Hepburn and Sons LLC

NSRP RA 20-01

Onboard Ship Integration of Laser Peening System for Lasting Aluminum Repairs

NSRP Planning, Production Processes and Facilities Panel Meeting
March 24th, 2021

Presenter: CDR Robert Medve, USN (Ret)
Director of Technology Transition
Hepburn and Sons LLC

NSRP NATIONAL SHIPBUILDING RESEARCH PROGRAM
Taking Shipbuilding and Repair to the Next Level
Proudly Celebrating 50 Years of Innovation

Overview

- Hepburn and Sons LLC & Tech Transition Process
- Compressive Residual Stress by Peening
- Laser Shock Peening (LSP) –Tailorable Residual Stress Profile
- Laser Shock Peening History
- Current Projects
  - NSRP RA 20-01 project – Onboard Ship Integration of Laser Peening System for Lasting Aluminum Repairs (REPAIR FOCUS)
  - SBIR N18A-T016 – Analysis of Dislocation Density, Recrystallization, and Residual Stress in 5XXX Aluminum using Laser Peening to mitigate Exfoliation Corrosion (NEW CONSTRUCTION FOCUS)
- Questions

Hepburn and Sons LLC

OUR LEADERSHIP

Hepburn and Sons LLC

CAPT Rick Hepburn, USN (Ret)
President, Chief Executive Officer (CEO)

Mr. Scott Hepburn
Principal, Chief Operations Officer

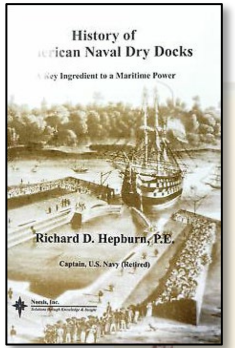
Mr. Eric Hepburn
Principal, Chief Financial Offer

Mrs. Samantha Hepburn Hertel
Principal, Customer Relations Officer

CDR Frank Koye, USN (Ret)
Chief Information Officer

COMPANY INFO

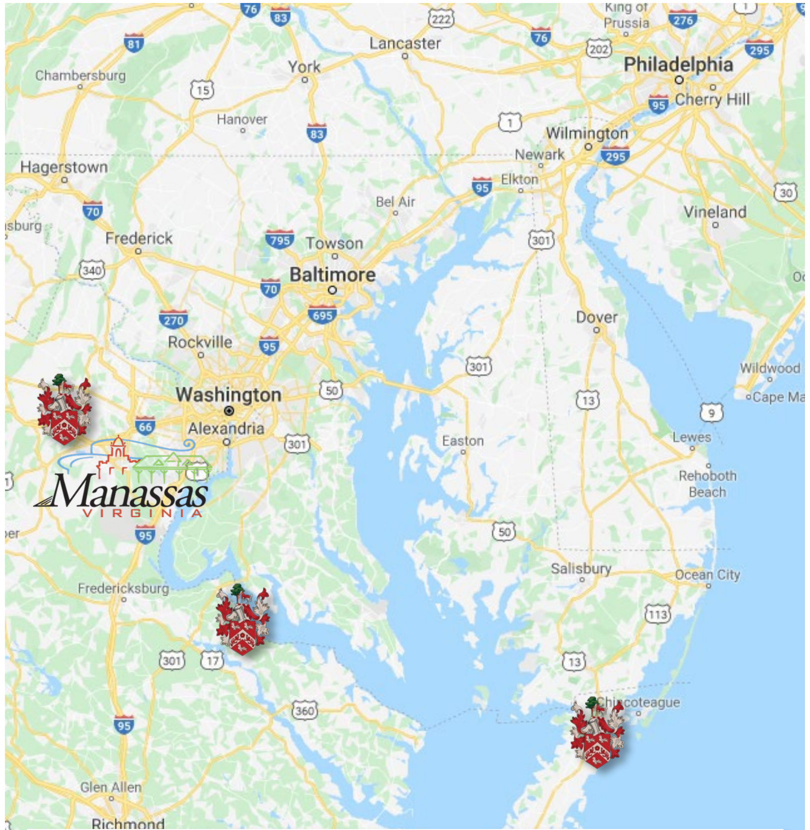
- Founded in July 2010
- Veteran Owned Small Business (VOSB)
- HQ in Manassas, VA | 2nd office in Atlantic, VA
- 50+ Employees
- Government Prime Contractor | SeaPort NxG
- Prince William County Business of the Year 2018
- DC Council of Engineering & Architectural Societies (DCCEAS)
  - *Engineers of the Year 2017 & 2019*



Rick Hepburn in front of USS Missouri BB-63 while in drydock

PRINCE WILLIAM CHAMBER BUSINESS AWARDS 2018

DCCEAS



WE ARE A COMPANY BUILT ON TRUST

We honor handshakes as rigorously as contracts. We keep trust at the forefront of every decision we make and customer we serve! We believe there is no greater principle in business than that of building a solid foundation of trust. We hold one another to the highest levels of integrity and ethics. We cherish every opportunity given to us by our clients.

Company Divisions

ADVISORY SERVICES

Tim Crone

Strategic Analysis
- Organizational structure analysis and development
- Optimal Bridge Design
- Dry dock capacity, demand, decision tools
- Directed energy ship integration
- Nuclear survivability
- Deployed maintenance approaches
- Shipyard quality culture

Anti-Fouling Surface Treatment Nano-Coating
- Anti-fouling surface treatments to improve ship heat exchanger maintenance and performance

Defense Threat Reduction Agency
- Support development of MIL-STD 4023 HEMP Protection of Ships
- Perform site HEMP assessments
- Develop HEMP Hardening and Ship Integration Training

Expert Witness
- Naval Architecture & Engineering
- Ship HM&E systems
- Navy ship asbestos insulation
- Shipyard operations
- Cruise ship engineering

TECHNOLOGY TRANSITION

Rob Medve

Insulated Bus Pipe (IBP)
- Standard/High Temperature IBP design and construction for shipboard use
- Co-Axial IBP Concept

MVDC Grounding & Fault Locality
- Shipboard Medium Voltage Direct Current

SUBSAFE Electrical Hull Penetrator for Directed Energy Weapon Systems
- kW class concept for submarine hull penetrator to transmit power inboard DE system to outboard HEL subsystem or DE System

Material Science & Mechanical Engineering
- Laser Shock Peening to improve structure and shafting fatigue life

ELECTROMAGNETIC SURVIVABILITY

Ben Ford

High-Altitude Electromagnetic Pulse (HEMP) Hardening

<u>AFRL/USAF</u>
- MIL-STD-188-125 solutions
- USAF facilities being added
- Threat-level testing of solutions

<u>U.S. ARMY</u>
- MIL-STD-461
- Modeling and HEMP hardening of ground vehicles

Support commercial power grid, and Department of Defense (DoD) components, primarily; Air Force, Defense Threat Reduction Agency (DTRA), Missile Defense Agency (MDA), and Navy
- Perform hardness analysis and assessments on systems
- Brief DoD leadership on HEMP effects, hardening status, and validation methods
- Brief DoD leadership to raise awareness of HEMP hardening and effects of HEMP on operations
- Coauthored MIL-STD-4023, HE

ENGINEERING SUPPORT SERVICES

Jeff Sinclair

DARPA
- Engineering SME Support

Wallops Island Engineering Test Center
- SEWIP Integration for CVN 78
- AEGIS ACB 20 & AMDR Integration

AEGIS Weapon System
- Lifetime Support Engineering
- In-Service Engineering
- Operational Training

Ship Self Defense System
- In-Service Engineering
- Combat System Development and Certification
- Combat System Test
- Software Support Agent
- Warfare Experiments
- Crew Familiarization/Training

Stakeholders

INDUSTRY CLIENTS & PARTNERS

BAE Systems
Northrop Grumman
Leidos
Huntington Ingalls
Fire Security
GD NASSCO & BIW
CENTRA Technology
Gryphon Technologies
CACI
McKean Defense
LSP Technologies
Interphase Materials
Frontier Technologies, Inc (FTI)
Advanced Technologies International (ATI)
American Society of Naval Engineers
Nichols Brothers Boat Builders
TEFELEN America
Stäubli
AeroNav Laboratories, Inc
Rolls Royce
ABB
Roxtec
RSL Advanced Lighting Technologies
Leonardo DRS
KATO Engineering
VT Halter Marine
ABS
Booz Allen Hamilton
Detyens
Wartzila


Directed Energy Systems


Aegis Ashore


SCSC Wallops Island

GOVERNMENT CLIENTS

- NAVSEA
  - Surface Combat Systems Center (SCSC) Wallops Island
  - SEA04, PMS 555
  - SEA21, PMS 407
  - NSWC Dahlgren Division
- National Shipbuilding Research Program (NSRP)
- PEO Ships, PMS 320, BIPO
- PEO Submarines
- Navy STTR/ SBIR Program
- ONR Code 35, PMS 405
- Air Force Research Lab (AFRL)/Global Strike Command
- Defense Threat Reduction Agency (DTRA)
- Missile Defense Agency (MDA)
- DARPA Tactical Technology Office (TTO)
- Commander Navy Regional Maintenance Center (CNRMC)
- U.S. Army

Our Process

Shepherd Innovation from Concept Definition to Capability Deployment

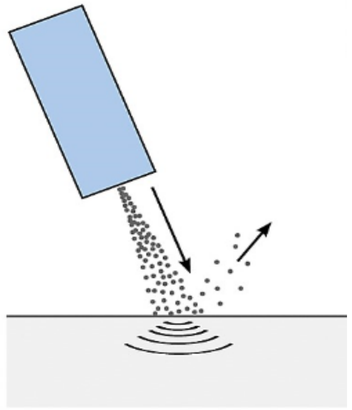
DEVELOP → TEST → QUALIFY → INTEGRATE → TRANSITION → DEPLOY

Hepburn and Sons Value

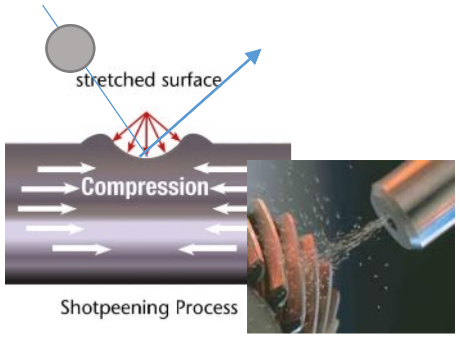
- **No need for technology developer to become experts in DoD acquisition**
- ↓ Cost of development
- ↓ Technology development and integration risks
- ↓ Time from start of technology development to capability deployment
- ↑ Likelihood of transition to acquisition & deployment to the DoD and/or industry

Compressive Residual Stress by Peening

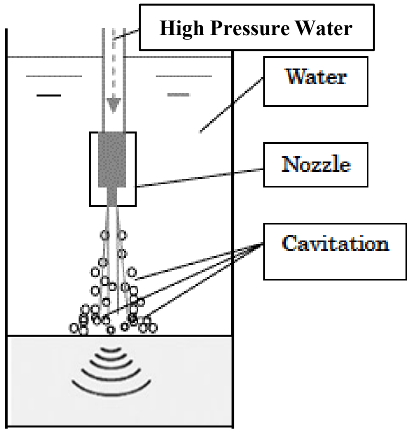
Shot Peening



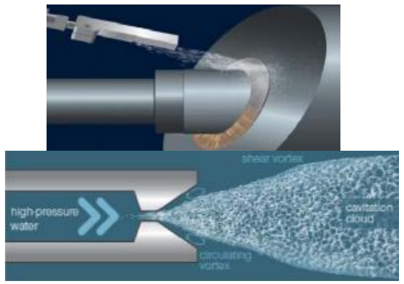
- Very near surface compressive residual stress often negated by surface finish
- Nondeterministic application
- Messy media (shot) must be collected



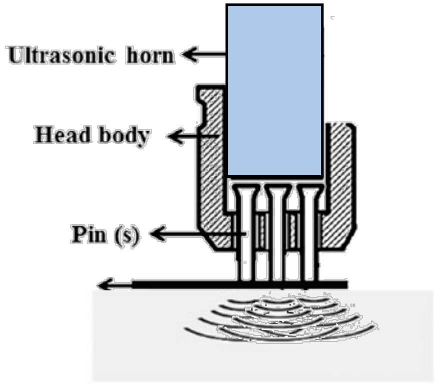
Cavitation Peening



- Similar compressive residual stress profile to shot peening, but uses bubbles under water
- Requires complex head or peening underwater
- No messy media to clean up

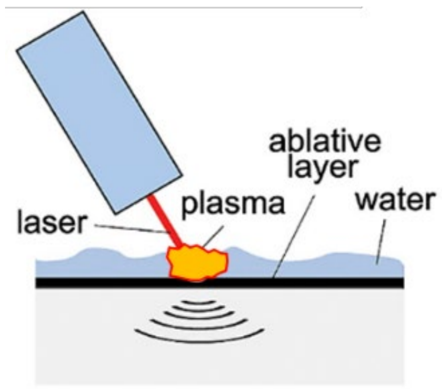


Ultrasonic Peening



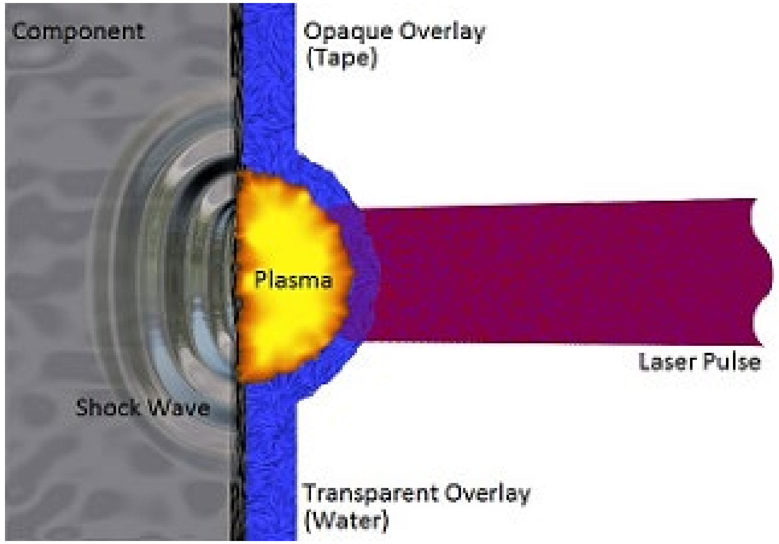
- Similar compressive residual stress profile to shot peening, but much better control
- Very mobile, single operator, low learning
- No messy media to clean up

Laser Shock Peening



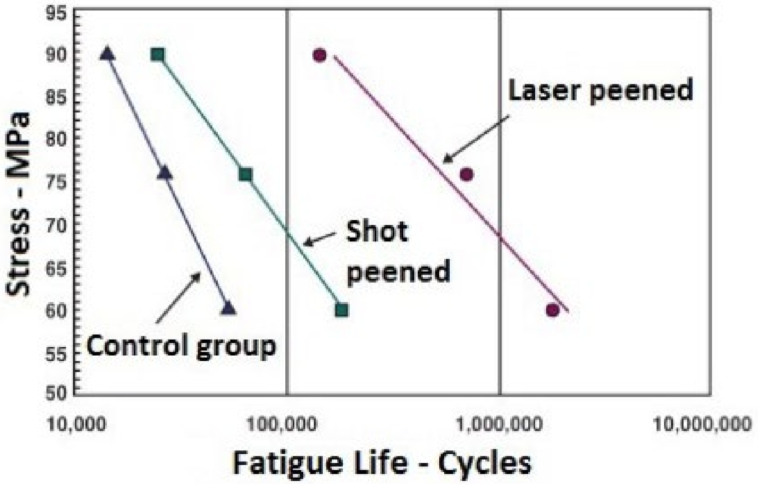
- Achieves highest compressive residual stress 5-10X deeper than other methods
- Water traps energy; plasma shock wave
- Laser pulses in the range of one million psi, 20 Hz

What is Laser Shock Peening ?

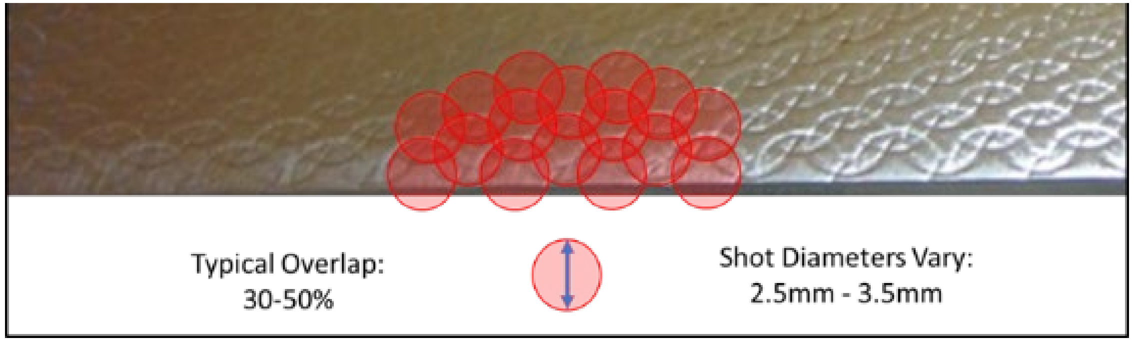


Parameters: Power Density-Pulse Width-layers, laser spot size
units: GW/cm2, nano-seconds, # layers to repeat
(Typically Displayed: 4-20-3)

Fatigue life of 6061-T6 Al SAE key hole specimen demonstrates 10x improvement of laser peening vs. shot peening



- High energy laser generates pressure pulses in the range of one million psi which plastically compress the metal as they propagate into the material
- Water overlay traps the energy, and a plasma is generated sending a shock wave into the material
- Transverse expansion results in residual compressive stress that is 10X deeper than conventional peening



25 Year Commercial Laser Shock Peening History

1990 2000 2010 2020 2030 2040

1980's Battelle Researched pulsed lasers

In 1995, LSPT started, first commercial supplier of laser peening equipment

In 1998, GE Aviation began production laser peening of the F101 fan blades in 1998 saving over $1B in maintenance

2010s F-22 & F-35 both get LSP ***Navy approved***

In 2015, Hepburn and Sons led the first NSRP project introducing laser peening to the Navy; for the last five years, we've shown its benefits in residual stress profiles, forming complex geometries, and mitigating fatigue cracking in sensitized aluminum and stress corrosion cracking; now funded to install a laser peening system onboard a ship for lasting aluminum repairs

Mid 1990s, Toshiba in Japan developed laser peening system for treating welds in nuclear plant pressure vessels

In 1991, the B-1B Lancer's F101 engine began experiencing titanium turbine blade failures that forced the grounding of the entire B-1 fleet. The primary hazard was foreign object damage (FOD), as ingested ice chunks and other hard objects were producing cracks in the blades that led to failure and irreparable engine damage.

Hepburn LSP Technology Transition Campaign

NSRP 2015 | NSRP 2016 | NSRP 2018 | NSRP 2020 | 6 Mo No-Cost Extension

NSRP 2017 | STTR PH I | SBIR PH II | Potential Acceleration for SBIR PH II

CONFORM | CONFORM II ?

Primary goal is to transition the capability to Navy and/or shipyard ownership for their use in extending life of vessels

LSP Technologies

- NSWC CD Laser Peening Research Cell via NISE, PEO USC, and/or CAPEX funded
- Shipyard purchases Procudo at repair yard through NSRP transition
- Submarine shaft manufacturer/repair yard(s) buys Procudo unit

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

NSRP 2015
Ph I: AA5456 Straighten door waviness induced by welding
Ph II: Steel Shaft Life Extension
Ph III: HSLA-65 Steel deck straightening

NSRP 2016 (Austal)
Ph I: New Construction Pretreatment and forming
Ph II: Cavitation Erosion and Galvanic Corrosion Prevention and repairs including treating sensitized aluminum

NSRP 2017 (Austal & NNS)
Foundational Research using laser scanners in conjunction with laser peening for forming complex shapes - metrology and shape predictions

NSRP 2018 (Austal & HII NNS)
Integration of 3D scanner with laser peening with predictive analytics for forming and corrective shaping, establishing radius of curvature max and S-N curves for AA5083

STTR/SBIR (The Ohio State University, University of Alabama, NSWC CD, Vigor) – NEW CONSTRUCTION
Ph I: evaluate laser peening benefits to mitigate exfoliation (corrosion delamination of aluminum) **Ph II:** transitioned to SBIR to laser peen a section of the LCS and put in service for duration and compare performance to adjacent untreated aluminum

NSRP 2020 (Vigor) - REPAIR
Integration of laser peening system at shipyard
Ph I: Build laser peening system and Beam Deck Delivery System
Ph II: Integrate onto ship and in shop at yard (CG or LCS)

Future Maritime Commercialization/Transition Markets
- USN Ship Construction/Maintenance/Repair
- New Commercial Ship Construction/Maintenance/Repair
- New Submarine Construction
- SCC Mitigation/eliminates flame straightening
- Forming Complex Structures
- Mitigation of Cavitation Erosion

Other Commercialization/Transition Markets
- Cold Forming Metal
- Armor Performance Enhancement
- Other

CONFORM (SEA 073 HII NNS)
Concept Formulation Contract with PEO SUB Sea 073 and HII NN to evaluate laser peening benefits to shafts and propellers
Ph I: evaluate life extension of submarine shafts
Ph II: evaluate NAB propeller lasting repairs (Not yet executed)

CONFORM (SEA 073, HII NNS)
Concept Formulation Contract with PEO SUB Sea 073 and HII NN to continue evaluation of laser peening benefits to shafts and propellers
Ph I: Medium scale submarine shaft testing
Ph II: Large scale submarine shaft testing

TARGET APPLICATIONS

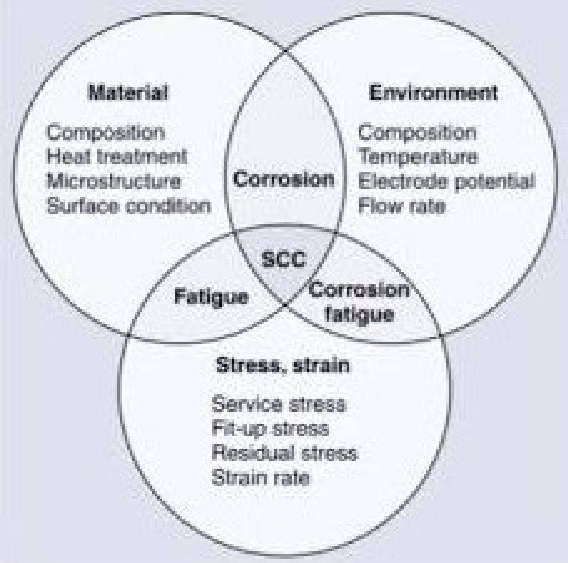
NSRP 2020

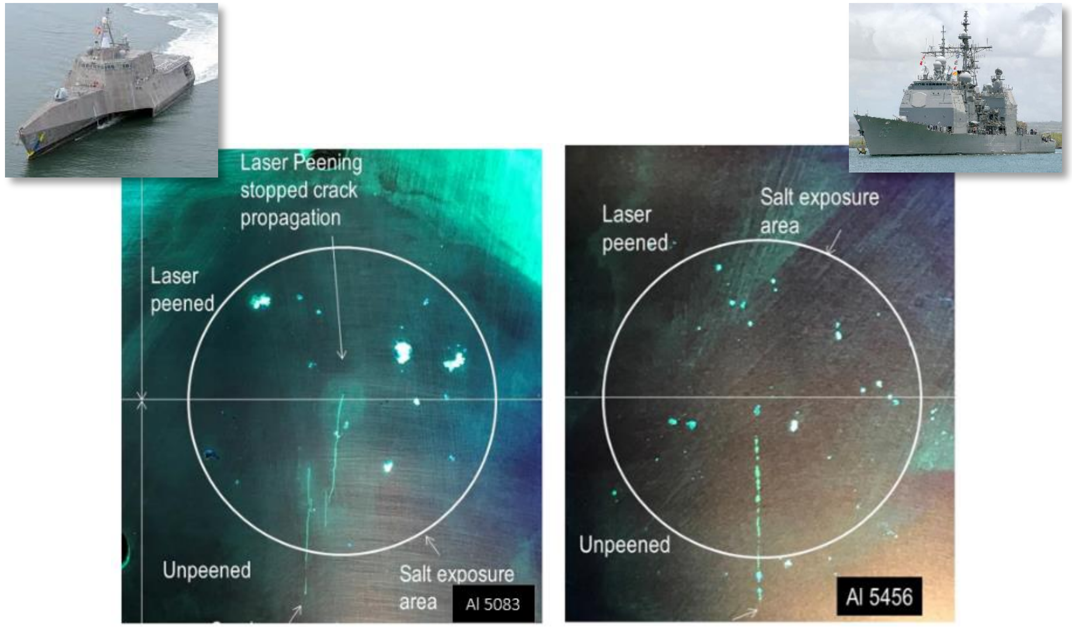
OHIO STATE | ALABAMA | VIGOR | AUSTAL | Newport News Shipbuilding | ABS | SBIR STTR | NSRP | PEO USC | TEAM SUBMARINE | NAVSEA

Laser Shock Peening Stops Cracks

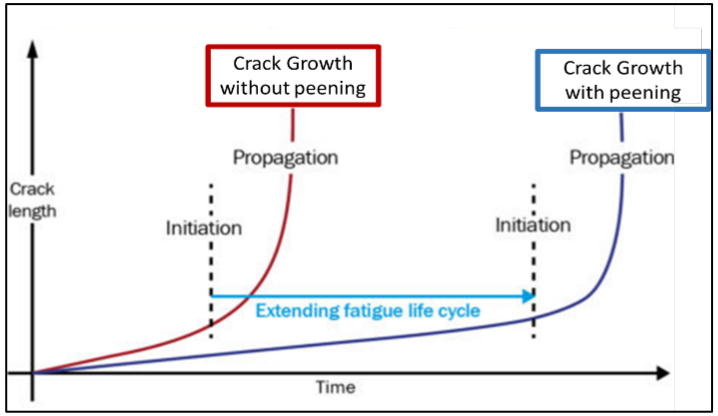
Laser Peening has been demonstrated to:

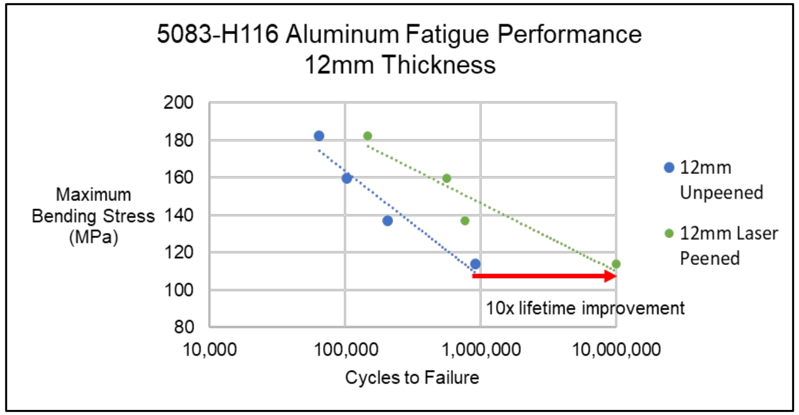
- Delay crack initiation and propagation
  - Stress Corrosion Cracking tests
- Increase Fatigue life
  - S-N curves: stress vs cycles

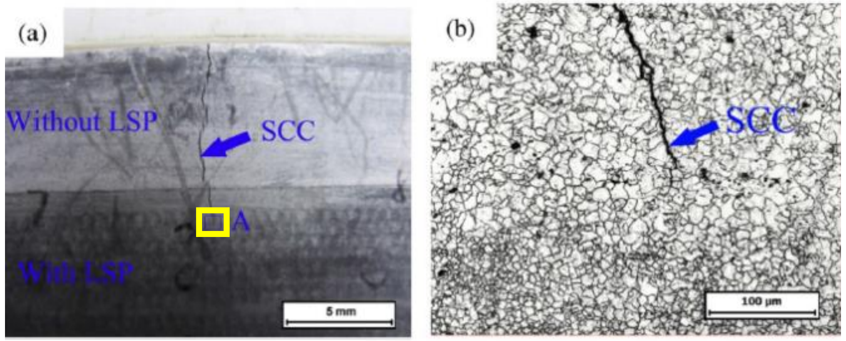




Cracks stop at the laser peened region yet propagated outside the corrosion boundary!



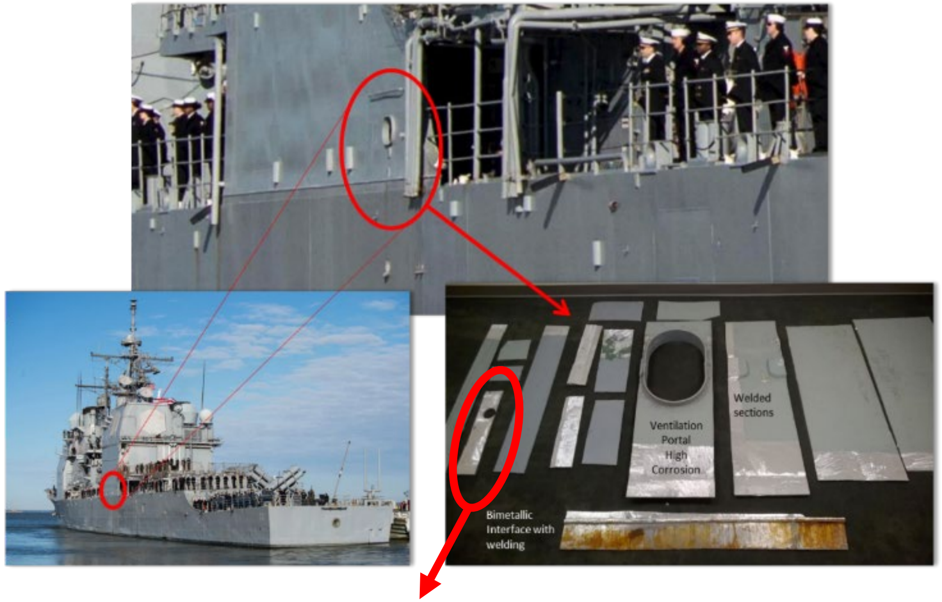




Gujba, A., & Medraj, M. (2014). Laser Peening Process and Its Impact on Materials Properties in Comparison with Shot Peening and Ultrasonic Impact Peening. *Materials, 7*(12), 7925-7974

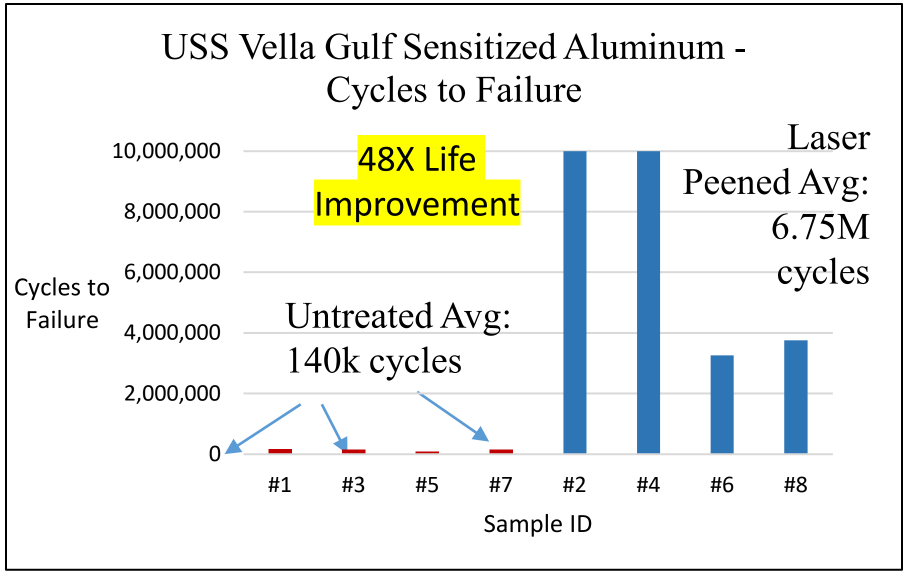
Cruiser - Laser Shock Peened Sensitized AA5456

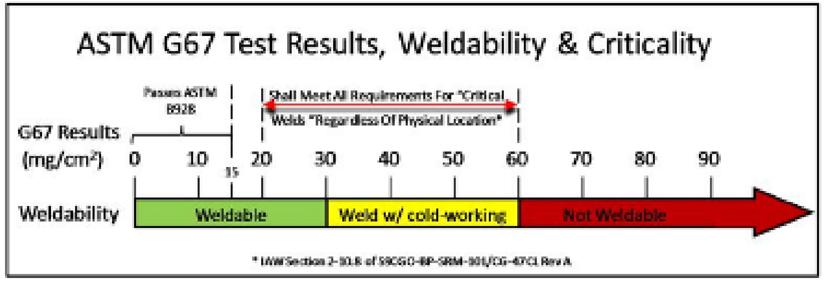
USS Vella Gulf (CG 72) - BAE Ship Repair Provided Aluminum 5456-H116



This sample formed 8 coupons for high cycle fatigue testing at 130ksi.

- Untreated samples all failed between 90 thousand and 150 thousand cycles, averaging **140,000 cycles**
- LSP samples averaged **6.75 million cycles** with two run outs over 10 million cycles
- **LSP samples saw a 48x lifetime extension on average**





Sensitization of 5XXX can be measured by mass loss in nitric acid. Greater mass loss correlates with poor weldability and potential for SCC.

NSRP 20-01 Onboard Ship Integration of Laser Peening System for Lasting Aluminum Repairs **(Proposed Phase II Re-baseline)**

LSP Technologies

Hepburn and Sons LLC

NAVSEA WARFARE CENTERS Carderock

VIGOR

Photo of Teammates with Procudo 200 (Shown L to R)

- Dr. Danny Georgiadis, Hepburn and Sons LLC
- Jeff Dulaney, CEO, LSP Technologies
- Richard McCreary, Vice President Business Development, Vigor

Phase I: Engineering Integration Requirements
12 Months

- NSWCCD Carderock to complete certification testing for 5XXX
- Develop Shipyard Integration Requirements
- Order Long lead items
- Order material and structure for test
- Shipyard visits/Coordination
- Safety: Meetings with Laser Safety Officer of Yard
- Beam delivery tests in lab
- Environmental Operation Assessment
- Review key applications of laser peening with Austal and Vigor
- Repair Yard Treating base/welded 5456
    - ➢ Treat key susceptible areas exposed to high heat

Phase II: Integration of System into Yard & on Ship
12 Months

Laser Shock Peening System Integration on Ship & in Yard

VIGOR

USS Cape St George CG-71

- Transport equipment to Yard
- Final installation/delivery of units to Yard
- Install system on ship
- Connect Utilities
- Select CG or LCS ship of availability in repair
- Calibration & Multiple Trials
- Laser peen section of 1m X 1m section of deck as practiced in lab during Phase I
- Install laser peening system in Yard for practice
- Training Shipyard personnel in laser peening: Operator, Maintenance, Safety
- Write Final Report documenting results and ROI

NSRP 20-01 Onboard Ship Integration of Laser Peening System for Lasting Aluminum Repairs (REPAIR FOCUS)

- Project Objectives:
  - **Demonstrate the laser peening** capability **onboard a ship** in repair and integration of the system **inside the Yard**
  - **Transition** the laser peening system to Navy or shipyard ownership for future treatment of aluminum superstructure to provide life extensions
  - **Test** - NSWC Carderock, Electrochemistry and Fracture Mechanics Metallurgy and Fire Protection Branch, Code 612
    - ✓ Conducted crack propagation testing
    - ✓ Conducted fatigue life testing
    - ✓ Compared laser peened and untreated 5XXX aluminum
    - ✓ Compared in air and in corrosive bath performance
  - Support achieving a **certification** of the technology to be used onboard vessels using 5XXX series aluminums including a letter from the TWH authorizing this project team to laser peen a CG or LCS

NSWC Carderock Division Testing

NSRP Results Update: Stress Corrosion Mitigation via Laser Shock Peening

The efficacy of LSP is being evaluated in two ways on Al5xxx-series:

- Rapid screening through slow rising stress intensity testing
- Alternate immersion testing in 4-point bend

Rapid screening has demonstrated:

- In the power density range of 1-4 GW/cm2, **higher power density typically performs better**
- Especially with intermediately sensitized AA5456-H116 (**4x crack growth rate decrease**)
- **Higher power density is critical for highly sensitized alloys**
- **AA5083-H116 is more difficult to protect, and only slightly benefitted from LSP**
- Overall, these tests showed that **LSP outperformed ultrasonic impact treatment**. These tests evaluated the worst-case scenario of a through-thickness crack, and so these **results are conservative**.

The 4-point bend testing:

- These tests are utilizing welded AA5xxx plates that are highly sensitized
- They have been running since October, and cracking has not occurred to demonstrate whether there is significant difference between the presence or lack of LSP

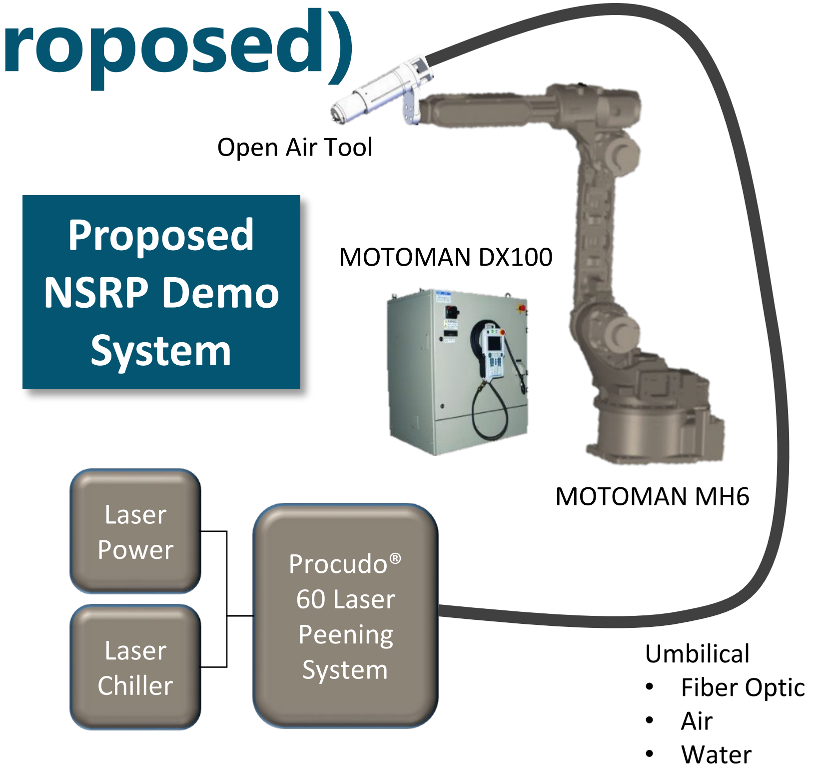
- **LSP will do no harm if used in place of UIT**
- **LSP performance can be adjusted**
- **UIT cannot be adjusted**

UIT surface (Left) vs LSP surface (right) at 1 GW/cm2(1-20-1):

- **NSWCCD recommends that LSP be approved for demonstrational use on AA5456-H116**
    - Letter signed by TWH 10 February 2021
- **NSWCCD soon to recommend and provide TWH letter for AA5083-H116**

Procudo® 60 Laser Shock Peening System **(Proposed)**

- Pre-COVID/NSRP Stop Work Original Solution: Procudo® 200 Laser Shock Peening System with Articulating Arm beam deck delivery and X Y Deck Scanning structure
  - Advantages:
    - Speed, higher power density for steel parts (harder metal applications).
  - Disadvantages:
    - Physical size, flexibility, set up time, Limited applicability of Beam Delivery System
- **Proposed Solution:** Procudo® 60 LSP System with Fiber Optic beam delivery and flexible peening tool
  - Technology became available in November 2020 and was not an option for the NSRP 2020 Project when originally proposed
  - Advantages:
    - Smaller system that is easier to move and set up
    - Less time onboard ship
    - Fiber optic delivery provides more flexibility with up to a 20-meter reach
    - Robot positioning of Open-Air Tool can laser peen multiple geometries
  - Disadvantage:
    - Slower than original equipment (Smaller spot size)



Objective System

First fiber optically delivered laser peening system shipped March 2021 to aircraft manufacturer

Sample Packaged Laser Peening System

Integration in Vigor Shipyard

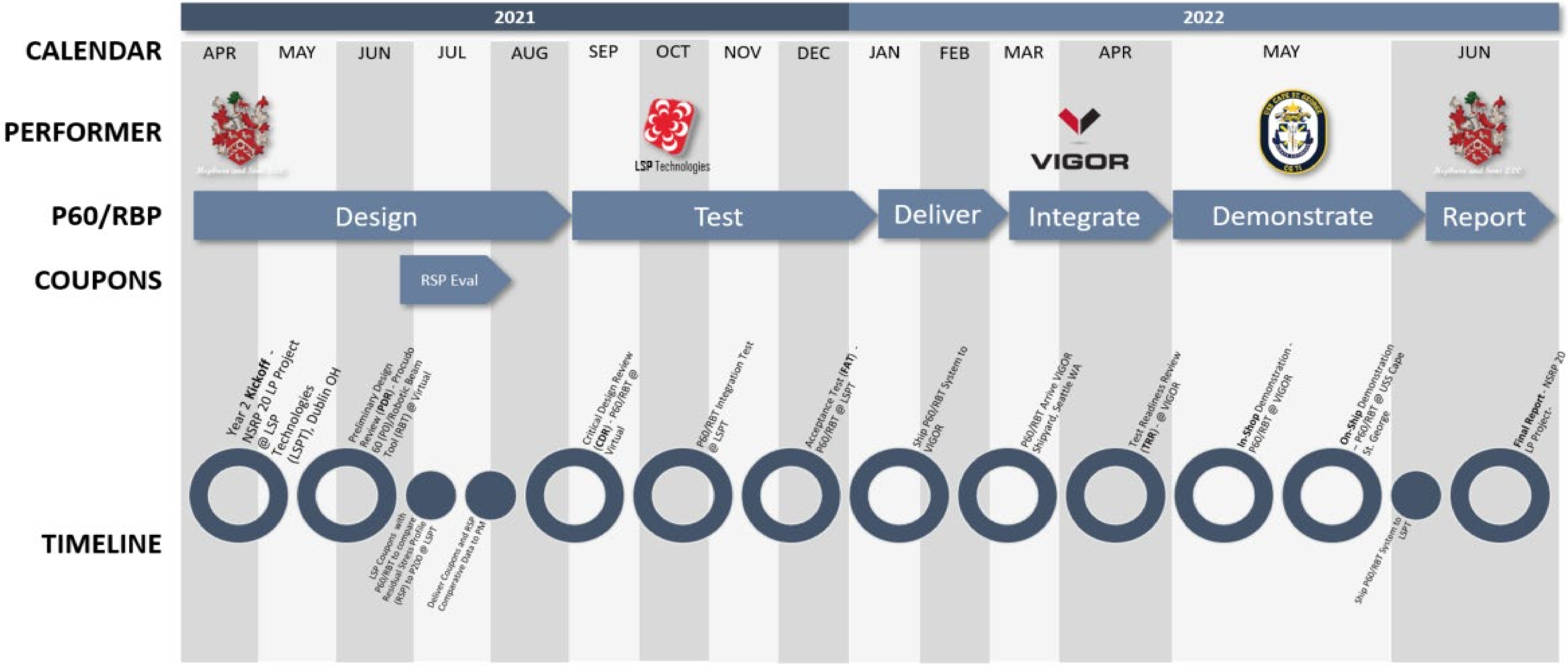
- In-shop location identified by Vigor
  - Laser Safety Officer engaged at Vigor resulting in draft Laser Safety Program to be established for in-yard and on-ship
  - Air, Water, Electrical installed
  - Budget planning for potential purchase of LSP capability and dedicated workspace
- Demonstrate LSP in-shop
  - Operator, Maintenance, Safety, as well as other observers
- Set up **proposed** Procudo® 60 Laser Peening System and LSP "Mock Deck"
- Assist Vigor with integration planning for potential purchase of LSP capability and dedicated workspace

Demonstration on Ship

- USS Cape St George (CG-71)
- LSP at least 1m^2
- Flight Deck will be tented while at Vigor
- Procudo® 60 (Robot and Open-Air Tool) will have additional laser safety tent when in operation

USS Cape St George (CG-71) Flight Deck Laser Peening Demonstration

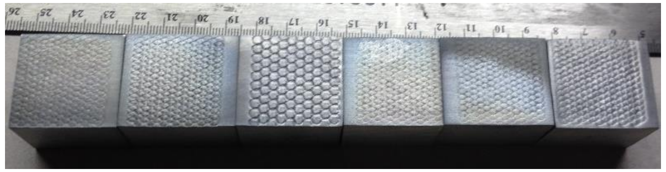
Future (Proposed) Schedule



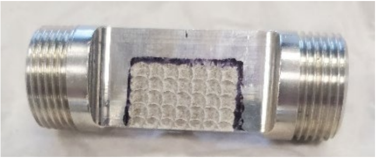
SBIR N18A-T016 – Analysis of Dislocation Density, Recrystallization, and Residual Stress in 5XXX Aluminum using Laser Peening to mitigate Exfoliation Corrosion (NEW CONSTRUCTION FOCUS)

LSP Technologies

- Phase II Base (24 mo. Jan 20-Jan 22) – OY1 (12 mo – LSP LCS)
  - Assess the effect of varying LSP process conditions, such as beam intensity, duration, spot size, and layers of treatment (LSPT)
  - Accelerated laboratory testing to measure exfoliation corrosion of LSP 5XXX and non-treated 5XXX control samples (OSU)
  - Determine the effect of LSP on the rate of sensitization (OSU)
  - Determine the effect of LSP on paint adhesion and mechanical bonding (OSU)
  - Expose laser shock peened plates to an operation representative environment (UA)
  - Measure residual stress profiles of pre-peened plates before and after installation how laser shock peening is relaxed in HAZ after welding (UA)



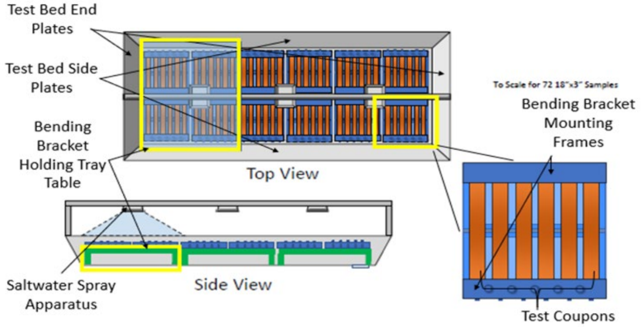
LSP Parameters Investigation

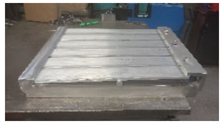


Test Sample LSP

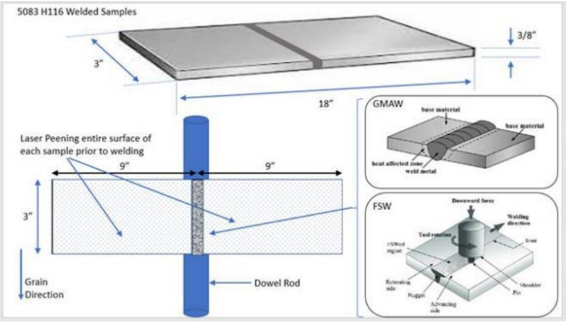
XRD – Residual Stress Measurement

Operational Environment System

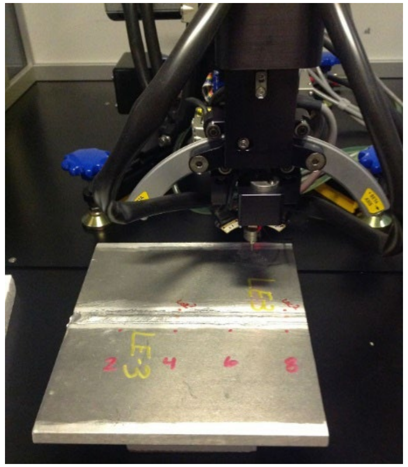




Actual Bending Bracket



GMAW and FSW some test samples



RS Measurement via Hole Drilling Method

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