Ferrium S53 LG Update

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Surface Finishing and Repair Issues for Sustaining New Military Aircraft

Tempe, AZ February 26-28, 2008

Report Documentation Page

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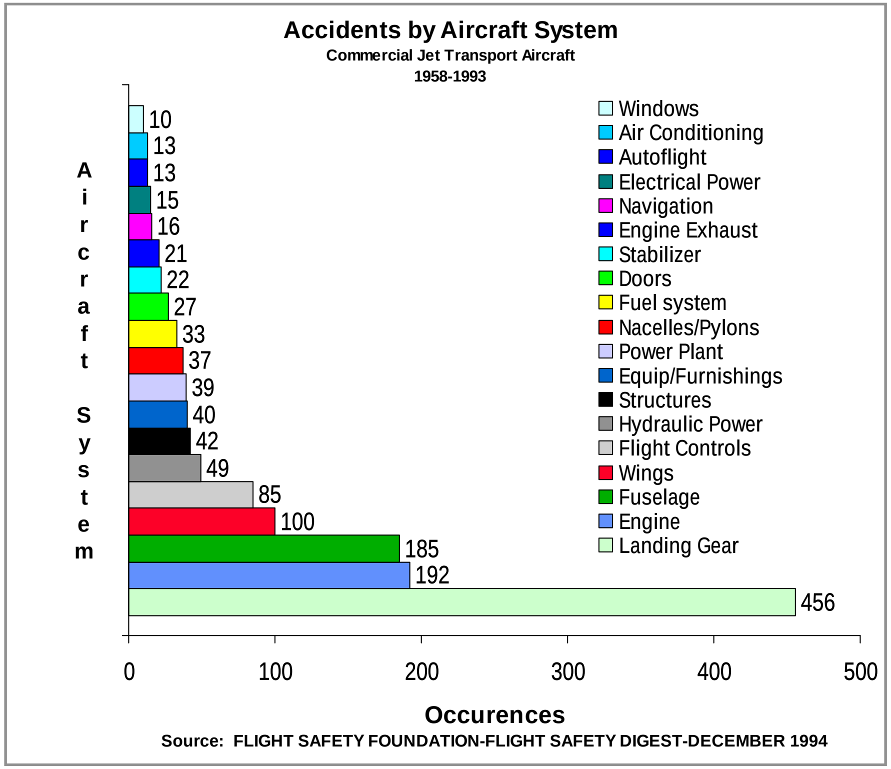
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Ferrium S53: A Nanostructured UHS Corrosion-Resistant Steel



SCC failure

HE failure

Issues:

Over $200 million spent in LG per year

80% corrosion related

SCC failures

Cad plating used to protect current steel

known carcinogen (Hill AFB ~ 2000 lbs/yr)

Benefits:

Dramatic reduction in LG cost (60%)

savings of $120 million per year

Significant reduction in SCC failures

Cadmium plating not required

General corrosion mitigated

80% of Steel Condemnations Avoided

SAE AMS 5922 Published

Issued January 2008

AMS 5922: Steel, Corrosion Resistant Bars and Forgings

10Cr-5.5Ni-14Co-2Mo-1W (0.19-0.23C)

Vacuum Induction Melted, Vacuum Arc Remelted, Normalized, Annealed

http://www.sae.org

(877) 606-7323

Commercial Suppliers:

- Carpenter Technology - Jan 07
- Latrobe Specialty Steel - Dec 07

SAE Aerospace — An SAE International Group	AEROSPACE MATERIAL SPECIFICATION	SAE AMS 5922 Issued 2008-01

Steel, Corrosion-Resistant, Bars, and Forgings
10Cr - 5.5Ni - 14Co - 2Mo - 1W (0.19-0.23C)
Vacuum Induction Melted, Vacuum Arc Remelted, Normalized, Annealed

RATIONALE

AMS 5922 is a new specification to cover corrosion-resistant steel bars and forgings.

1. SCOPE

1.1 Form

This specification covers a corrosion-resistant, premium aircraft-quality alloy steel in the form of bars, forgings, and stock for forging.

1.2 Application

These products have been used typically for heat treated parts requiring a combination of high strength, good toughness, weldability, and stress corrosion resistance, but usage is not limited to such applications. Product after heat treatment should attain a minimum tensile strength of 280 ksi (1931 MPa).

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS 2241	Tolerances, Corrosion and Heat-Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Bars and Wire
AMS 2248	Chemical Check Analysis Limits, Corrosion and Heat-Resistant Steels and Alloys, Maraging and Other Highly-Alloyed Steels, and Iron Alloys
AMS 2300	Steel Cleanliness, Premium Aircraft-Quality, Magnetic Particle Inspection Procedure
AMS 2315	Determination of Delta Ferrite Content
AMS 2371	Quality Assurance Sampling and Testing, Corrosion and Heat-Resistant Steels and Alloys, Wrought Products and Forging Stock
AMS 2374	Quality Assurance Sampling and Testing, Corrosion and Heat-Resistant Steel and Alloy Forgings
AMS 2750	Pyrometry
AMS 2806	Identification, Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels and Corrosion and Heat-Resistant Steels and Alloys

MMPDS Full Dataset Submitted

Over 1200 data points from 10 production heats of AMS 5922 has been submitted to MMPDS for consideration at the April meeting in Las Vegas. The data shown here is the property minimums proposed for the committee agenda (GSG Item 08-01).

2.6.X Ferrium S53

2.6.X.0 *Comments and Properties* — Ferrium S53 is a secondary hardening, martensitic corrosion resistant steel used for parts requiring good fracture toughness, good corrosion resistance, and high resistance to stress-corrosion cracking with ultimate tensile strength greater than 280 ksi. Ferrium S53 is available in a wide variety of sizes and forms, including billet, bar, and forgings. The alloy is produced by vacuum induction melting followed by vacuum-arc remelting.

Manufacturing Considerations - Ferrium S53 is supplied in a normalized and annealed condition. The alloy is readily forged and machined. A dimensional expansion of approximately 0.003 in./in. occurs upon quenching and age hardening from the annealed condition. This fact should be considered before finish machining prior to heat treatment.

Heat Treatment - The heat treatment for this alloy consists of heating to 1985 ±27°F for 1 hour, quenching in oil (or equivalent), cooling to -100°F or lower for 1 hour, warming in air to room temperature, aging at 934 ±12°F for 3 hours, quenching in oil (or equivalent), cooling to -100°F or lower for 1 hour, warming in air to room temperature, aging at 900 ±18°F for 12 hours, and cooling in air (or equivalent).

Environmental Considerations - The general corrosion resistance of Ferrium S53 approaches that of 15-5PH. While the alloy is corrosion resistant, users should consider the specific environment when determining surface preparation/treatment. The alloy is highly resistant to stress-corrosion cracking compared to other ultra high-strength steels.

Table 2.6.X.0(b). Design Mechanical and Physical Properties of Ferrium S53 Steel Bar

Specification	AMS 5922	
Form	Bar and Forging	
Temper	HT to 280 ksi	
Diameter, in.	1.750-8.000	
Basis	A	B
Mechanical Properties:		
F_{tu}, ksi:		
L	280[a]	284
T	280	283
F_{ty}, ksi:		
L	213[a]	218
T	211	218
F_{cy}, ksi:		
L	245	250
T	251	257
F_{su}, ksi		
L-S	176	178
T-S	176	178
F_{bru}^{b}, ksi (e/D = 1.5) :		
L	440	446
T	437	443
F_{bru}^{b}, ksi (e/D = 2.0) :		
L	569	577
T	571	580
F_{bry}^{b}, ksi (e/D = 2.0) :		
L	351	359
T	348	357
F_{bry}^{b}, ksi (e/D = 2.0) :		
L	417	426
T	423	433
e, percent (S-Basis)	11	...
RA, percent (S-Basis)	44	...
E, 10^3 ksi :	29.6	
E_c, 10^3 ksi:	30.7	
G, 10^3 ksi:	...	
μ,	...	

Ferrium S53 Mechanical Properties

Ferrium S53 Average Longitudinal Properties:

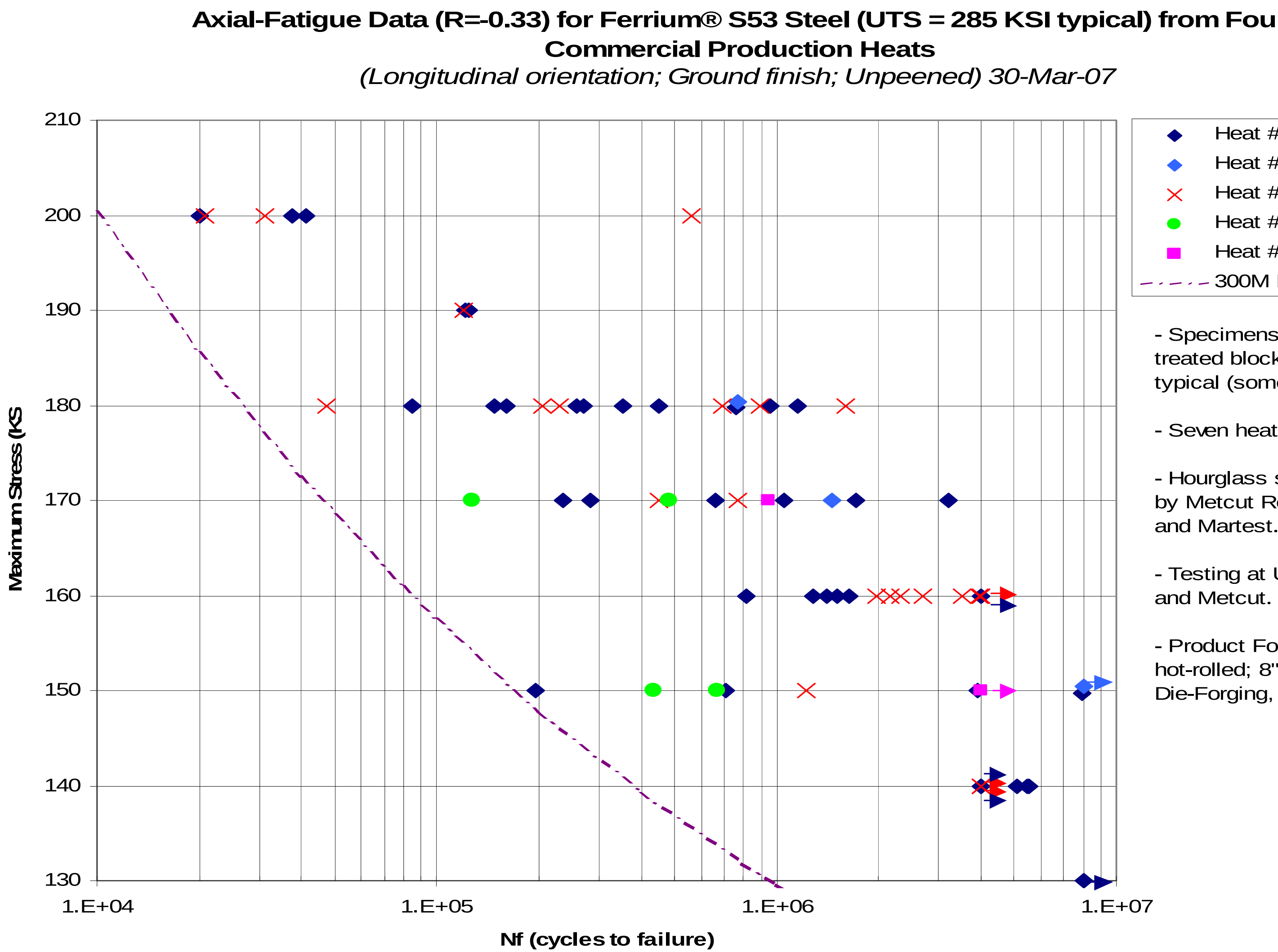
UTS* (ksi)	YS* (ksi)	El.* (%)	RA* (%)	Fcy (ksi)	Fsu (ksi)	Hardness (Rc)	CVN* (ft-lb.)	Kic (ksi√in)
288	225	14-16	55-65	255	181	54	18	66

Orientation: L or LR
*Average values, 10 heats, minimum 10 samples 3 lots per heat

300M and Ferrium S53 A-basis *Minimum* Longitudinal Properties:

	UTS (ksi)	YS (ksi)	El. (%)	RA (%)	Fcy (ksi)	Fsu (ksi)	Kic (ksi√in)
300M	280	230	8	30	247	162	--
S53	280	213	11	44	245	176	50

Axial Fatigue



- Specimens excised from heat treated block thckness of 2" typical (some of 1" and 4").

- Seven heat treat lots.

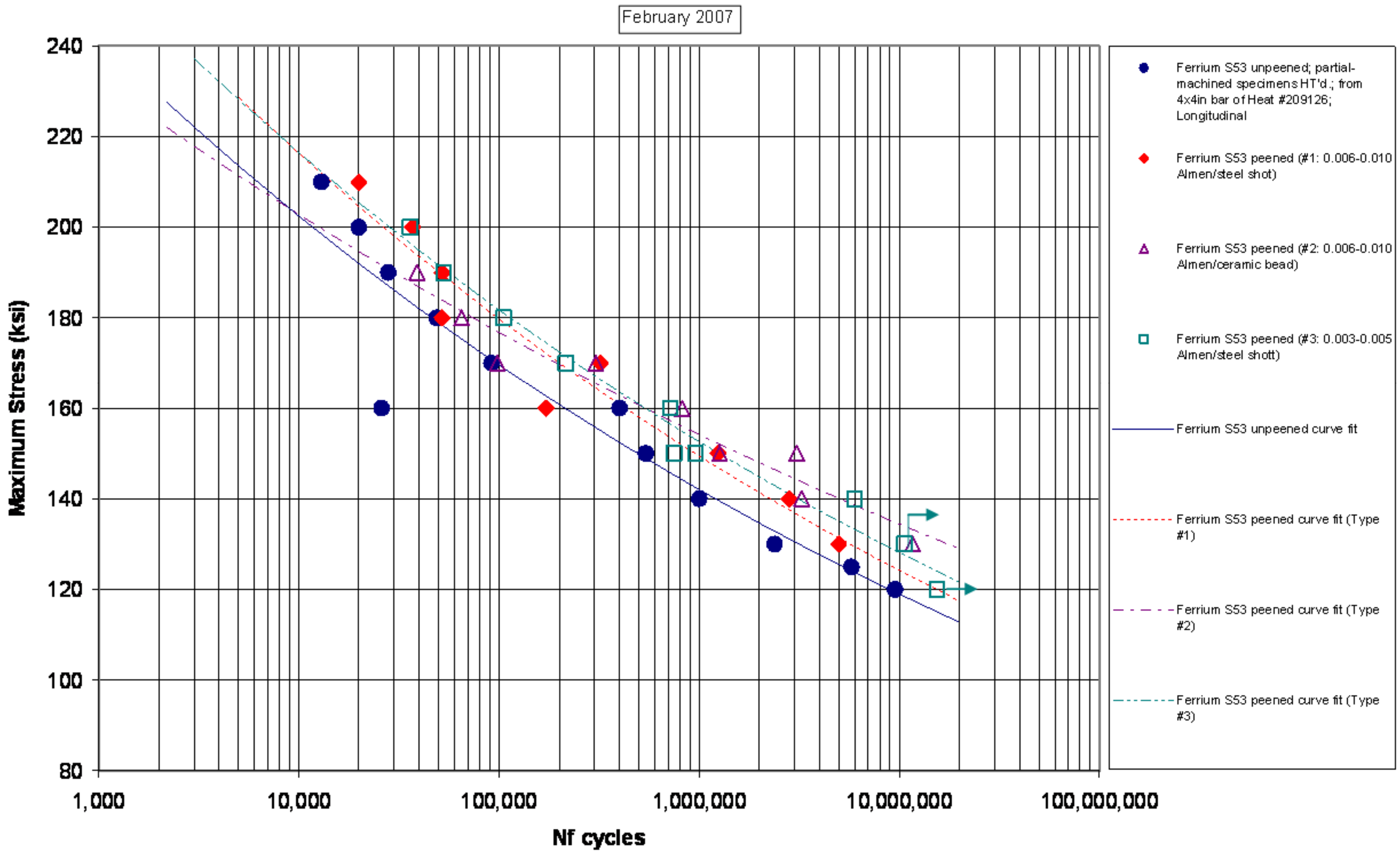
- Hourglass specimen fabrication by Metcut Research, WMT&R, and Martest.

- Testing at U. of Idaho, WMT&R, and Metcut.

- Product Forms: Bar, 4" RCS hot-rolled; 8" dia. rotary forged; Die-Forging, 5" dia.

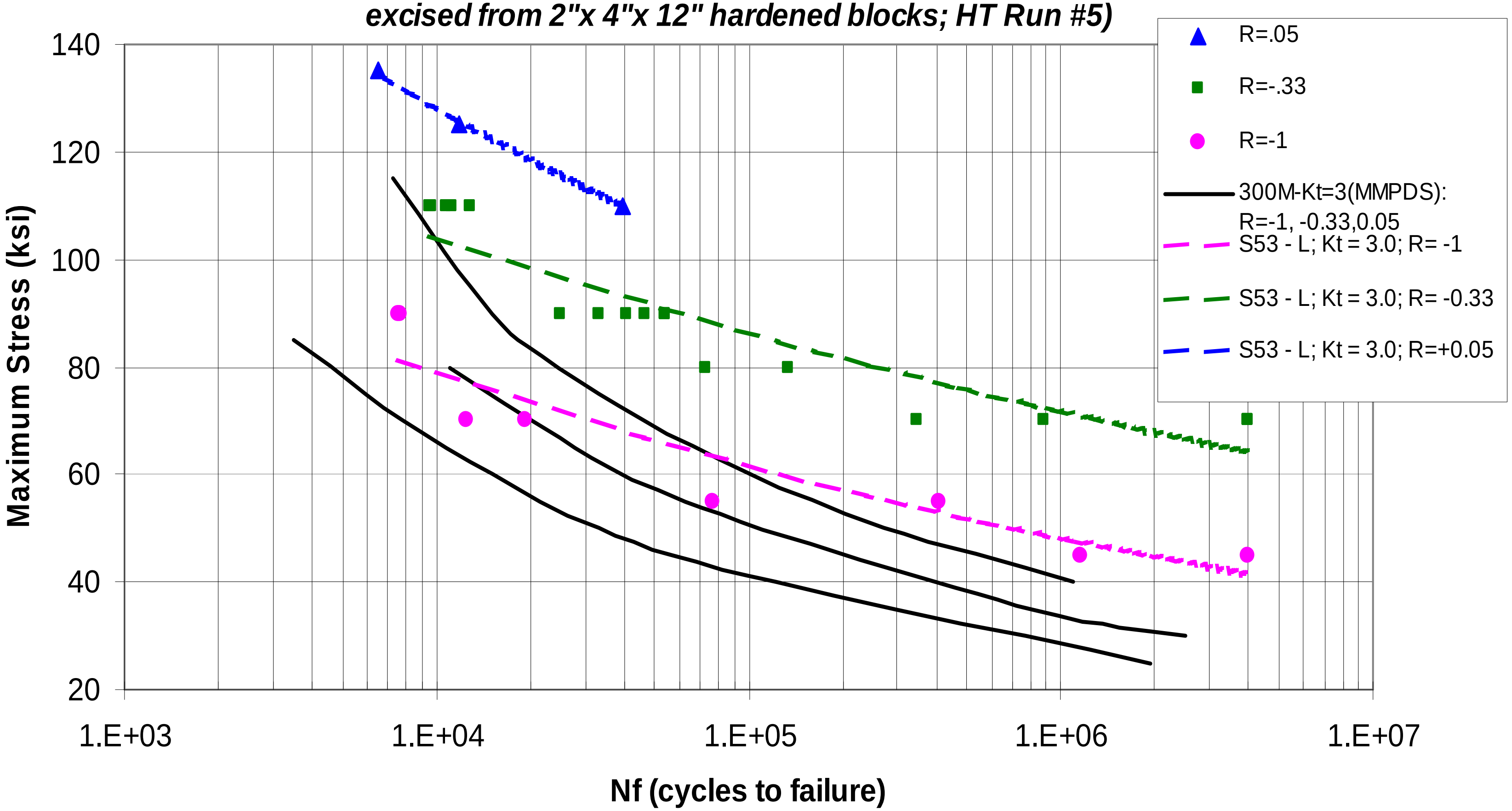
Bending Fatigue

Rotating Beam Bending Fatigue (R=-1) Data for Ferrium S53 (UTS=285ksi typical) both unpeened and peened per MIL-S-13165 parameters and a lower peen intensity



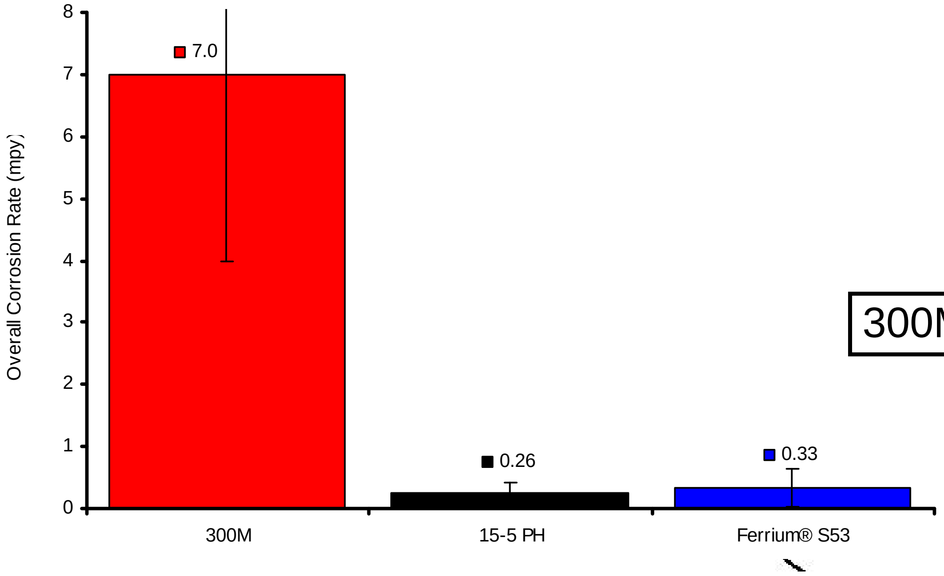
Notched Fatigue

Axial-Notched (Kt =3.0) Fatigue Data for Ferrium S53 Corrosion Resistant Steel (UTS=285 ksi) Bar from Production Heat Heat #209126
(Longitudinal orientation & polished finish. Code S180L; Specimens excised from 2"x 4"x 12" hardened blocks; HT Run #5)



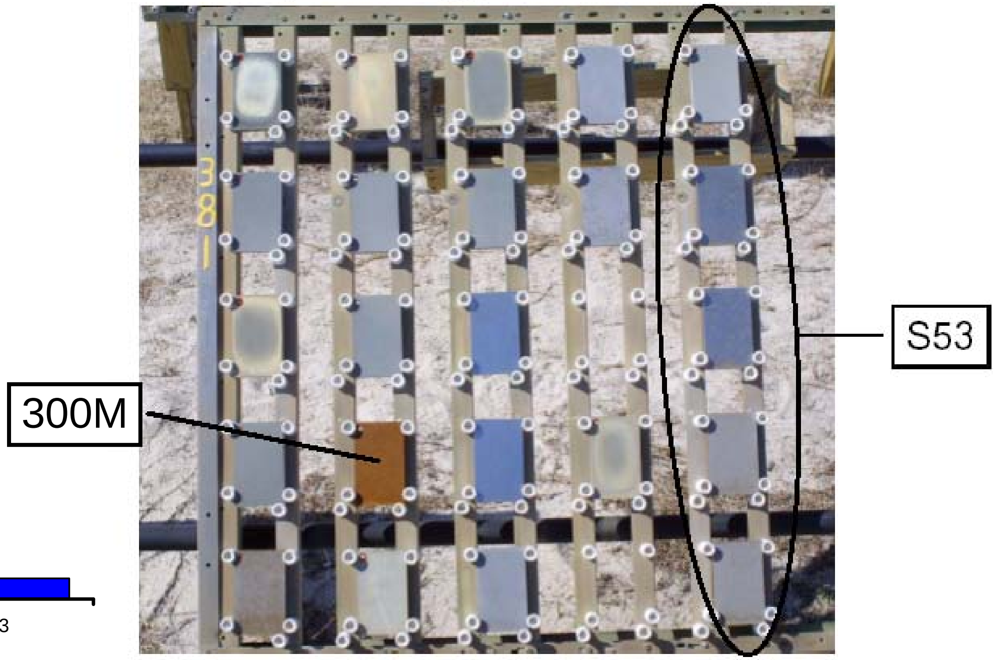
General Corrosion Behavior

Anodic polarization, 3.5% NaCl



1 week exposure

Corrosion - Exposure @ Kure Beach NC



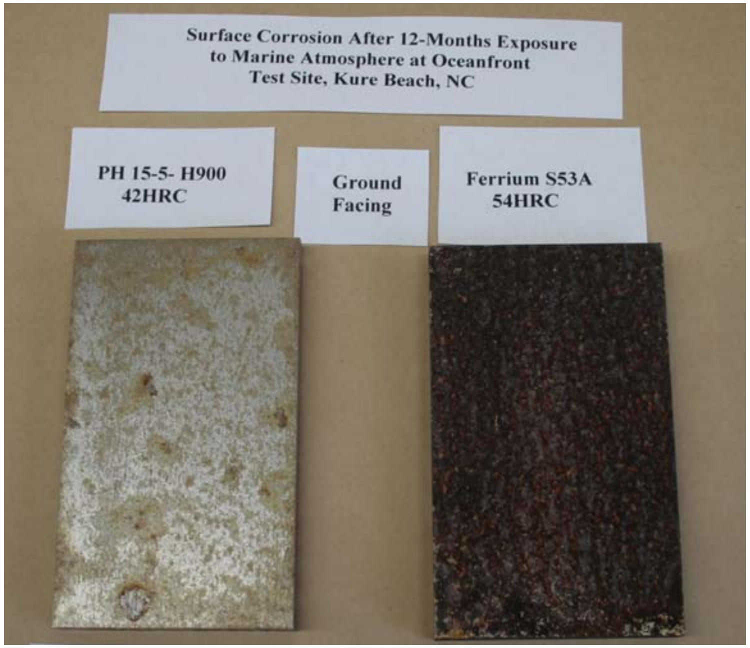
Outdoor Exposure Studies (Chicago, IL)

Marine Exposure Studies (Kure Beach, NC)

Initial Studies: 12 months

PH 15-5 (195 ksi)
~ 0.0005”
pit depth

S53A (285 ksi)
0.001” ~ 0.002”
pit depth



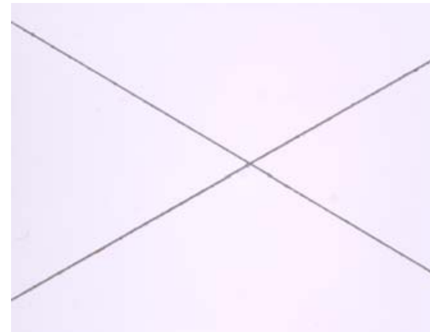
Follow-up Studies: 3 months

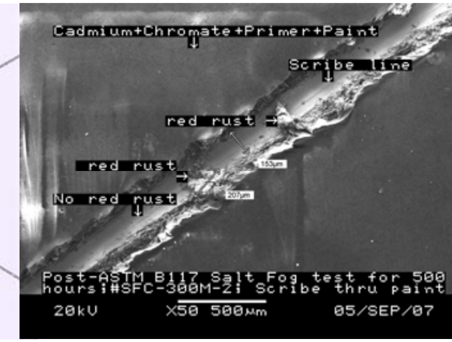
S53 (AMS 5922) (288 ksi)
0.001” ~ 0.002”
pit depth

Conclusions: Both 15-5 and S53 would require prime and paint in aggressive environments. Final spec AMS5922 material behaves very similar to S53A materials in initial studies.

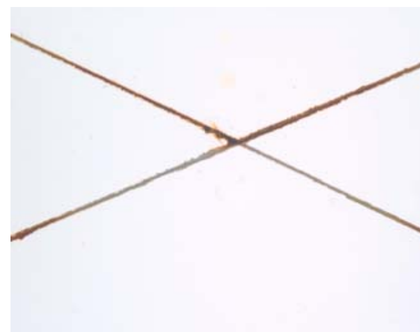
B117 Painted & Scribed Panel Tests
5% NaCl – 500hrs

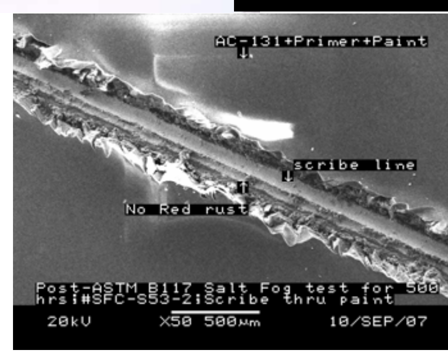
300M (AMS 6257) Cd + Chromate + Prime & Paint: Presents with a small number of localized corrosion sites, indicating the cathodic protection offered by the Cd layer adjacent to a scribed bare zone of 300M appears to be limited to less than 500hrs in a salt fog cabinet test environment.



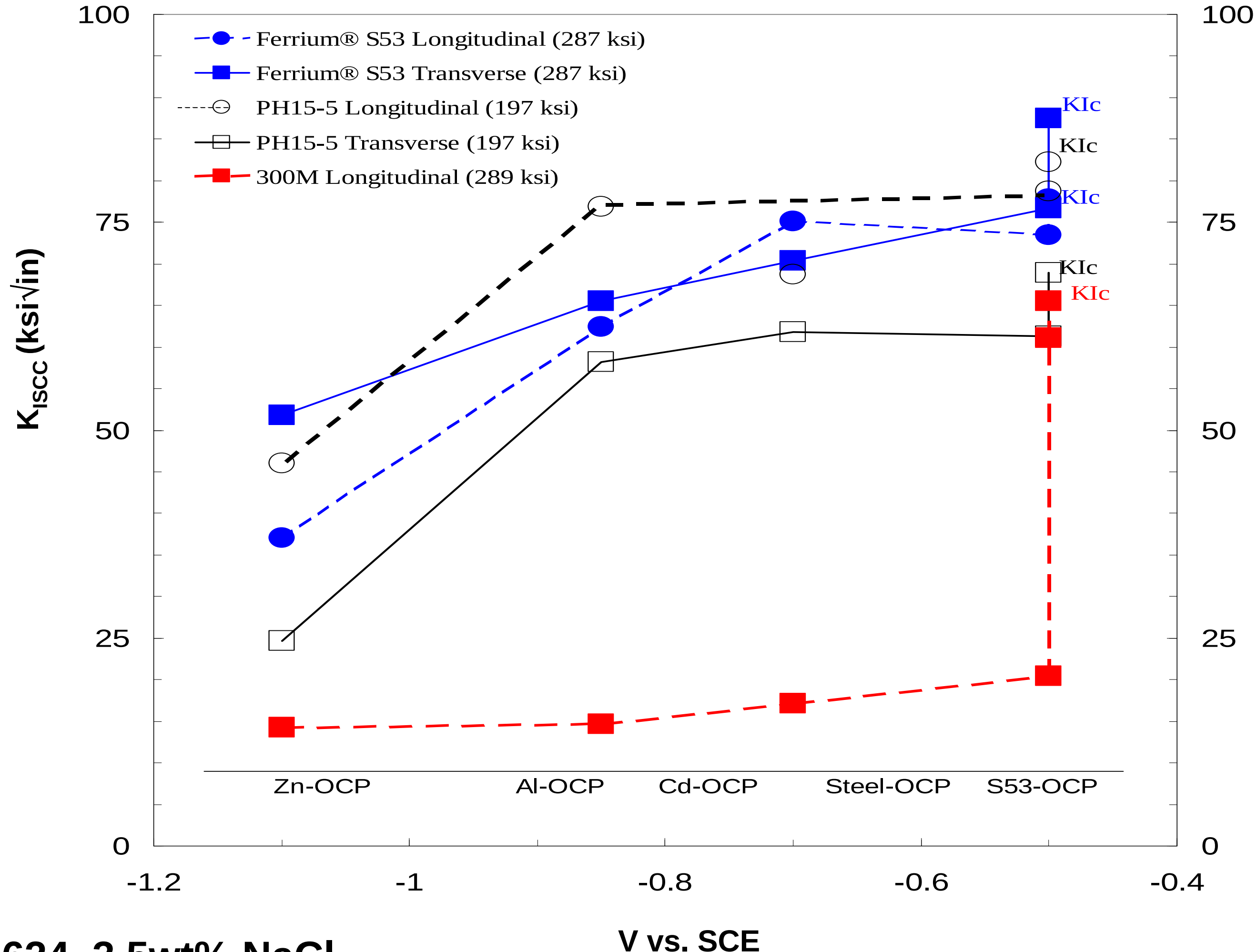


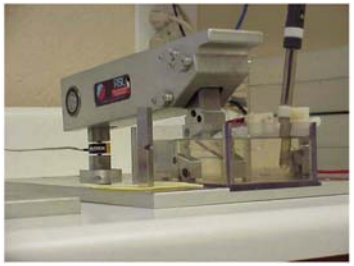
Ferrium S53 (AMS 5922) AC-131+Prime & Paint: Presents with a larger number of localized corrosion sites with some localized regions of no corrosion attack. The paint protection system is effective, i.e. no undercutting of the primer and paint system was observed and the extent of corrosion was consistent with previous marine exposure studies (i.e. limited attack with small pits and some areas displaying resilient passive film protection).





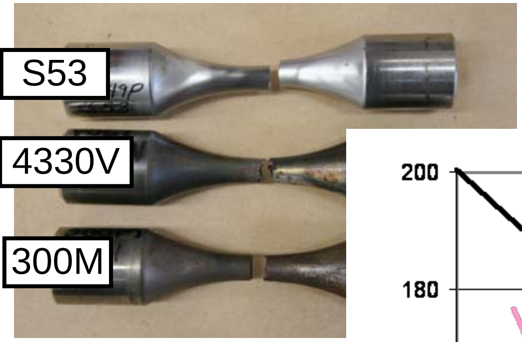
Stress Corrosion Cracking Threshold

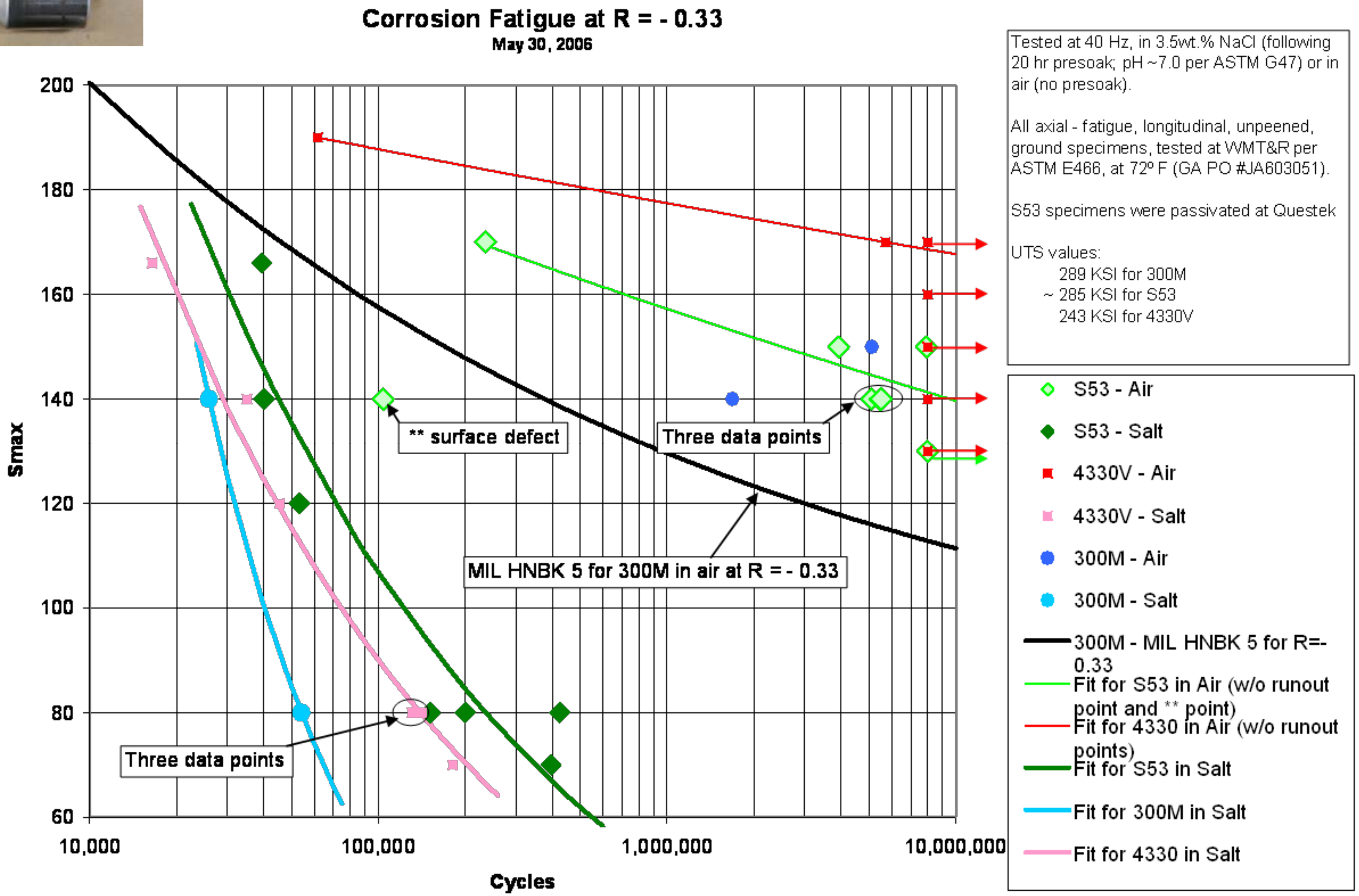




ASTM F1624, 3.5wt% NaCl

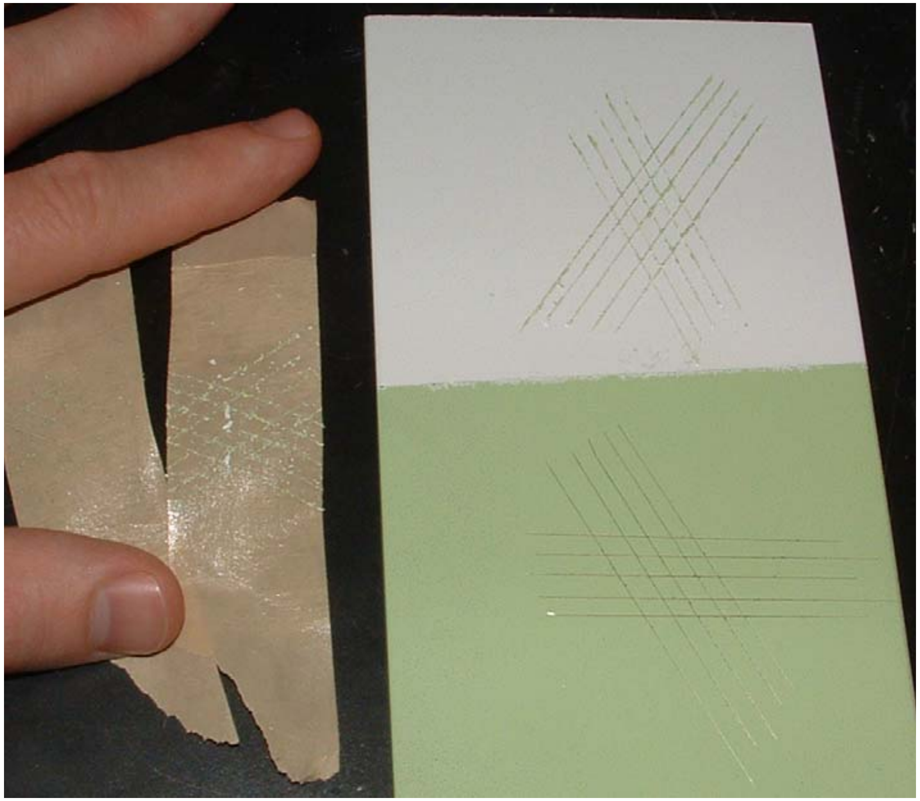
Corrosion Fatigue





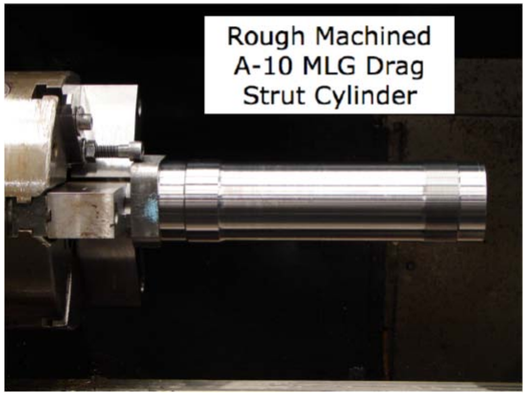
Coating/Finishing Operations

- Post-machining inspection
- Shot peen per Mil-S-13165
- Degrease
- Passivate per QPS-S53-PAS-HNO3
- Rinse and dry.
- Bake component at 375^{o}F for 4 hrs.
- Garnet grit blast at 30psig +15/ -0psig.
- Primer Adhesion (AC-131) application
- Primer per Mil-PRF-85582
- Paint per Mil-PRF-85285
- Cure paint for 7 full days.



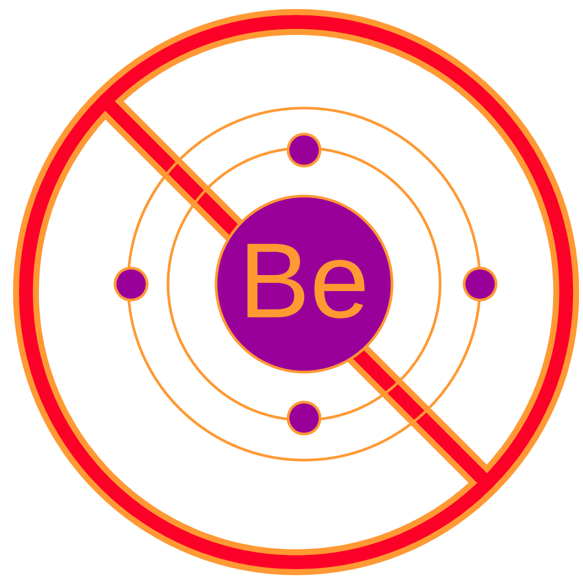
Demonstration

- A-10 Main Landing Gear Piston & Drag Brace Strut
  - Analysis and Design to Achieve Final Qualification
  - Perform landing gear strut testing of S53 Main Landing Gear Piston to qualification standards
    - Fatigue test Per Mil-A-8866
    - Limit Load test
  - Conduct a Field Service Evaluation with fully processed components on an A-10 aircraft.



NAVAIR

QuesTek®
INNOVATIONS LLC



Product Objective

Goal: Design Be-free, high-strength copper bushing alloy to eliminate health concerns of current Cu-1.9Be alloy

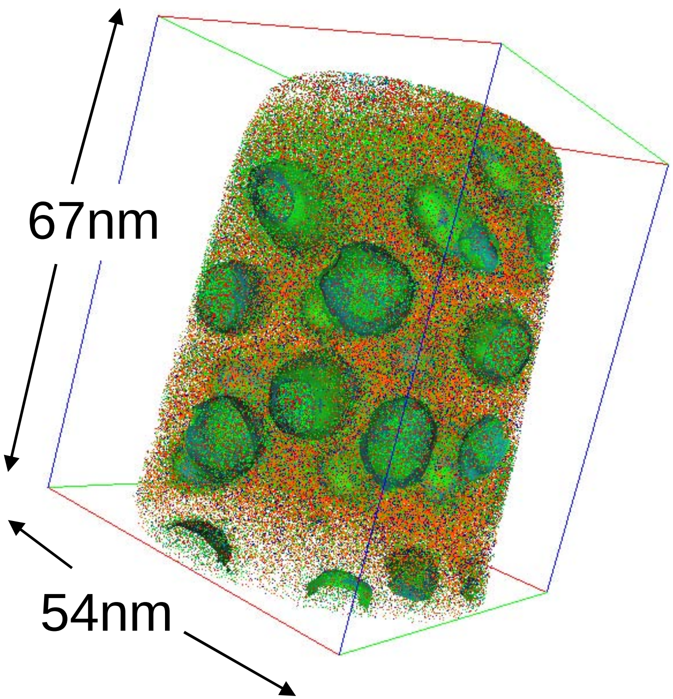
Incumbent Alloy (Cu – 1.9Be)

- High strength
- Low coefficient of sliding friction
- Application in aerospace bushings
- Run against high strength steel

NAVAIR Phase II SBIR, Topic# N05-009:

"Computational Materials Design of a High-Strength Copper Alloy to Replace BeCu Alloys"

1st Generation Prototype Achievements

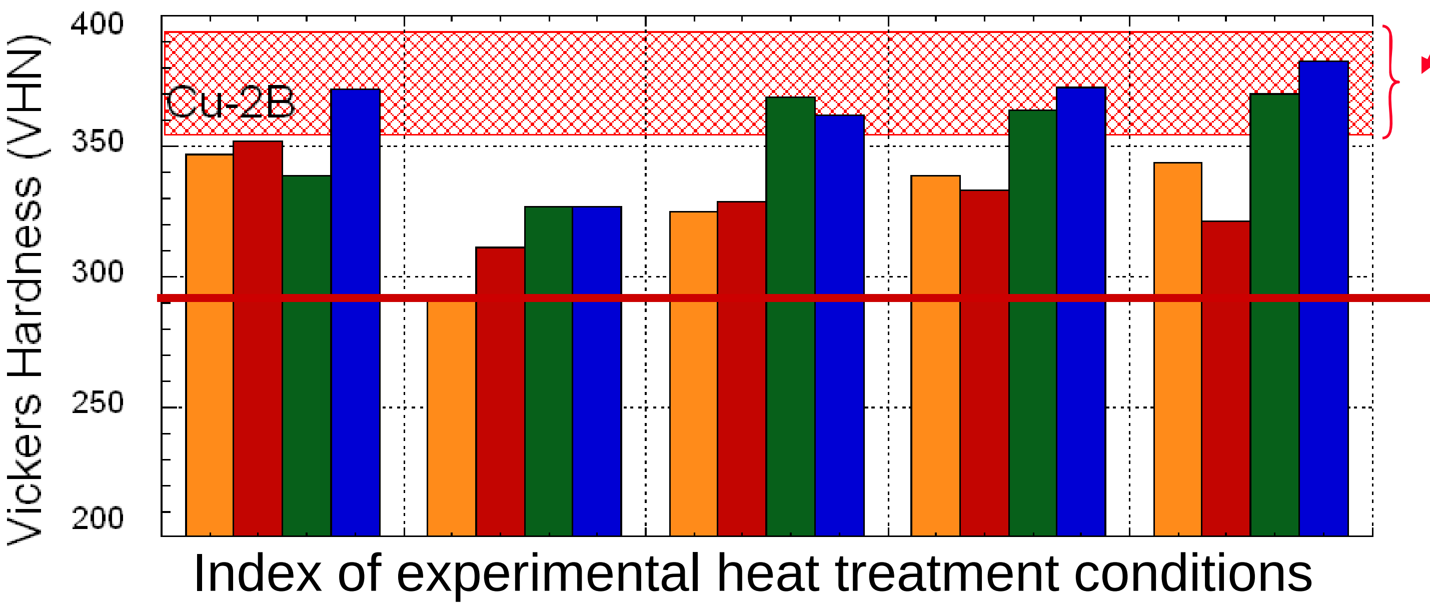


- 127 ksi yield strength with 3% elongation demonstrated
- Unique nanostructure → precipitation strengthening
- Wear behavior (pin-on-disk) evaluation by Lockheed Martin: as-good-as or better-than Cu-1.9Be alloy

2nd Generation Prototype Progress

- Encouraging strengthening response
  - Similar to Cu-1.9Be hardness
  - Higher hardness than 1st generation prototypes
- Next steps for these prototypes
  - Validate tensile strength
  - Validate wear behavior

CuBe
354 – 390 VHN



BioDur & ToughMet
estimate:
275 - 290 VHN

QuesTek Innovations LLC

Features & Benefits vs. Competitive Materials

Characteristics	Cu-Be (Cu-1.9 Be)	ToughMet® 3 (Cu-15Ni-8Sn)	BioDur® CCM (Co-Cr-Mo)	QuesTek *Cuprium™*
0.2 % Yield Strength	**140 ksi (non-CW)**	**•110 ksi (non-CW)** **•110-170 ksi (CW)**	**• 85 ksi (non-CW)** **• 110 - 135 ksi (warm-worked)**	**•Goal: 140 ksi (non- CW)** **•127 ksi (non-CW) demo**
Elongation	**3 %**	**•10 % (non-CW)** **•<2% (CW)**	**26%**	**•Goal: >5%** **•3% demo**
Wear Ranking	**3 (worst)**	**2**	**1 (best)**	**2**
Cold workability	**Good**	**Excellent**	**Excellent**	**Good?**
Cold work required?	**No**	**Yes**	**Yes**	**No**
Hot workability	**Good**	**Very Bad**	**Good**	**Good- Fair?**
Melting Technique	**• Various techniques, limited Be suppliers**	**•Proprietary techniques:** **• *Equicast*** **• *Osprey***	**•VIM + ESR, limited suppliers**	**•Various casting techniques possible**

Timeline of Development

- Complete 2nd generation prototype characterization – **May 2008**
- Final alloy design – **July 2008**
- Production of final alloy design – **October 2008**
- Demonstration of material performance goals – **December 2008**
- Accelerated Insertion of Materials (AIM) process for material qualification (seeking funding) – **2009**
- AMS specification – **2010 - 2012**
- Licensed supplier(s) - **2010 - 2012**