
  - Hard Chrome Alternatives Team (HCAT) Panels
  - HCAT Shafts
    - Designed to simulate actuators used in military aircraft
- Corrosion testing in accordance with:
  - ASTM B117
  - HCAT Joint Test Protocol, "Validation of HVOF Thermal Spray Coatings as Replacements for Hard Chrome Plating On Hydraulic/Pneumatic Actuators, Part I – Coupon Testing," dated January 19, 2004

Corrosion Testing – Specimens

- TDPMD Shafts
  - 1045 alloy cold rolled steel shafts, 38 mm (1.5") in diameter, 101.5 mm (4") lengths
  - Controls
    - Bare (uncoated) shafts
    - EHC, 2 mils, per SAE AMS-QQ-C-320, "Chromium Plating (Electrodeposited)"
  - Candidate Mitigation Technologies
    - Repair technology – Commercial off-the-Shelf (COTS) TS
    - Enhancement technology - EHC with COTS surface treatment (ST)
    - Replacement (plating) technology – COTS EN

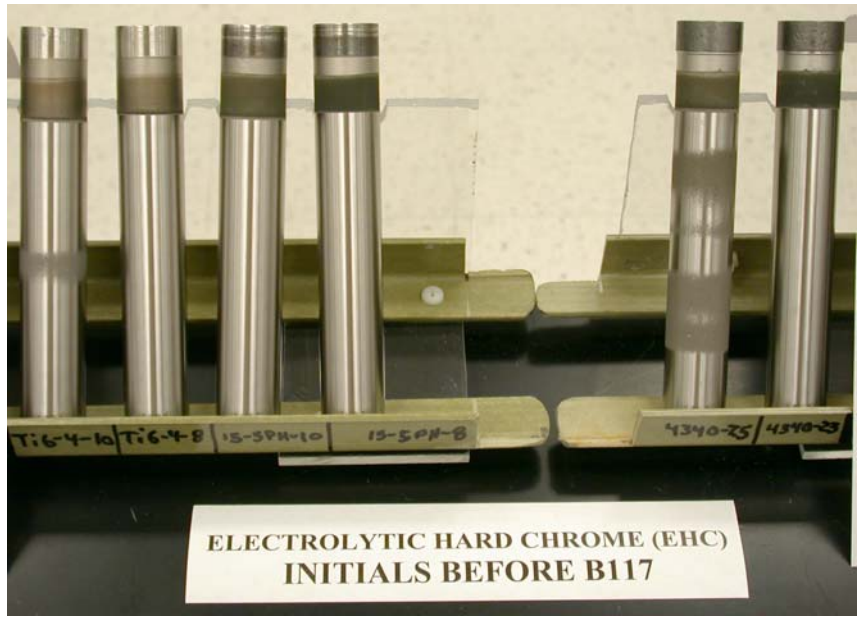
Corrosion Testing – Specimens (cont.)

- HCAT Panels
  - EHC and TS coated panels
  - Three substrates
    - 4340 steel alloy
    - Precipitation hardened (PH) 15-5 steel
    - Titanium 6-4 alloy
  - Three coatings
    - EHC
    - Thermal sprayed tungsten carbide cobalt chrome
    - Thermal sprayed T400



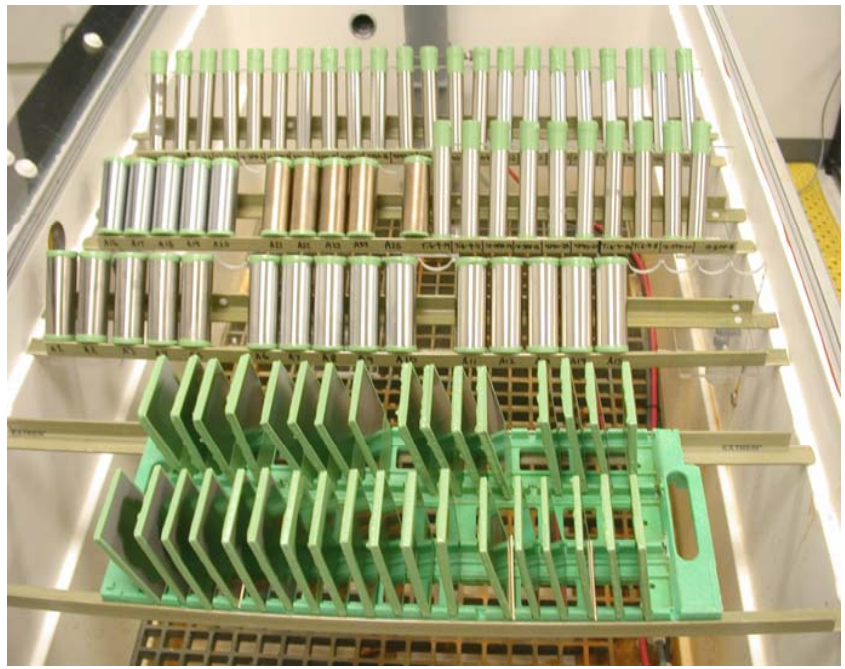
Corrosion Testing – Specimens (cont.)

- HCAT Shafts
  - EHC and TS coated specimens
  - Three substrates
    - 4340 steel alloy
    - PH 15-5 steel
    - Titanium 6-4 alloy
  - Four coatings
    - EHC
    - Thermal sprayed tungsten carbide cobalt chrome
    - Thermal sprayed chromium carbide
    - Thermal sprayed T400

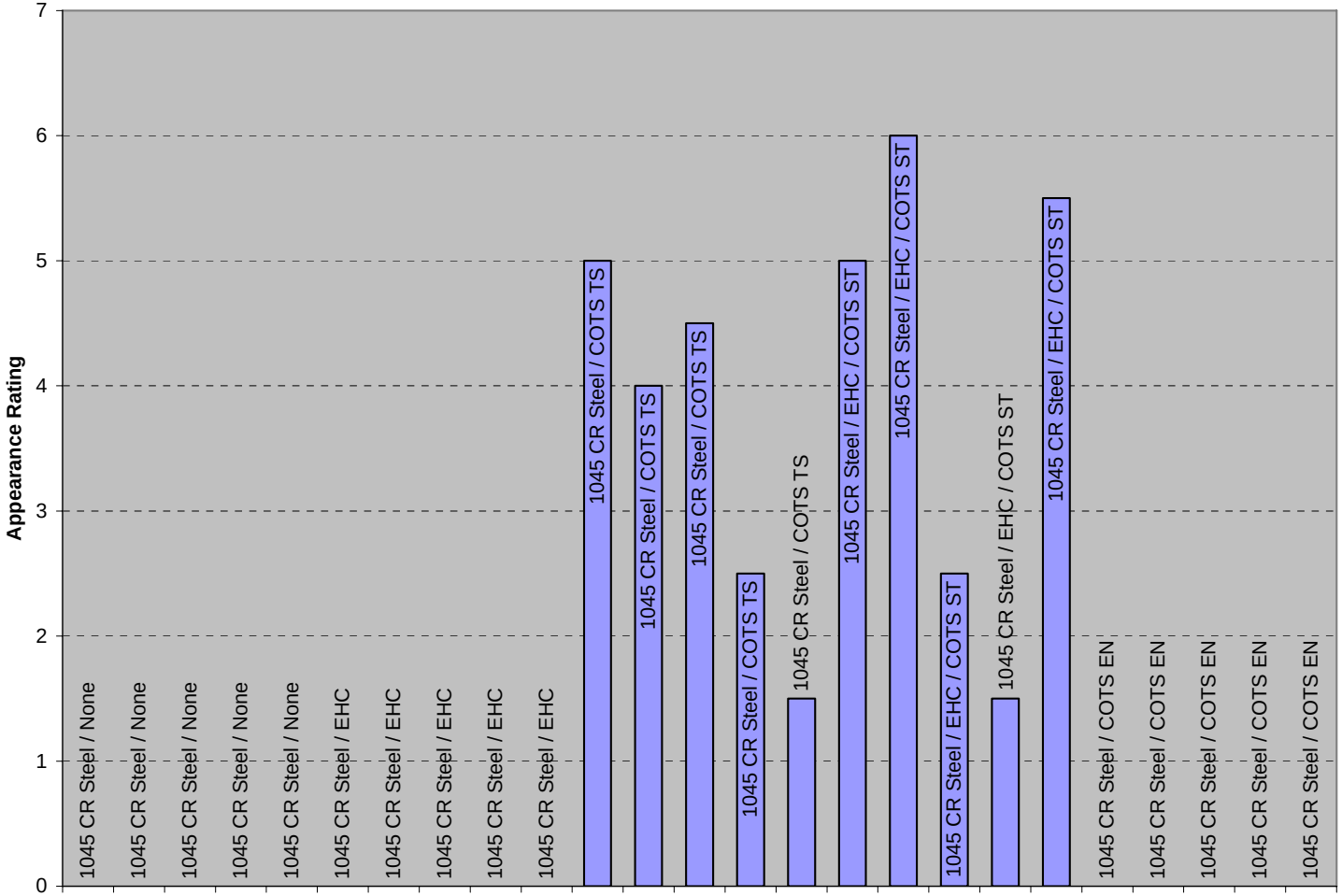


Corrosion Testing – Test Plan

- ASTM B117, 1000 hours duration total
  - Cleaned in accordance with ASTM G1 before and after test
  - Interval evaluations
    - Photographed at select intervals
    - Rated in accordance with ASTM B537
    - Protection and appearance ratings
  - Appearance ratings at 1000 hours presented



Corrosion Test Results – TDPMD Shafts



B117 – Appearance Rating After 1000 Hours

Corrosion Test Results – TDPMD Shafts (cont.)

- TDPMD specimens after 619 hours of B117

COTS TS

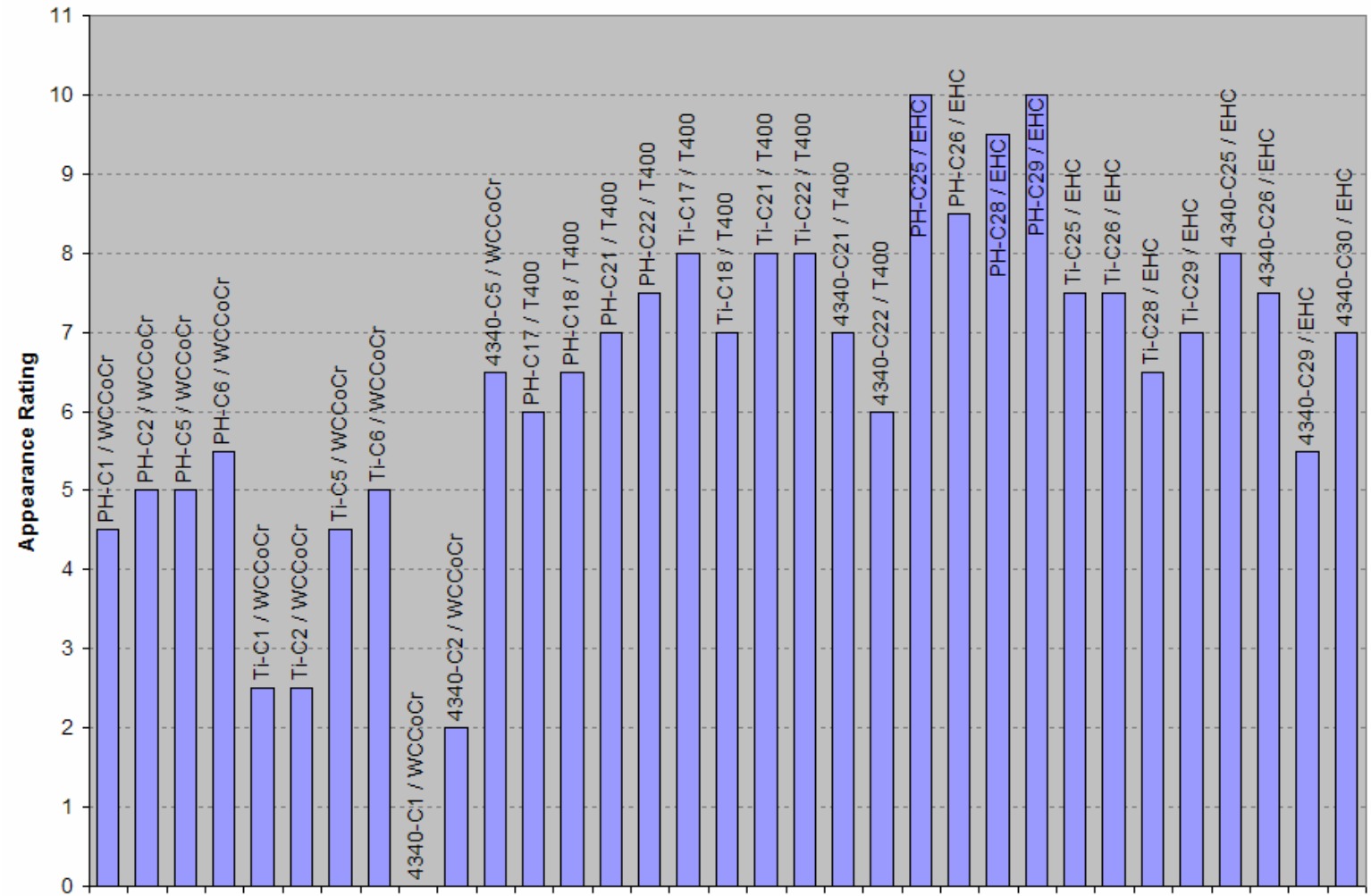
COTS ST

COTS EN

Corrosion Test Results – TDPMD Shafts (cont.)

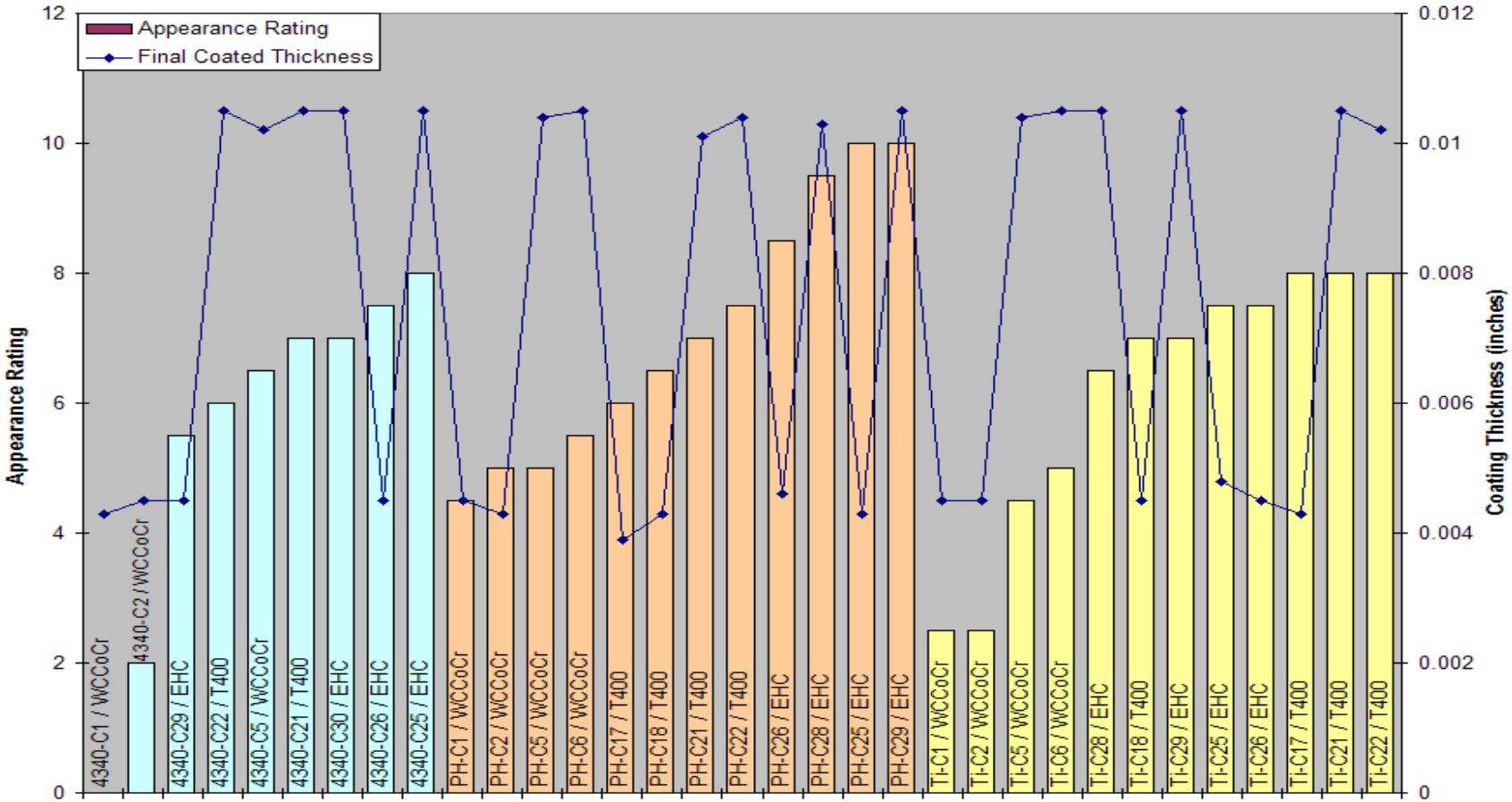
- Uncoated and EHC-plated shafts exhibited high corrosion rates, as expected
- COTS TS provided improved protection when compared to uncoated and EHC
- COTS ST provided improved performance to EHC
- COTS EN exhibited significant corrosion
- Corrosion performance enhancement of TS and ST specimens over EHC is evident

Corrosion Test Results – HCAT Panels



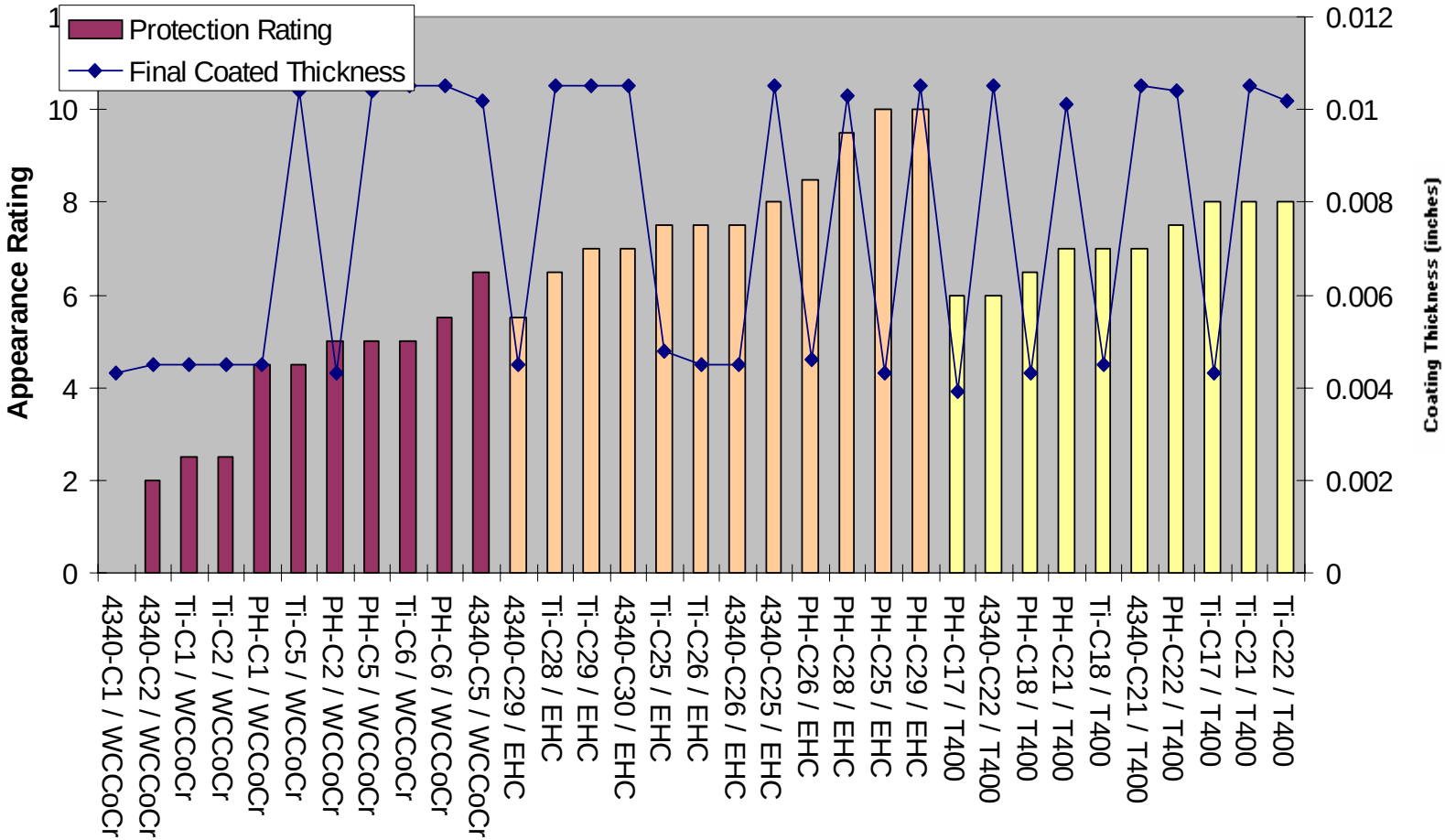
B117 – Appearance Rating After 1000 Hours

Corrosion Test Results – HCAT Panels (cont.)



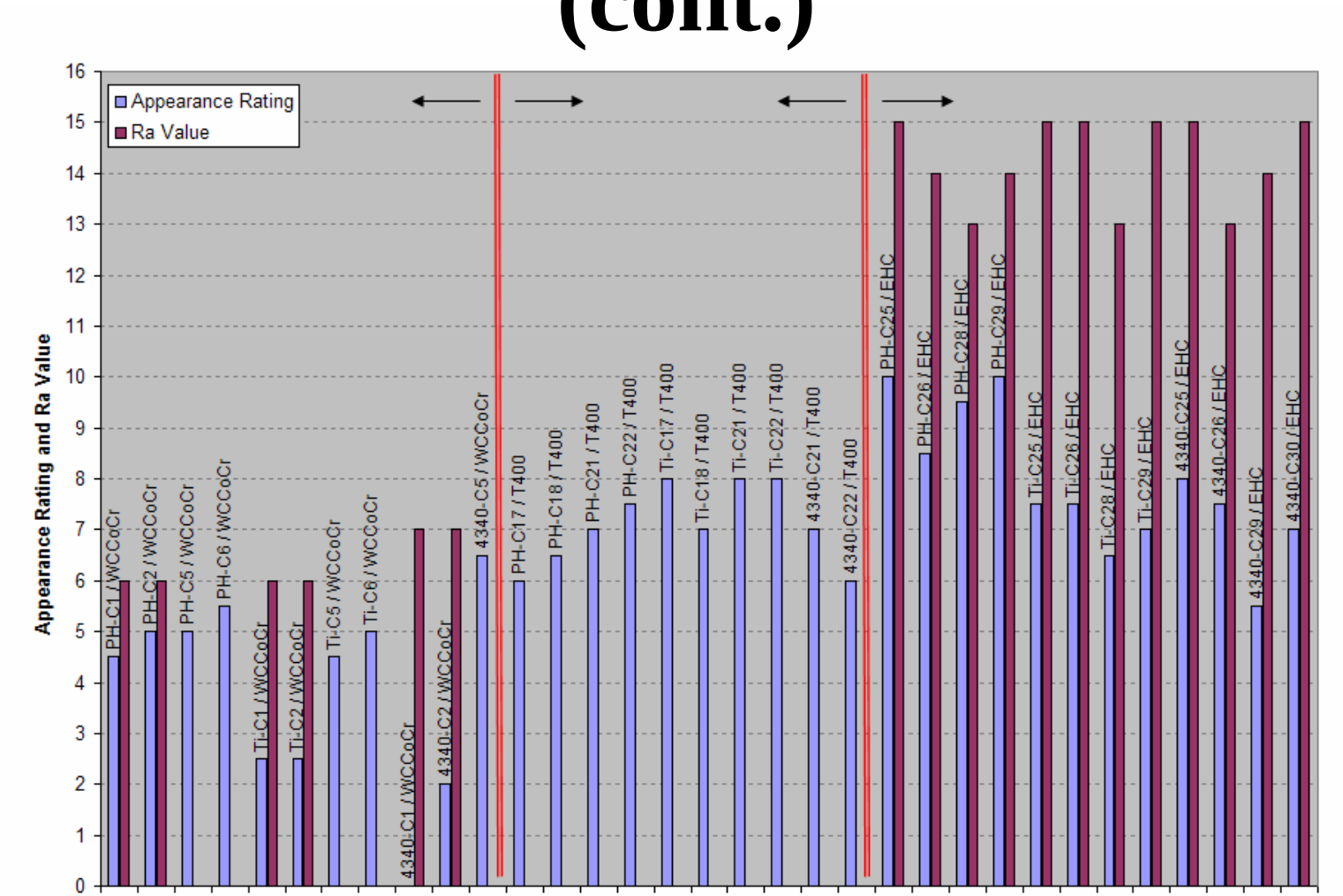
Coating Thickness vs. Appearance Rating After 1000 Hours, by Substrate

Corrosion Test Results – HCAT Panels (cont.)



Coating Thickness vs. Appearance Rating After 1000 Hours, by Coating

Corrosion Test Results – HCAT Panels (cont.)



Surface Roughness (Ra) vs. Appearance Rating after 1000 Hours, by Coating

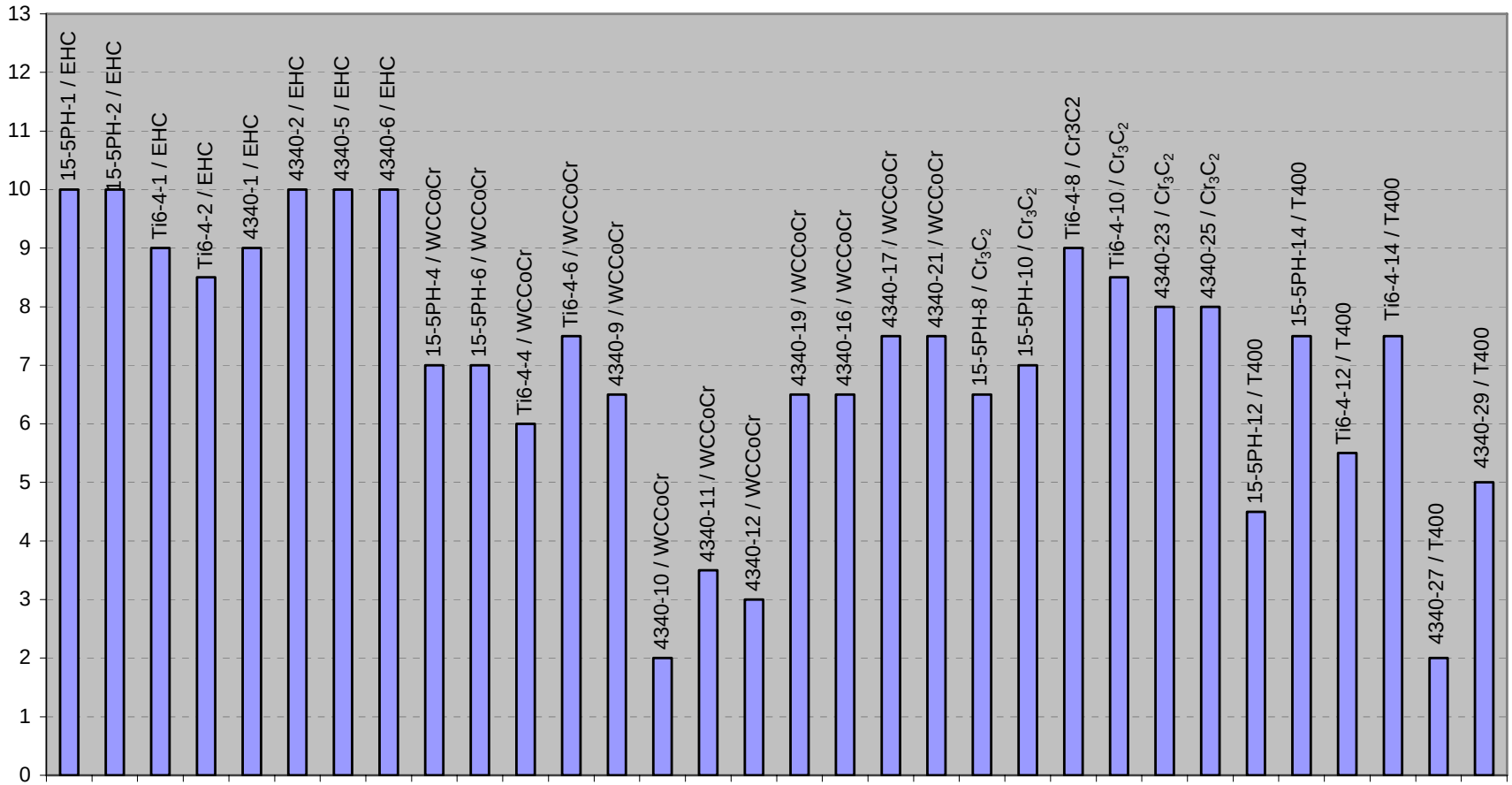
Corrosion Test Results – HCAT Panels (cont.)

- Results very different than those of TDPMD specimens
  - Performed better than all TDPMD specimens
  - Could be related to process, but probably influence of coating thickness
- Some substrate influence
- EHC best performer on all three substrates
- T400 comparable to EHC on all three substrates
- Tungsten carbide cobalt slightly less protection than EHC
  - Inconsistent with past HCAT work

Corrosion Test Results – HCAT Panels (cont.)

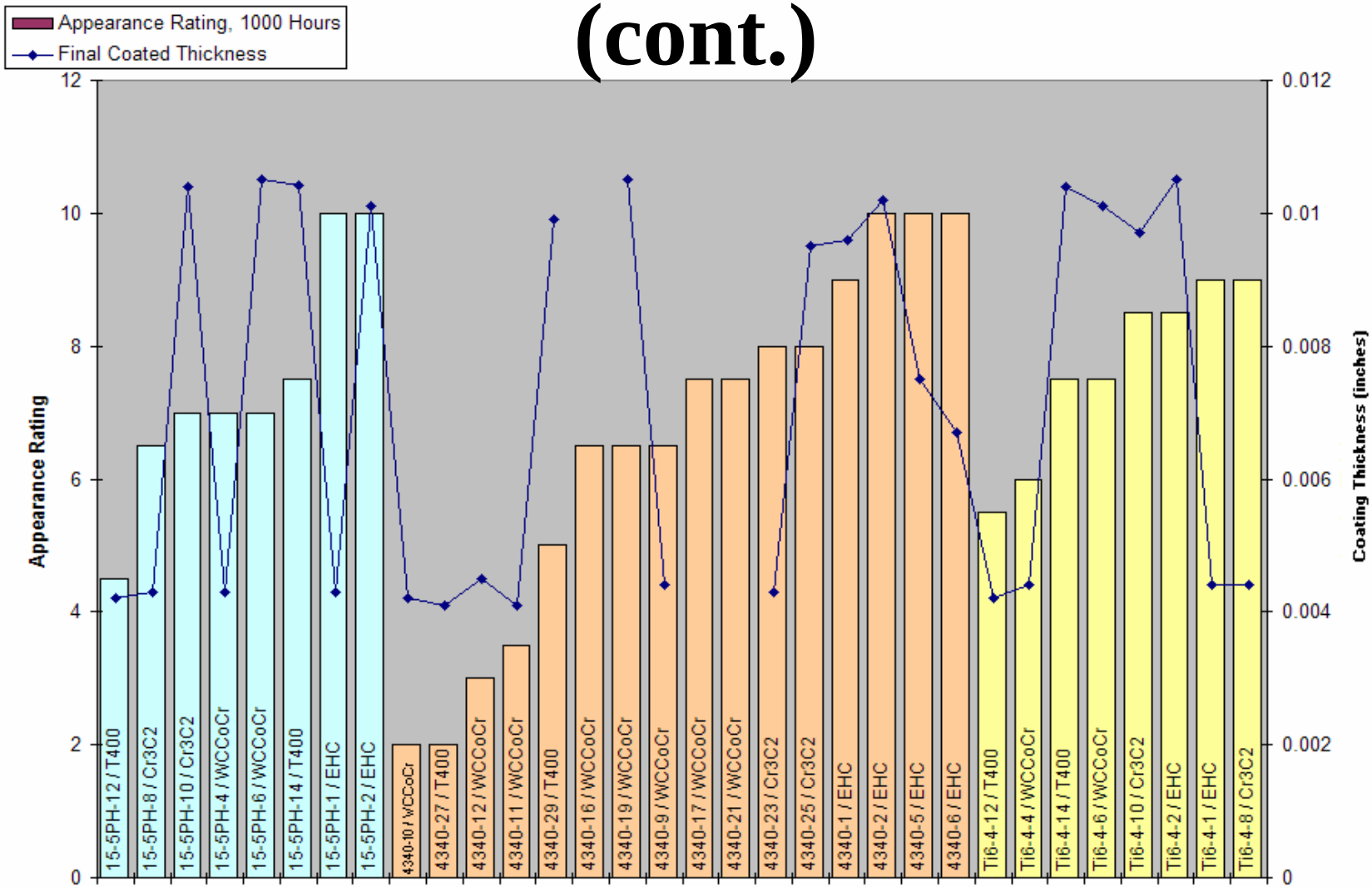
- Appearance rating related to coating thickness
- Appearance rating vs. Ra results inconclusive, but apparently independent of appearance rating
  - NOTE: Ra = average surface roughness, not

Corrosion Test Results – HCAT Shafts



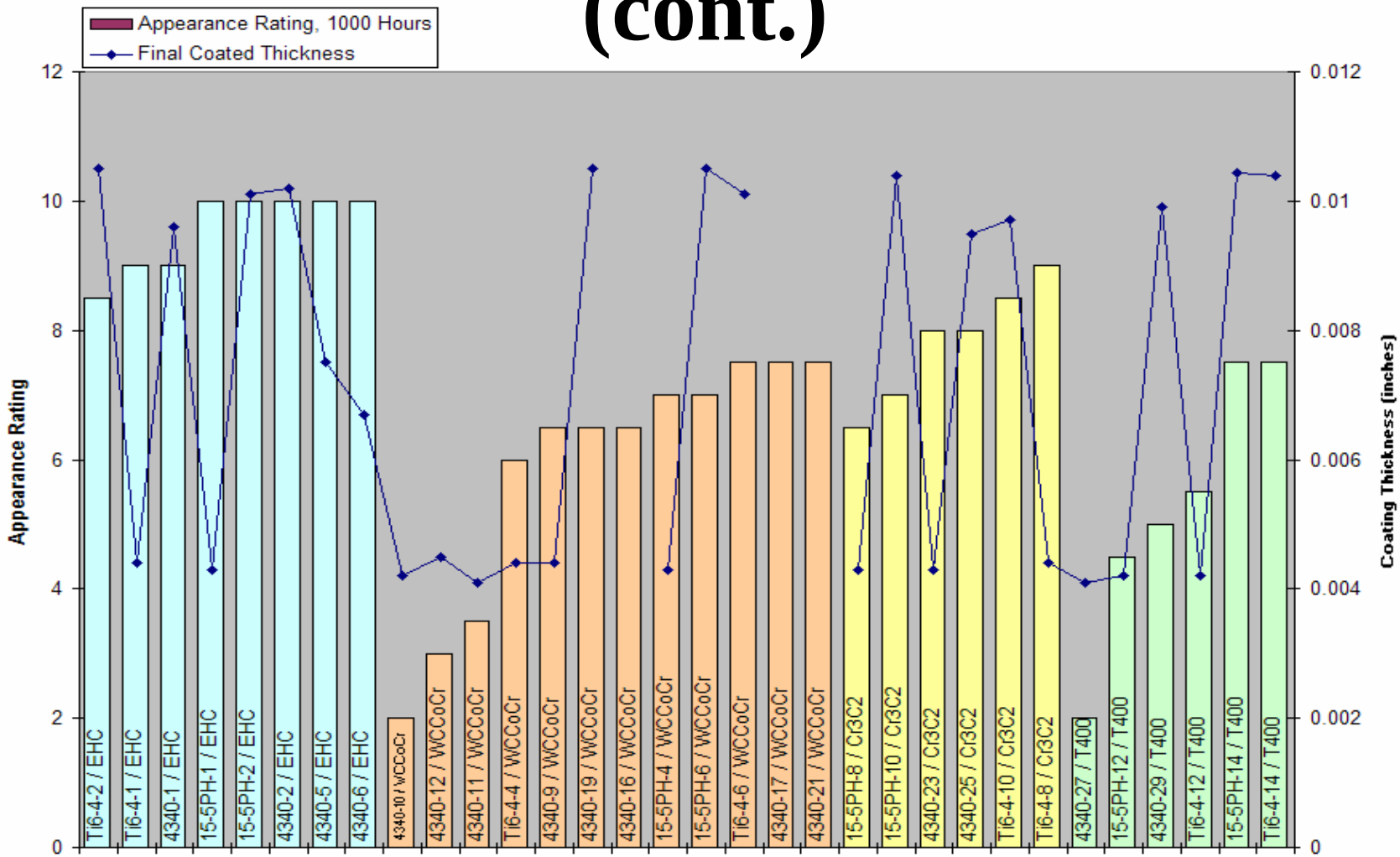
B117 – Appearance Rating After 1000 Hours

Corrosion Test Results – HCAT Shafts (cont.)



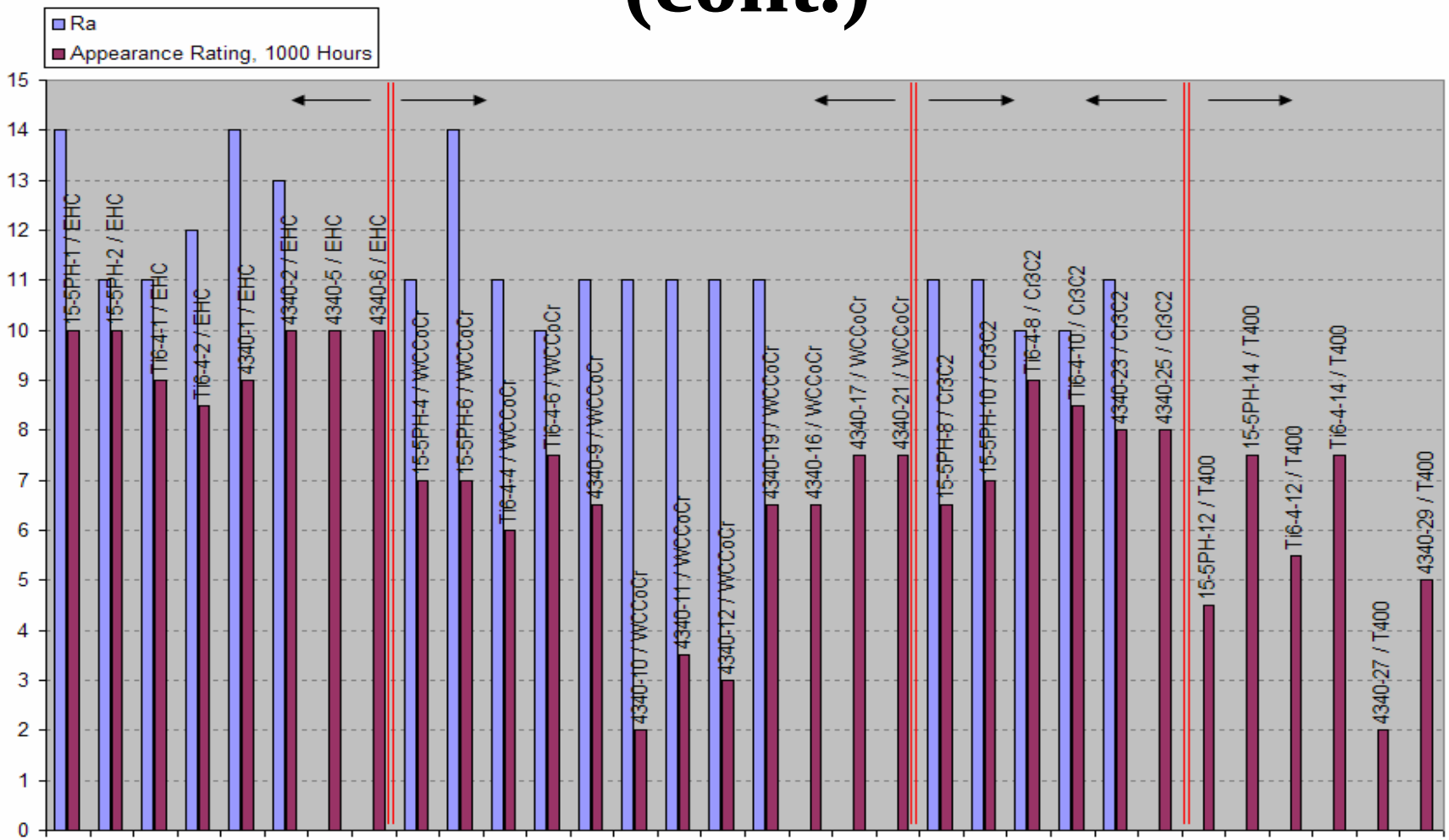
Coating Thickness vs. Appearance Rating After 1000 Hours, by Substrate

Corrosion Test Results – HCAT Shafts (cont.)



Coating Thickness vs. Appearance Rating After 1000 Hours, by Coating

Corrosion Test Results – HCAT Shafts (cont.)



Ra vs. Appearance Rating after 1000 Hours, by Coating

Corrosion Test Results – HCAT Shafts (cont.)

- Results very different than those of TDPMD specimens
  - Performed better than all TDPMD specimens
  - Could be related to process, but probably influenced by coating thickness
- Some substrate influence
- EHC best performer on all three substrates
- Chrome carbide, tungsten carbide provided similar protection (but slightly less than EHC)
- T400 provided less protection
  - Consistent with past HCAT work

Corrosion Test Results – HCAT Shafts (cont.)

- Appearance rating related to coating thickness
- Appearance rating vs. Ra results inconclusive, but apparently independent of appearance rating

Summary

- Emerging need to replace EHC for many military applications
  - Hydraulic actuators
- Alternative actuator coatings for ground vehicle applications
  - COTS ST provided significant enhancement to EHC
    - Might be useful for field repair
    - Eventual OEM utilization ??
  - COTS TS promising as well

Summary (cont.)

- Alternative actuator coatings for aerospace applications
  - TS coatings somewhat comparable to EHC for aerospace applications
  - Chromium carbide, tungsten carbide most promising
- Corrosion performance of EHC specimens was inconsistent between groups (TDPMD shafts vs. HCAT panels and shafts)
  - Dependent upon processing, coating thickness, substrate influence

Summary (cont.)

- Further work
  - Evaluate COTS surface treatment for field repair of EHC-plated components
    - More comprehensive corrosion testing
    - Compatibility with hydraulic fluid
    - Mechanical and wear testing
    - Field testing
      - Dynamic testing (e.g. test track, in theater)
      - Storage

Acknowledgments

- This work was funded under the U.S. Army TDPMD Program
- The authors wish to thank
  - The U.S. Army Corrosion Office
  - Depot maintenance personnel interviewed under this effort
  - HCAT
  - Mr. Larry Gintert of *CTC*

BACKUP SLIDES

Introduction

- Corrosion of hydraulic components in military systems is an important operability and sustainment (O&S) concern
  - Full impact often not recognized
- Impact of hydraulic fluid leakage
  - Leakage at Class Three (falling droplets) = Not Mission Capable (NMC) (*SOURCE: Area Maintenance Support Activity, Orlando, FL*)
- Root causes
  - Dirt and/or sand contamination
  - Rock impingement
  - Non-use of equipment

Introduction

- Hydraulic systems/hydraulics – “transmitting force and/or motion through the medium of a confined liquid” (*source: FM 5-499, Hydraulics*)
  - Also referred to as fluid power
- Used on a variety of commercial systems, as well as military systems
  - Aircraft
  - Ground vehicles
  - Transport systems
  - Weapons systems

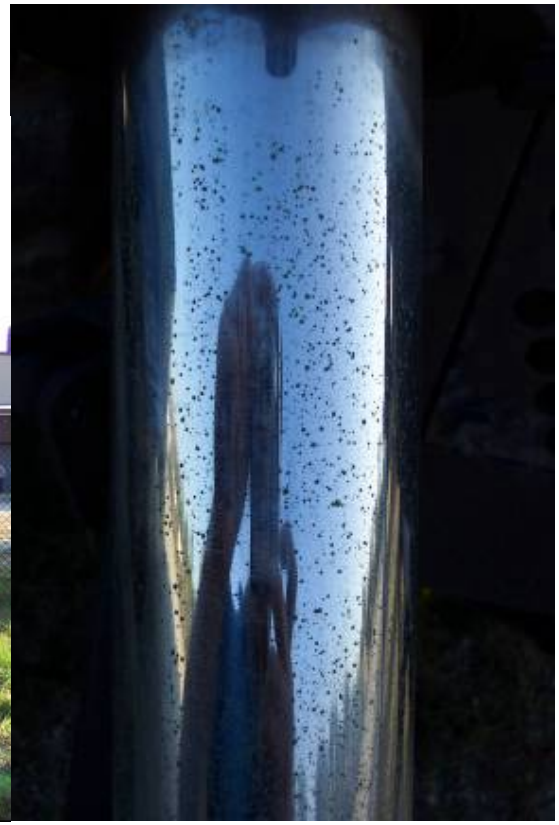
Actuator Coating Research (cont.)

- Issues related to EHC
  - Environmental, safety, and health concerns regarding potential exposure to hexavalent chromium during EHC deposition process
    - Regulatory constraints (and related costs) associated with handling and disposal of wastes
    - New regulations impact cost and availability of EHC
  - Limited degree of corrosion protection
    - Significant corrosion issues noted during military depot visits

Actuator Coating Research – Field/Depot Assessments (Fort Hood)

- Corrosion on Actuator of M4K Tactical Forklift

Actuator Coating Research – Field/Depot Assessments (Fort Benning)



- Pitting Corrosion on Actuator on Wheeled Tractor

Photos from Anniston Army Depot (ANAD)

Corrosion on Hydraulic Actuator

Photos from ANAD

Corrosion on Hydraulic Actuator

Impact of Hydraulic Corrosion on Selected Assets

- Operational Readiness
  - Goals (per AR 220-1)
    - 90% for everything except aircraft
    - 75% for aircraft
  - With this in mind, M9 ACE readiness
    - Historically – 68–92% (Report, "Analysis of Operational Readiness Rates," West Point, July 1998)
    - 2004, CONUS – 85–88% (per M9 PM, TACOM)
    - 2004, Iraq – 90% start, 70% finish (Report, "Op. Iraqi Freedom Engineer Lessons Learned," Nov. 2003)
    - Mostly due to hydraulic failure (bursting, hose failure)

Impact of Hydraulic Corrosion on Selected Assets (cont.)

- Operational Readiness
  - Goals (per AR 220-1)
    - 90% for everything except aircraft
    - 75% for aircraft
  - With this in mind, PLS readiness
    - Historically – about 92% (Source: *Tactical Wheel Vehicle Strategy for the Army*, *April 2004*)
    - Only in service since 1994
    - Total fleet size of over 3,500 trucks
      - Approximately 1,000 (28%) in Iraq theater
    - Mostly due to hydraulic failure (bursting, hose failure)

Impact of Hydraulic Corrosion on Selected Assets (cont.)

- Hose Life Expectancy
  - “Hoses usually replaced every 3 years, much more frequently now” (USMC LOGCOM, Albany, GA)
  - “Quality of hose materials critical” (AMSA, Orlando)
  - ACE and PLS TMs procured, under review for more info
- Differences between commercial and military equipment
  - Commercial hoses not painted, military hoses CARC painted
    - Impact evident but mechanism not clear (AMSA)
  - Commercial systems used constantly, military systems (especially Reserve units) storaged for months (even years)

Implementation

- Technology Readiness Level = 7
- Demonstration/Validation Plan
  - Completed (FY04)
    - Stakeholders established (TACOM, vendors, HCAT, OEMs)
    - Downselected candidate components, materials, weapons system(s), and manufacturer (process, etc.)
    - Test specimens procured
    - Existing test data gathered, gap matrix drafted
    - Completed test plans (FY04)
    - Obtained stakeholder approval for test plans (FY04)
    - Implemented test plans (performance assessment) (FY04/FY05)
      - Conducted testing on component level (lab testing)

Implementation (cont.)

- Demonstration/Validation Plan (cont.)
  - To be completed
    - Complete initial ROI calculations (FY05)
    - Present results to stakeholders (FY05)
    - Implement test plans (performance assessment) (FY05)
      - Conduct testing on system level (field testing)
        - » Field deployment (USMC, Aberdeen, etc.)
        - » Storage in field (AMSA, Orlando, FL)
    - Present results to stakeholders (FY05…..)