

*DEVELOPMENT OF A NEW HIGH-PERFORMANCE
GAS CARBURIZABLE GEAR STEEL*



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Improved gear steel for the V-22 tiltrotor*Navy requirements for:*

- Higher survivability
- Smaller package sizes
- Longer maintenance intervals

Driving the need for rotorcraft transmission with:

- High power densities
- Higher operating temperatures

A new gear steel with:

- High-strength
- High-toughness
- Highly fatigue-resistant
- Better temperature resistance

“Significantly enhance the performance of gears and provide increased power density and operational life”

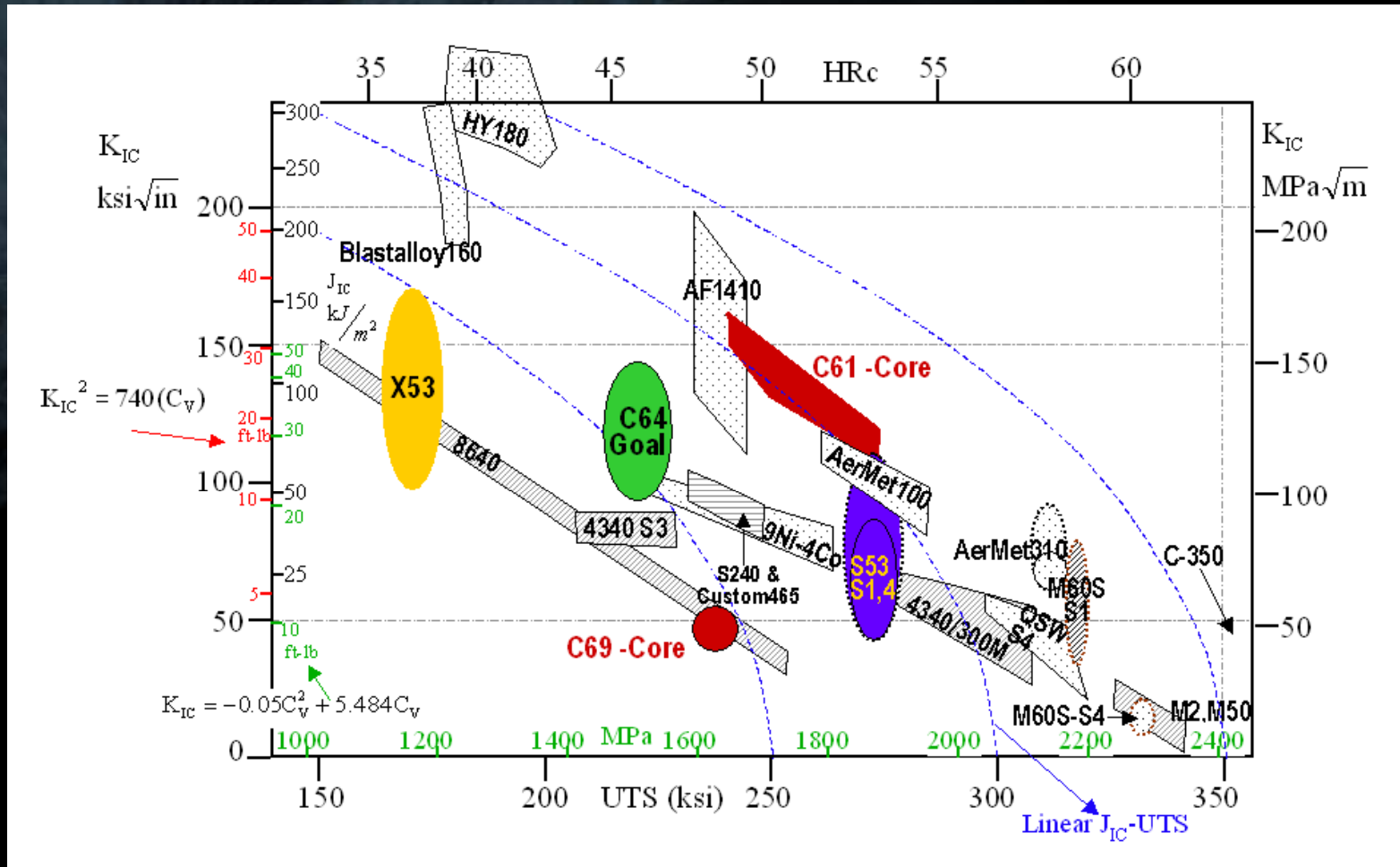
***- STTR Topic #: N05-T006
Solicitation***

NAV AIR

Bell Helicopter
A Textron Company



Bell Boeing
THE TILTROTOR TEAM

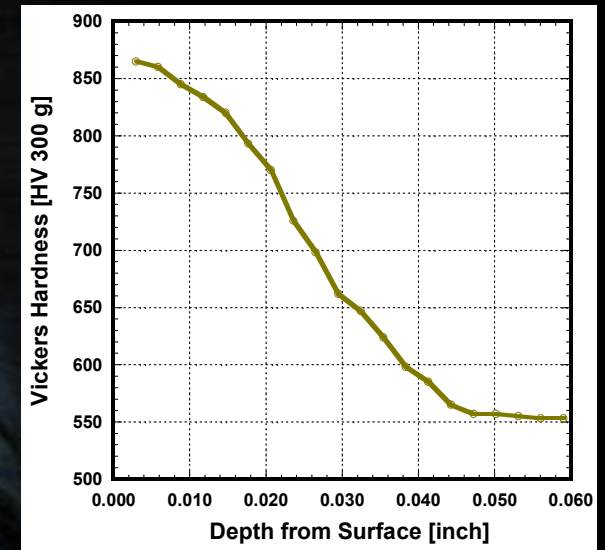


Comparison of core properties
 Pyrowear X53 vs. *Ferrium C64*

- Developed at Northwestern University by Greg Olson, Charles Kuehmann, and John Wise
- Optimal Microstructure
 - Fe-Ni-Co lath martensite
 - Efficient nano-scale M_2C carbide strengthening
 - Primary carbide-free
- High temperature (vacuum) carburized
- Secondary-hardened
- Exclusively licensed by QuesTek Innovations LLC
 - U.S. Patent 6,176,946B1
- Commercial production and heat treatment

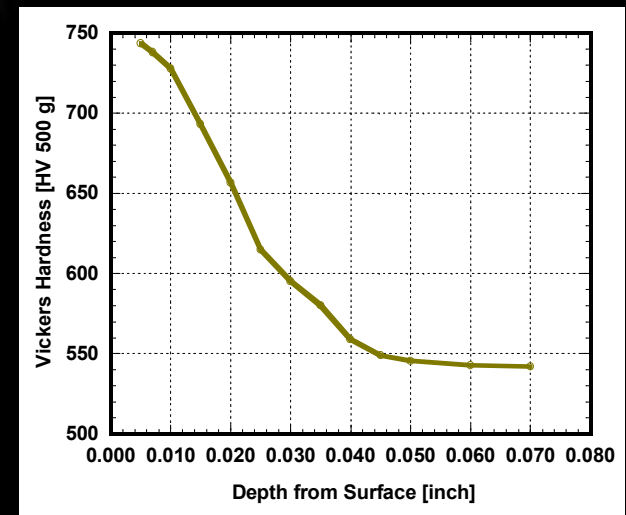
- C69**
- Excellent surface HRC & fatigue resistance
 - High Temperature Resistance

Temper	YS (ksi)	UTS (ksi)	EI (%)	Core (HRC)	Case (HRC)
<i>Overage</i>	180	230	17	48-50	65-67



- C61**
- High strength / toughness core
 - High Temperature Resistance

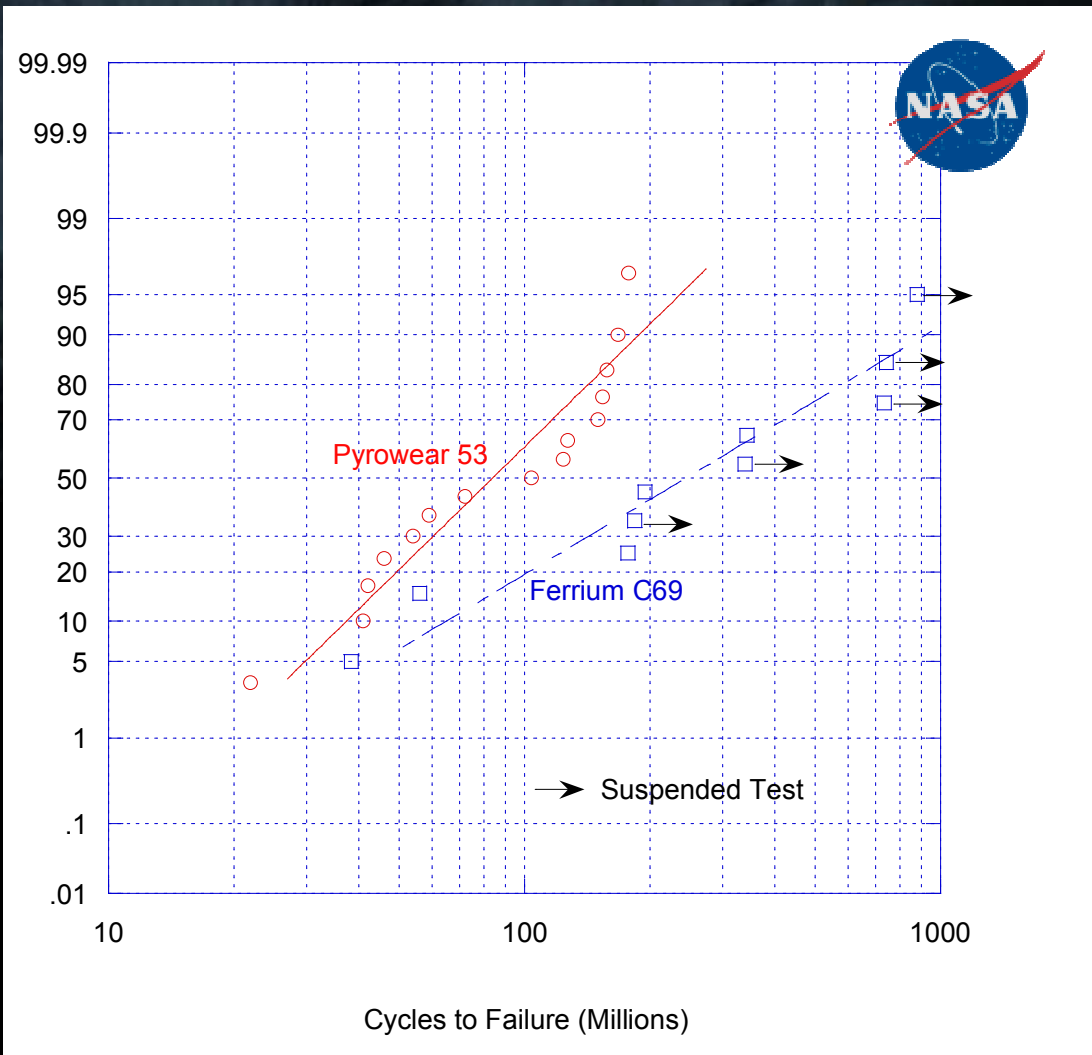
Temper	YS (ksi)	UTS (ksi)	EI (%)	Core (HRC)	CVN (ft-lb)	K _{IC}
<i>Peak</i>	230	250	16	50-52	40	>105
<i>Overage</i>	225	240	16	48-50	50	>105



- Off-road series
 - SCORE, SNORE, CORR
- Ring and pinion
 - Class 1/2-1600 (4.57 ratio)
- Baseline-8620 and 9310
 - Typically fail in two races or less
 - Failures by notch root fatigue
- C61 Introduced Jan. 2005
 - 50% market share and growing



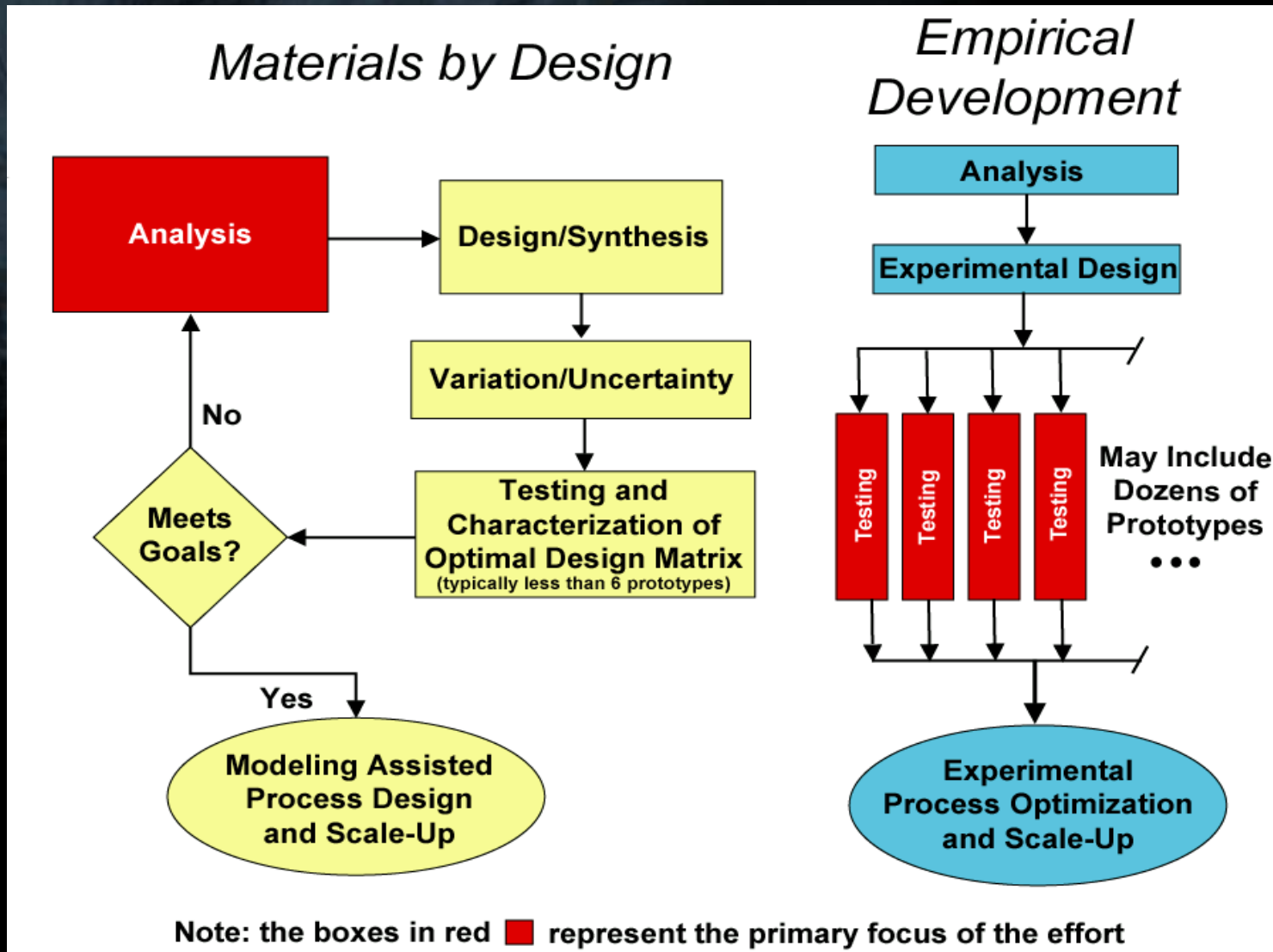
4-6x improvement
in life



- NASA Glenn Research Center
- Supported by Battelle
- Recirculating Spur Gear Fatigue Rig
- *Ferrium®* C69, Case carburized & ground
- Measure surface fatigue, benchmark against Pyrowear53
- 24 gears yield 12 data points
- Set to test surface fatigue, pitting tendency

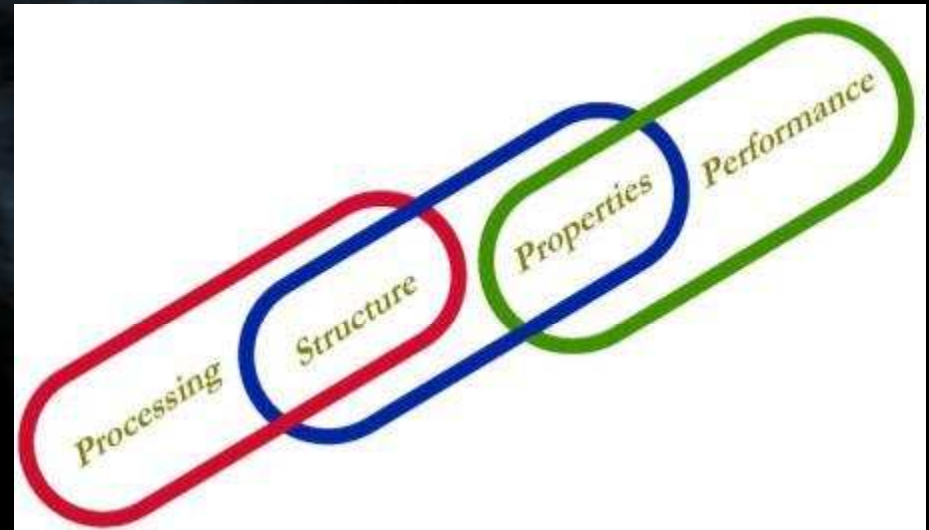
- Fatigue strength increase of 25%
- Gas and vacuum carburizable
- Core strength ~220 ksi UTS
- Core fracture toughness ~90 ksi√in
- Suitable for super-finishing
- Stable microstructure/hardness up to 400°C
- Machinability
- Minimal heat treat distortion

Traditional Approach: Empirical Alloy Discovery



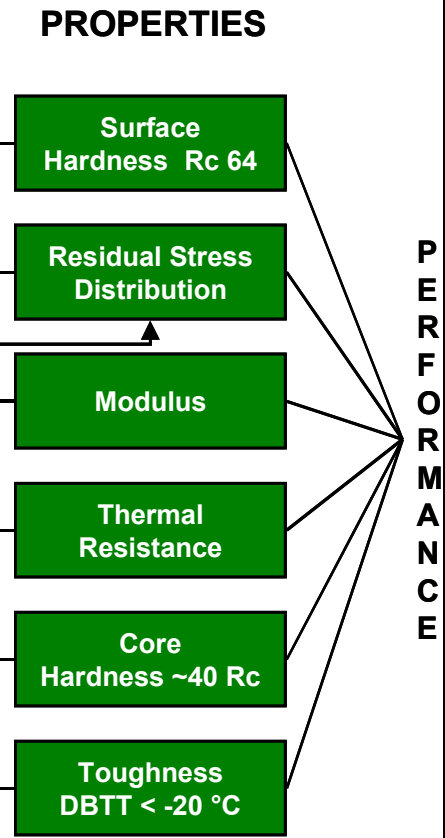
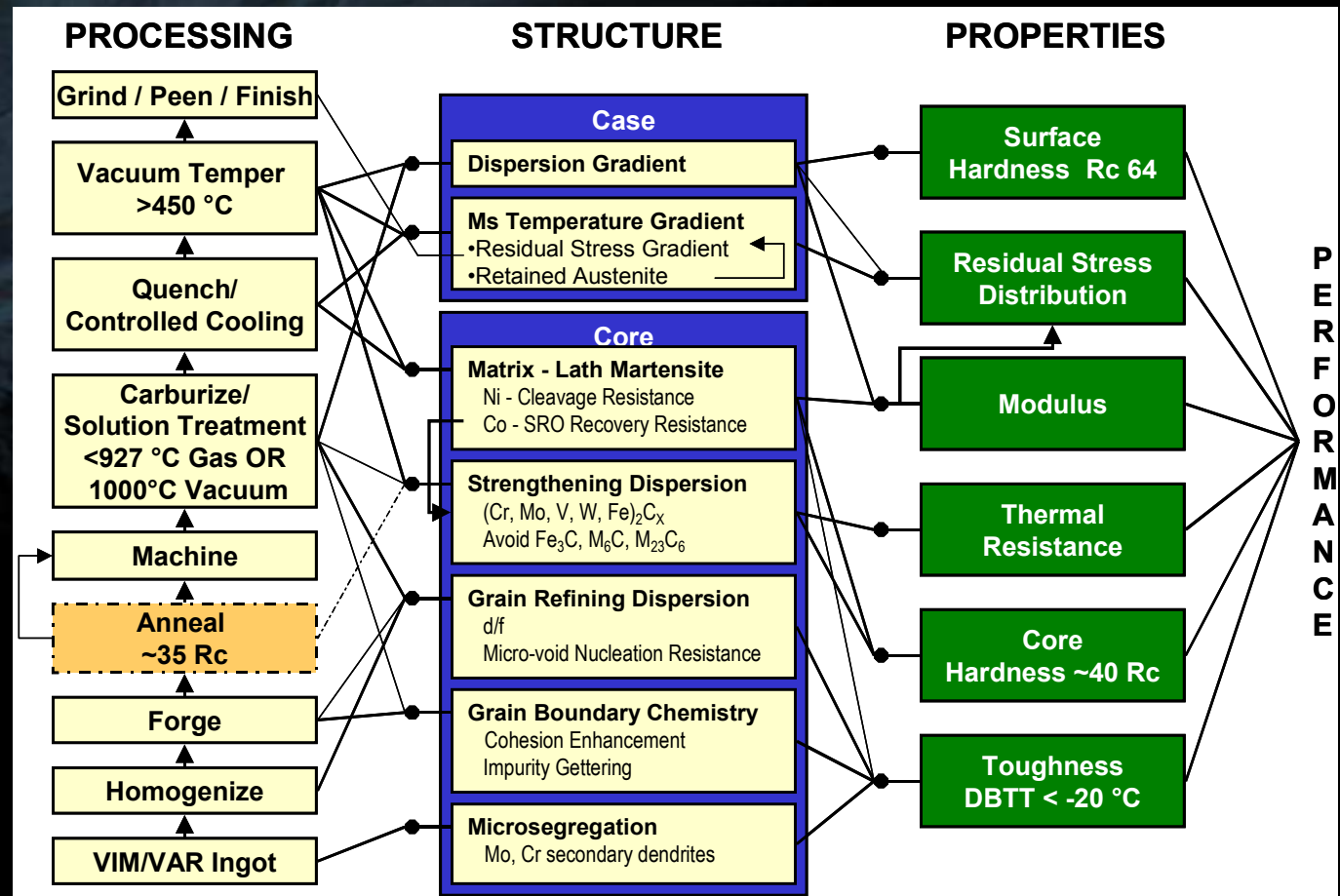
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 - Faster
 - Cheaper
- Designed Properties
 - Accelerated Insertion
 - Stronger patents
- Niche applications
- Accelerates the creation, development, and insertion of new and enabling materials for defense-based systems



Alloy Design Chart

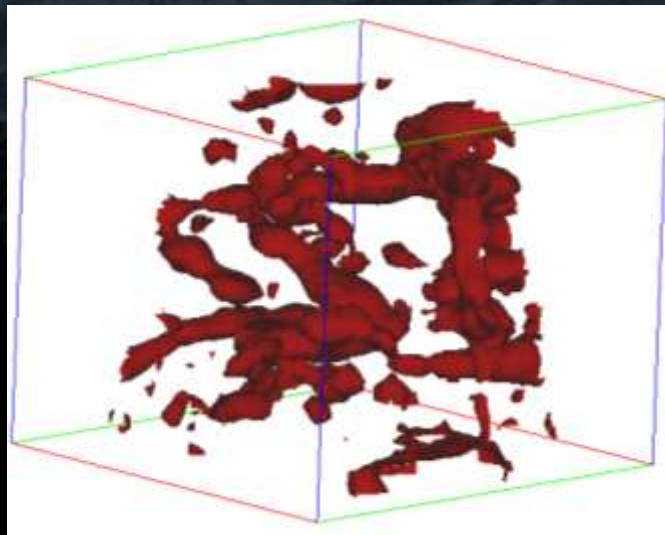
- Optimal Microstructure
 - Fe-Ni-Co lath martensite
 - Efficient nano-scale M₂C carbide strengthening
 - Primary carbide-free
- High temperature (vacuum) carburized
- Secondary-hardened
- Initial prototype production
 - Validate predicted properties



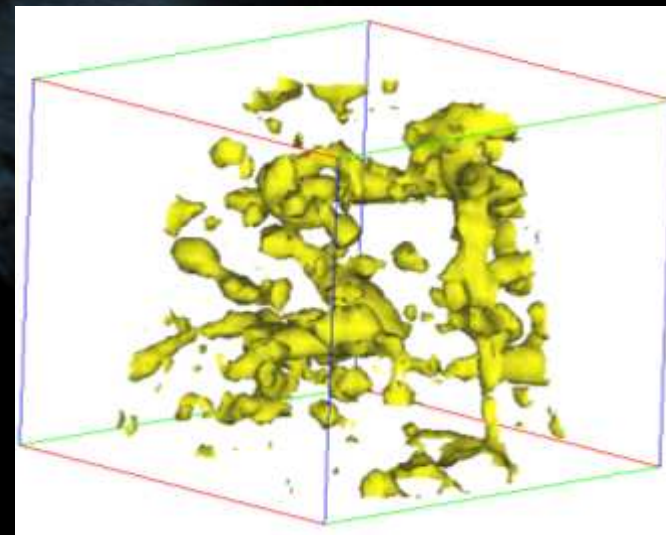
Validate Critical Design Factors (Core)

- Validate core nano-scale carbide dispersion: Local Electron Atom Probe analysis
 - High tensile elongation for all tested alloys and conditions

65 x 65 x 35 nm³ dimensions



C surfaces



Cr surfaces

- Reasonably low core annealed hardness for machinability: C64 ~33 R_C vs. C61: ~36 R_C

Relative comparison of X53 and C64 properties

Fatigue Strength (ksi)	25% increase	}	Increased power density
Yield Strength (ksi)	40% increase		
Ultimate Tensile Strength (ksi)	36% increase		
Increased Case Hardness	R _c 62-64 vs. R _c 60-62	}	Better dry run performance and efficiency
Fracture Toughness (ksi√in)	Same		
Tempering Temperature (°F)	500°F higher		
Processing (heat treat, machining)	Same - adaptable		

- Alloy produced at full scale (10,000 lb.) at Carpenter Technologies
 - Tensile: 202 ksi 0.2% YS, 228 ksi UTS (typical)
 - Toughness: 85 ksi√in
- Preliminary carburization (gas, vacuum) and heat treatment optimization is complete
- Fatigue data development is underway
 - Rolling-sliding contact fatigue
 - Single-tooth bending fatigue
 - Rotating spur gear fatigue data
 - Scoring
 - Pitting
 - Bending

- Current development
 - Initial production and coupon testing

<u>STTR</u>	<u>Milestone</u>	<u>TRL</u>	<u>Measure of success</u>	<u>TRL date</u>
Phase 1-Yr 1	Sample testing and process optimization	2-3	Laboratory data	June 2007
Phase 2-Yr 1	Full scale alloy production	4	Steel mill certification	July 2007
Phase 2-Yr 2	Coupon fatigue testing	4	Fatigue test data	January 2008
Phase 2-Option 1	Rotating spur gear fatigue testing	5	Fatigue test data	January 2009
Phase 2-Option 2	Full-rig testing	6	Material fatigue allowances	January 2010

V-22 tiltrotor transmission

- Full-rig (component-level) fatigue testing
- V-22 upgrade targeted as initial Navy application

Other rotorcraft (and other) applications

- Increase volume
- Generate data for AMS specification

- Future development
 - Ingot production, full-rig testing, and specification development

<u>TRL</u>	<u>Required tests, demos, next steps</u>	<u>Target date</u>	<u>Organizations to be involved</u>
7	Production of two further heats, with testing and initial aerospace qualification	~2011	<ul style="list-style-type: none"> • Navy / DoD (rotorcraft platform system managers) • Steel producers (e.g., Carpenter, Latrobe) • Rotorcraft manufacturers (Bell, Boeing, Sikorsky, Augusta-Wentland) • Drive system engineers
7-8	Production of seven further heats, with testing and full aerospace qualification	~2014	“
7-8	System (flight) testing of full scale heat components	~2014	“
9	Mission (flight) testing of full scale heat components	~2016	“

- Currently working with Bell Helicopter (V-22)
 - Qualification testing
- Boeing / Army interest for Apache (AH-64)
 - Enhanced Rotorcraft Drive System (ERDS) program
 - Also CH-47
- Other strategic partners related to:
 - Aerospace gearing applications
 - Oil / gas / energy gearing applications
 - Racing
 - Industrial gears
- Typical Partners
 - Component OEMs
 - Rotorcraft manufacturers (military and commercial)
 - Alloy producers
 - End users

- Materials design and processing lead
- File utility patents
 - Maintain and defend
- Define manufacturing specifications
 - Qualify multiple alloy manufacturers
 - Material procurement
 - Secure AMS / MMPDS specifications as needed
 - Qualify secondary processors
 - Forging
 - Machining
 - Heat-Treatment
 - Carburization
 - Peening / superfinishing

- Leader in emerging field of Computational Materials Design
- Solving complex material issues for
 - DoD, NASA, DOE, NSF, Industry
- Carburized Steel, Stainless Steel, High-strength Steel, Wrought and Cast Aluminum, Nickel, Copper
- Technology of the Year - IndustryWeek
- DoD/SERDP Project of the Year - *Ferrium*® S53
- Fortune 500 Breakout Company
- Patents: 13 Issued, 33 Pending

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