TITANIUM 2006

22nd ITA Conference & Exposition

01 – 04 October 2006, San Diego CA

TITANIUM RESEARCH & DEVELOPMENT FOR NAVAL APPLICATIONS

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Requirements for Navy Materials

- **Higher Strength**
  - Weight Reduction
  - Increased Performance
  - Increased Payload
- **Improved Weldability**
  - Structural Fabrication
  - Repair Welding
- **Survivability**
  - Shock / Blast Loading
  - Toughness @ Low Temperatures
  - Ballistic Resistance
- **Affordability**
  - Acquisition Cost
  - Life Cycle Cost

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Navy Littoral Operations

Marine Corps EFV

Hardness Against Underwater Explosions (UNDEX), Air Blast, Ballistic and Fragment Penetration

Increased Speed & Improved Protection Systems

Reduced Surface Ship Signatures Required - RF, IR, Visible, Magnetic, Acoustic

Surface Combatant – DDG 1000

Reduced Submarine and UUV Magnetic and Acoustic Signatures

Titanium for Marine Service

- Titanium offers excellent strength-to-weight benefit
- Range of strengths available through alloy selection (50 to 115 ksi yield strength)
- No seawater corrosion concerns
- Less maintenance man-hours required
- High recycle value or re-use possible
- Excellent fire and shock resistance
- No ductile-to-brittle toughness transition
- Nonmagnetic
- Excellent compatibility with composites

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TITANIUM & Ti ALLOY USAGE IN USN SHIPS

Ship Class	Total Weight of Titanium per Ship (lb)
CVN 68	16,500
CG 47	20,800
DDG 51	33,700
SSN 688	31,375
SSBN / SSGN	31,375
SSN 21	75,175
SSN 774	31,375
LPD 17	136,650

Navy Titanium R&D Projects

- **Metallic Material Advanced Development & Certification Program**
  - **Project on Ti 5111 Evaluation for Critical Applications**
  - **Certification of Ti-5111 Fasteners for Shock Applications**
- **Unmanned Undersea Vehicle (UUV) Pressure Hulls**
  - **Investment Cast Ti-5111 & Ti CP-2LO**
  - **Ti-5111 Forgings**
- **Titanium Welding Fabrication R&D Projects**
  - **FSW, Flux-assisted Welding (Including FCAW), GMAW-PA**
  - **Laser Peening for Weld Fatigue Improvement**
- **CVN 21 Manufacturing Technology Project**
  - **Titanium Applications**
  - **Ballistic Testing**
- **Technical Support to Low-Cost Ti Program (DARPA)**
  - **Evaluation of Solid-State Ti Plate (Armstrong Process)**
  - **Ti Applications – Future Navy / Navy After Next**
- **ALVIN HOV Technical Support**
  - **New Pressure Hull (Ti-6Al-4V ELI Forgings)**

Ti - 5111 Marine Grade Aloy

Ti-5111 = Ti 5Al-1V-1Sn-1Zr-.8Mo-.1Si

- Developed under ONR/TIMET project as a tough, weldable, high strength alloy
- More producible alternate to Navy Ti-100 (Ti-6211)
- Commercially available since late 1990's
- Corrosion resistance equal to CP grade 2 or Ti-6-4 ELI titanium
- No SCC concerns in sea water
- Displays highest toughness of any high strength Ti alloy
- Product forms are plate, sheet, bar, rod, castings, forgings, & fasteners
- Continuing focus of Navy projects to certify Ti-5111 for critical ship and submarine applications

Ti-5111 Evaluation

OBJECTIVE: Support approval and certification for critical applications in surface ships and submarines

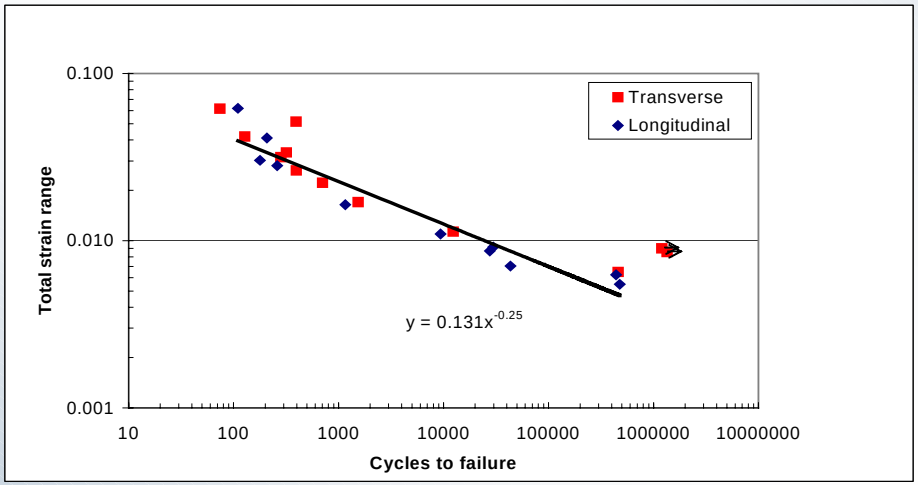
- **Mechanical & physical properties of Ti-5111 plate, bar, forgings, castings and weldments (weld metal & HAZ)**
- **Ti-5111 products under evaluation:**
  - **¼, ½, 1, and 2 inch thick plate**
  - **GTAW weld metal & HAZ in 1-inch plate**
  - **½, 1, 2, 3½, and 4 inch diameter bar**
  - **8-inch diameter forging**
  - **Graphite mold & Investment cast plates**
- **Evaluation of Ti-5111 fasteners for wetted, shock applications**
- **Draft NAVSEA Technical Publication, "Requirements for Titanium & Titanium Alloys for Ship and Submarine Applications"**

Ti-5111 Evaluation

Ti-5111 Engineering Data Developed

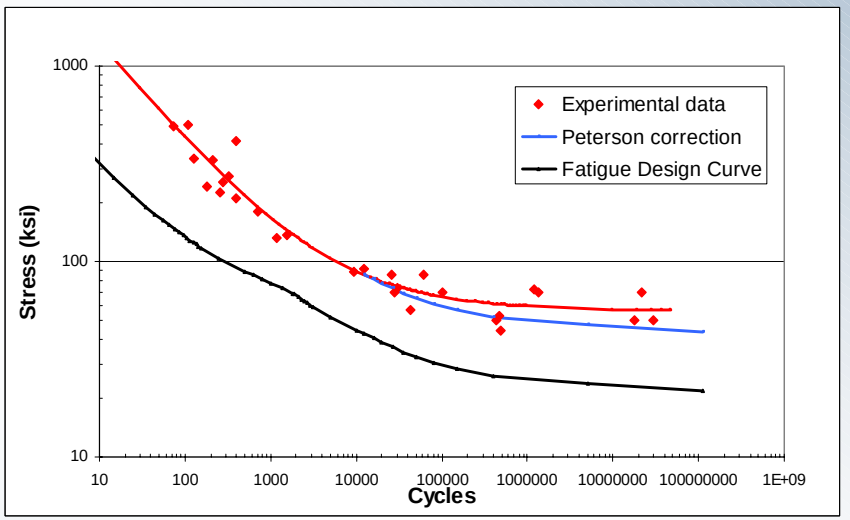
- Procure Ti-5111 Products
- Tensile Properties
- Charpy V-notch Properties
- Dynamic Tear Properties
- Fracture Toughness
- Hardness
- Compression Properties
- Thermal Properties
- Elastic Constants
- Dynamic Tensile Properties
- Dynamic Fracture Toughness
- Low-Cycle Fatigue Properties
- High-Cycle Fatigue Properties
- Fatigue Crack Growth Rates
- Corrosion Fatigue Properties
- Structural Element Tests
- Explosion Tests
- Stress Corrosion Properties

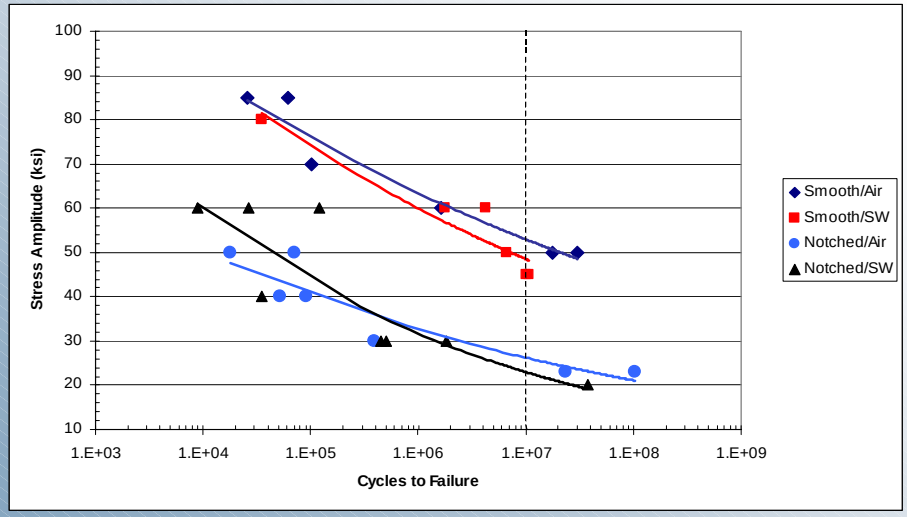
Ti-5111 Fatigue Properties



⇦ **Low-Cycle Fatigue**

Design Fatigue Curve





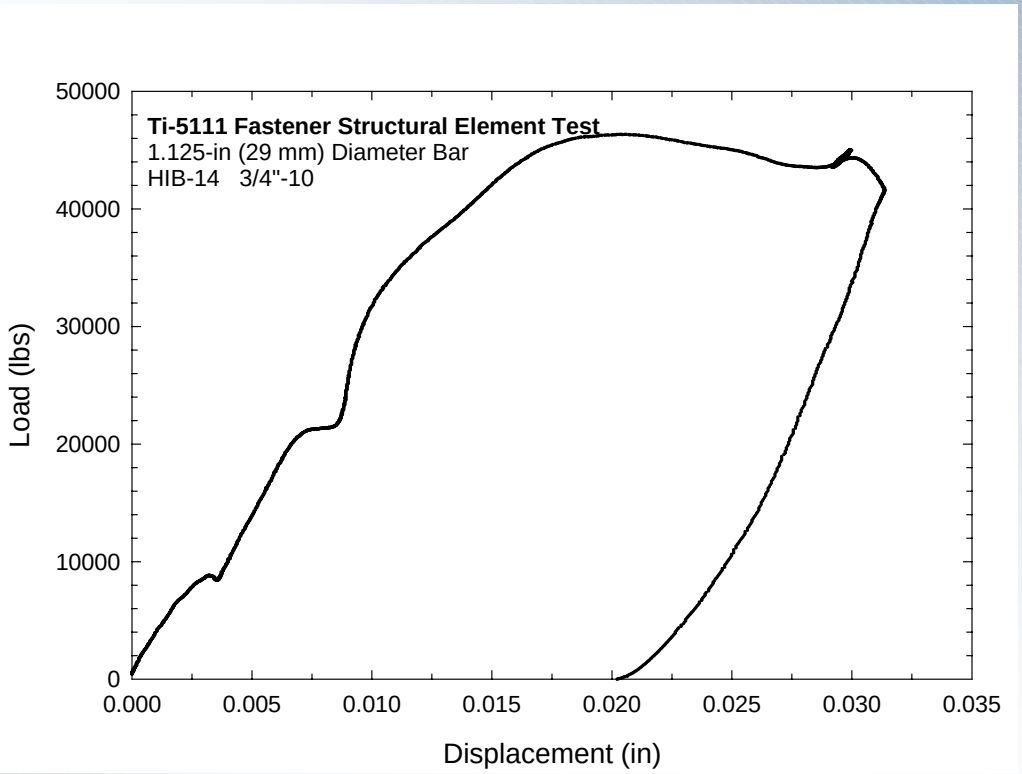
⇦ **High-Cycle Fatigue**

Fastener Dynamic Fracture Test

Ti-5111 Fastener Test

EDM Flaw

Load vs. Displacement



Test stopped prior to failure

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Ti-5111 for Naval Applications

Ti-5111 Navy Service Application

- Extensive evaluation for Submarine Communications Mast Structure
- Mast is welded Ti-5111 structure – plate, bar, & forging
- Over 45 Masts deployed / first deployed in 2000

Cast Titanium & Ti-5111 Alloy

Unmanned Undersea Vehicles (UUV)

Near net-shape pressure hull castings

Hull Inserts, Penetrations

Trial Casting
Ti CP-2LO UUV Hull Section

Trial Casting

Ti-5111 UUV Hull Section

High-Speed Ships (LCS)

Castings (Waterjet components - impellers, pump casings, ducts)

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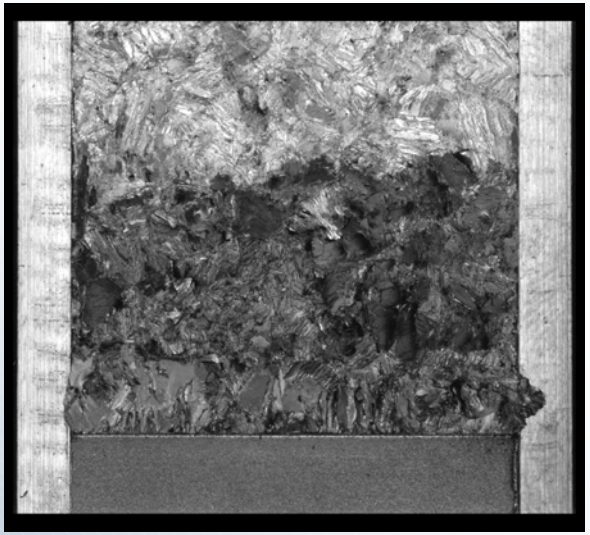
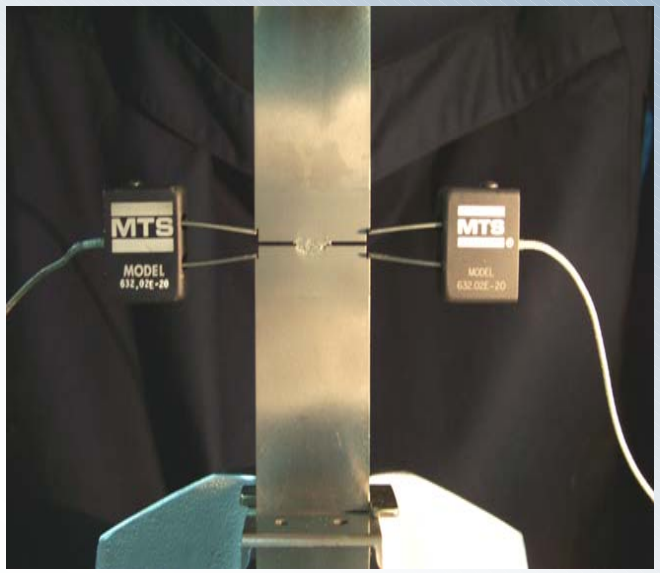
Cast Ti Fracture Toughness



Cast Ti-5111
1-in Thick

Cast Ti CP-2
1-in Thick

0.15-in Thick Ti-5111
Investment Casting



Titanium Welding

High fabrication costs relative to steel and aluminum alloys limit Navy applications

Titanium Welding Cost Drivers

- **Specialized gas shielding**
- **Low productivity welding processes**
- **Labor intensive joint designs and preparation procedures**

ONR R&D Goal

Weld large structures in a shipyard environment

⇒ **Develop higher productivity welding processes**

- **Flux-assisted & flux-cored arc welding**
- **Friction stir welding**
- **Pulsed gas metal arc welding with waveform control**

Titanium FCAW Feasibility

Titanium Welding Fluxes

- CaF_2 based
- Reagent grade purity

Chemical Composition, wt %

	Formula P-A	Formula P-B	Formula C
CaF_2	85	45	70
NaF	1	--	1
BaF_2	--	7	--
LaF_3	--	20	--
SrF_2	--	28	--
MgF_2	--	--	15
$BaCl_2$	14	--	14

Ti FCAW Wire Drawing Demo

- 0.160-inch OD to 0.055-inch OD, 22 dies at 5 mil reduction each
- No intermediate annealing
- Demonstrated reduction to 0.052-inch OD
- Wire breakage, 30-40m lengths

GTAW with Ti CP-2 flux-cored wire

Titanium Friction Stir Welding

FSW Benefits

- Fewer passes
- Minimal joint preparation
- Environmentally-friendly and safe (no fume, arc, or spatter)
- Solid state – minimal distortion
- Minimal post weld clean up
- Reduced post weld inspection (no porosity or lack of fusion)

Army project at EWI demonstrated FSW butt and tee joints in ½-inch Ti-6Al-4V & model structures fabricated

Navy effort at EWI to develop friction stir welding of up to ½-inch thick Ti-5111

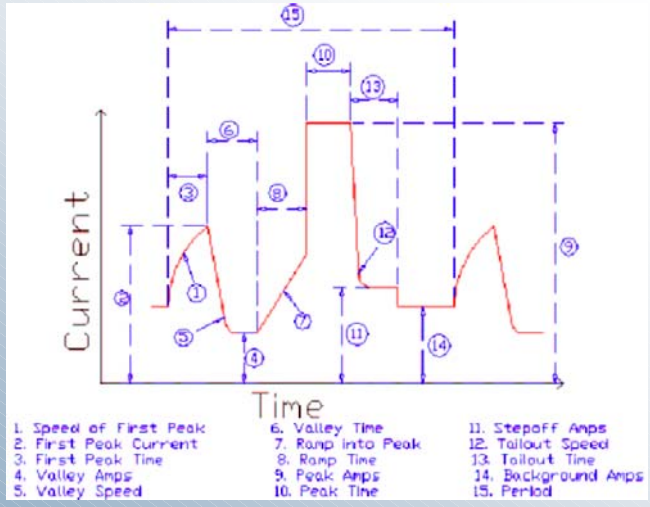
Work in progress to develop tooling & process parameters

Ti-5111 FSW

Titanium GMAW-PA

ONR Project - pulsed gas metal-arc welding process for all position welding of large structures

- Upgraded software and installed waveform algorithms
- Fabricated weldments in Ti-CP grade 2 plate
- Evaluation of mechanical properties in progress



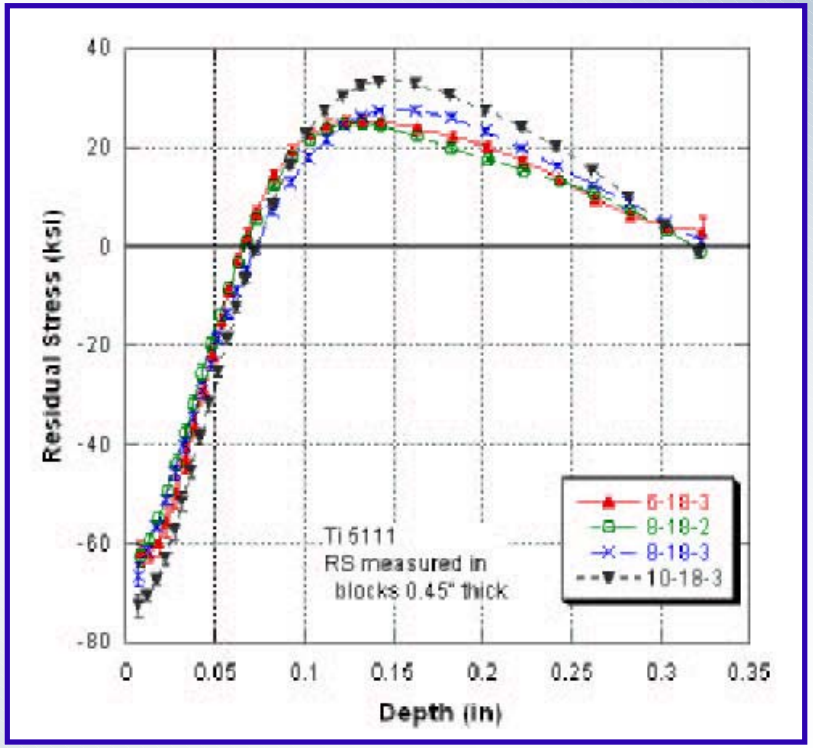
Double Pulse Waveform Definitions for Wave Designer 2000

Ti-CP Weldment Produced with Double Pulse/Droplet Waveform

Laser Peening of Ti-5111 Welds

- *Extension of conventional shot peening*
- *High intensity laser induces deep residual compressive stress*
- *Residual stresses are influenced by processing parameters*

- **Produces high level of compressive residual stress**
- **Applied to 1-in thick weldment made with Ti-5111 filler wire by GTAW**
- **Machined 4 point bend fatigue coupons**
- **Peening at MIC and fatigue testing at UC-Davis in progress**



CVN 21 - Potential Ti Applications

- CVN 21 (CVN 78 & 79)
  - Island Structure
  - Doors
  - Fasteners
  - Elevator Platforms
  - Sponsons
  - Piping & Valves
  - Armor

Mainmast concept for CVN 77 (Courtesy of NGNN).

Challenges for Ti alloy Technology Development

Processing & Alloy Development

- Extraction Methods
- Plasma Arc/EB Single Melting
- Improved Ingot Casting Processes

Joining Process Development

- Flux-Assisted & Flux-Cored Arc Welding
- Friction Stir Welding
- High Productivity GMAW
- Dissimilar Metal Joining

Improved Fatigue Performance

- Weldment/Joint Design
- Post Weld Treatments/Process
  - » **Laser peening**
  - » **Ultrasonic impact treatment**
  - » **Low plasticity burnishing**
  - » **Friction stir processing**

SUMMARY

- Titanium is the optimum engineering material for seawater service
- Titanium has been successfully used in the Navy for decades, primarily in ship & submarine machinery systems
- Increased used and large structural applications are limited by high material & fabrication costs
- Although initial cost may be more than offset by reduced maintenance and end of life value, ***ship acquisition cost rules***
- New opportunities exist for titanium to enhance structural efficiency of Navy ships for increased payload, range, stability, and operating cycles
- Development of lower cost Ti products and high productivity welding processes will be required to support increased usage

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Thank You for Your Attention