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
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

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

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

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

  - U.S. ARMY
    - 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

Approved for public release; distribution is unlimited
Stakeholders

INDUSTRY CLIENTS & PARTNERS

BAE Systems
Northrop Grumman
Leidos
Huntington Ingalls
Fire Security
GO 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
TEFLEEN America
Stäubli
AeroNav Laboratories, Inc
Rolls Royce
ABB
Roxtec
RSL Advanced Lighting Technologies
Leonardo DRS
KATO Engineering
VT Halter Marine
ABS
Booz Allen Hamilton
Delays
Wartella

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 [ITTO]
• Commander Navy Regional Maintenance Center [CNRMC]
• U.S. Army
Shepherd Innovation from Concept Definition to Capability Deployment

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?

- 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.

[Diagram showing components and processes of 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)
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.


In 2010, F-22 & F-35 both get LSP 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.

In 1980’s Battelle researched pulsed lasers.

In 1980’s Battelle researched pulsed lasers.
Hepburn LSP Technology Transition Campaign

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

**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 (Austral)**
- Ph I: New Construction Pretreatment and forming
- Ph II: Cavitation Erosion and Galvanic Corrosion Prevention and repairs including treating sensitized aluminum

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

**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 2018 (Vigor) - REPAIR**
- 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

**NSRP 2018 (Austral & HII NNS)**
- Integration of 3D scanner with laser peening for forming complex shapes - metrology and shape predictions

**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

**NSRP 2020**
- Potential Acceleration for SBIR Ph II
- Submarine shaft manufacturer/repair yard(s) buys Procudo unit

**Potential Acceleration for SBIR Ph II**
- Shipyard purchases Procudo at repair yard through NSRP transition

**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

**TARGET APPLICATIONS**
- Virginia Class SSN
- Ticonderoga Class CG
- Freedom Class LCS
- Spearhead Class EPF

Approved for public release; distribution is unlimited
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!

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)

## 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**

![LSP Technologies]()<br>
![Hepburn and Sons LLC]()<br>
![NAVSEA warfare centers Carderock]()<br>
![Vigor]()<br>

<table>
<thead>
<tr>
<th>Laser Shock Peening System Integration on Ship &amp; in Yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Transport equipment to Yard</td>
</tr>
<tr>
<td>- Final installation/delivery of units to Yard</td>
</tr>
<tr>
<td>- Install system on ship</td>
</tr>
<tr>
<td>- Connect Utilities</td>
</tr>
<tr>
<td>- Select CG or LCS ship of availability in repair</td>
</tr>
<tr>
<td>- Calibration &amp; Multiple Trials</td>
</tr>
<tr>
<td>- Laser peen section of 1m x 1m section of deck as practiced in lab during Phase I</td>
</tr>
<tr>
<td>- Install laser peening system in Yard for practice</td>
</tr>
<tr>
<td>- Training Shipyard personnel in laser peening: Operator, Maintenance, Safety</td>
</tr>
<tr>
<td>- Write Final Report documenting results and ROI</td>
</tr>
</tbody>
</table>

---

*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

---

Approved for public release; distribution is unlimited
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
NSW 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/cm\(^2\), 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

• 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)
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 1m²
• Flight Deck will be tented while at Vigor
• Procudo® 60 (Robot and Open-Air Tool) will have additional laser safety tent when in operation
Future (Proposed) Schedule

<table>
<thead>
<tr>
<th>CALENDAR</th>
<th>2021</th>
<th></th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td>APR</td>
<td>MAY</td>
<td>JUN</td>
<td>JUL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PERFORMER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P60/RBP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COUPONS</td>
<td>Design</td>
<td>Test</td>
<td>Deliver</td>
</tr>
<tr>
<td>Timeline</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SBIR N18A-T016 – Analysis of Dislocation Density, Recrystallization, and Residual Stress in 5XXX Aluminum using Laser Peening to mitigate Exfoliation Corrosion (NEW CONSTRUCTION FOCUS)

• 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)