NSRP | National Shipbuilding Research Program

Pulsed Laser Comparison Tool

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Dr. Melissa Klingenberg, Mr. Steve Brown, and Mr. Dave Rearick – Penn State ARL
Mr. James Brooks – Newport News Shipbuilding

Today's Presentation

- Issues
- Background
- Goal & Objectives
- Proposed Timeline
- Proposed Approach
- Next Steps
- Acknowledgements
- Questions

Issues

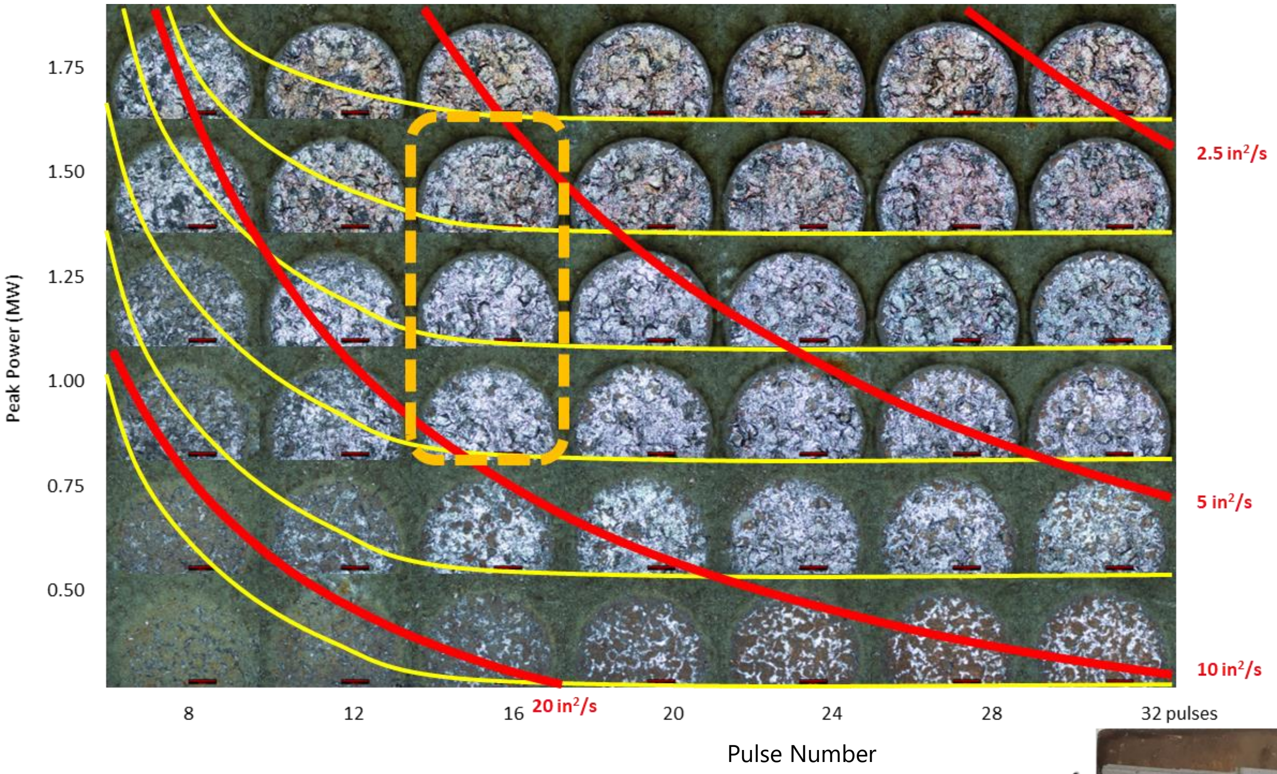
- Shipyards (SYs) desire to change from conventional, manually operated coatings removal tools to laser ablation (LA) to avoid health and safety concerns and excessive material removal associated with conventional tools.
- SYs have been pursuing laser ablation (LA) use since the mid-to-late 2000s (at least).
  - The earliest projects did not lead to approval for use.
    - Conducted broad application projects consisting of informal evaluation of ability to strip paint.
    - Examined unique applications with established test plans; final qualification testing provided uncertain results.
  - Early to not-so-distant past (circa 2017-19) projects addressed widely varying applications.
    - Steel applications ranged from subs to surface ships for corrosion and coating removal.
    - Aluminum applications targeted surface ships for corrosion and coating removal, as well as use of lasers to passivate surfaces.
  - Completion of ONR ManTech “Laser Ablation of Pre-construction Primer on HSLA Steels” is expected to lead to LA approval for use on most steels, provided subsequent blasting is conducted.
    - Evaluated 100s of parameters/factors that dominated material degradation and optimized stripping rate.
      - Created process map for in-line 1kW pulsed fiber laser based on laser variables dominating material characteristics and removal rate/completeness.
- SYs desire to also use hand-held LA tools for other applications, but transition from in-line LA tool isn’t straightforward.
  - Different lasers have different peak energies, different processing variables, different spot sizes that lead to different energy densities.

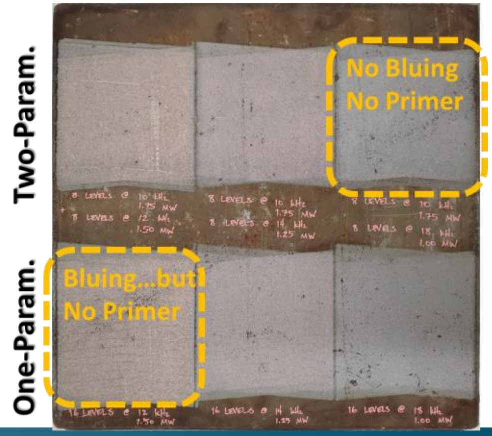
Background

- Recall under ONR ManTech Project
  - Over 1000 stripping trials were conducted to reduce optimal operating parameters.
  - Team established processing grid with iso-energy contours and then overlaid associated processing rates to compare with conventional processing.
  - Examined processing variables and influence on surface characteristics.
  - Determined dominant process variables and means to quickly determine processing parameters for similar paint removal.
  - Conducted testing of steel stripped using optimal parameters.

Background: Energy Deposition and Process Speed

- Developed iso-LA and iso-speed contours
  - Red lines = maximum, theoretic processing speed (in2/s)
    - Baseline blast speed is 2.5 in^2/s
  - Yellow lines show LA primer removal reaches steady-state after ~ 20 pulses followed by melting thereafter (for this scenario)
  - Orange dotted box = sweet-spot
    - Higher Radiant Exposure rows show onset of bluing
    - Lowest Radiant Exposure row shows steady-state of primer removal after 20 pulses (similar in other rows).

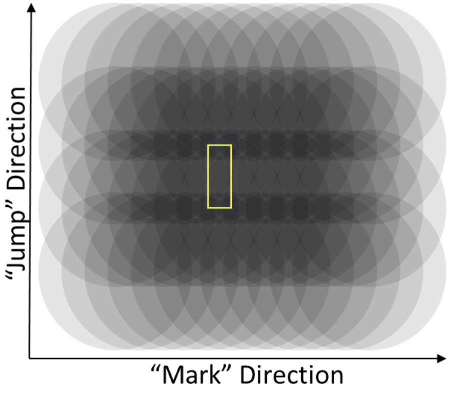


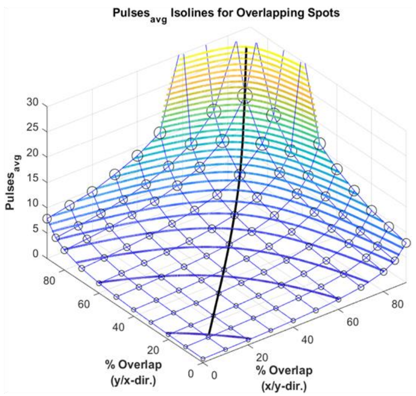


Best single-parameter set removed primer, but slightly blued the substrate
Multi-parameter approach removed the primer and the shallow bluing of the substrate
Multi-parameter approach initially “hit harder”, but fewer times; followed with softer hits

Background: Refining Understanding

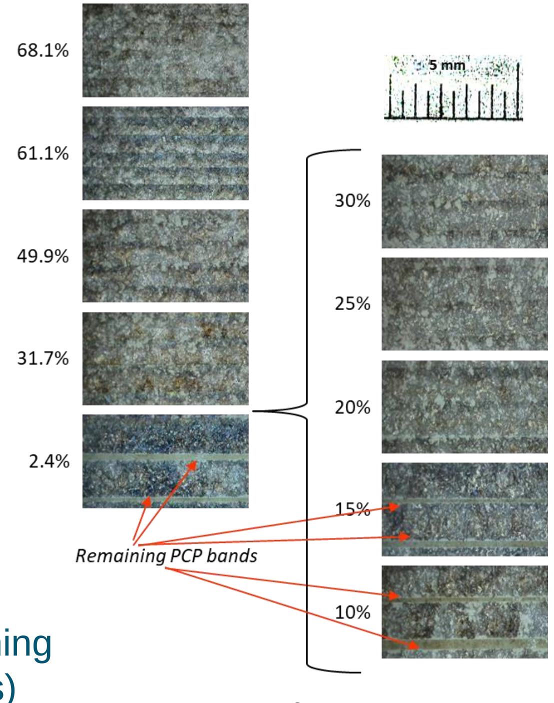
- Used image analysis to estimate average # of pulses
- Average pulses number drives strip rate
  - Image processing (below) revealed P_{avg} = 0 to 30 is sufficient for ablation of PCP on HSLA
  - P_{avg} > 30 is overly sensitive to changes in % Overlap.





- Changes in jump direction affect LA rate more than mark direction.
  - Maximizing distance in jump direction maximizes processing rate
  - Avoid extremes to avoid non-ideal beam behavior (e.g., non-top hat energy profiles).
  - More data scatter occurs as the images get darker
    - Process sensitivity increases with the number of layers.

- Conducted experiments to determine limitations of non-symmetric pulse overlap
  - Fixed Avg. Power and Frequency
  - Radiant Exposure, Pulse$_{avg}$, and Pulse Duration to intentionally retain a slight haze of PCP
  - Varied % Overlap in jump and marking directions
- Findings:
  - % Jump Overlap >20% resulted in equivalent ablation
    - Equivalent ablation = constant % remaining PCP (minor discoloration differences are ignored as will be with "clean-up" pass)
  - % Jump Overlap <20% resulted in unequivalent ablation
  - Non ideal top hat spots are produced. Must be considered during process optimization.
  - Decreasing % Jump Overlap correlates with increasing carriage velocity and more-time-sensitive scanning (hence the non-uniform jump distances)



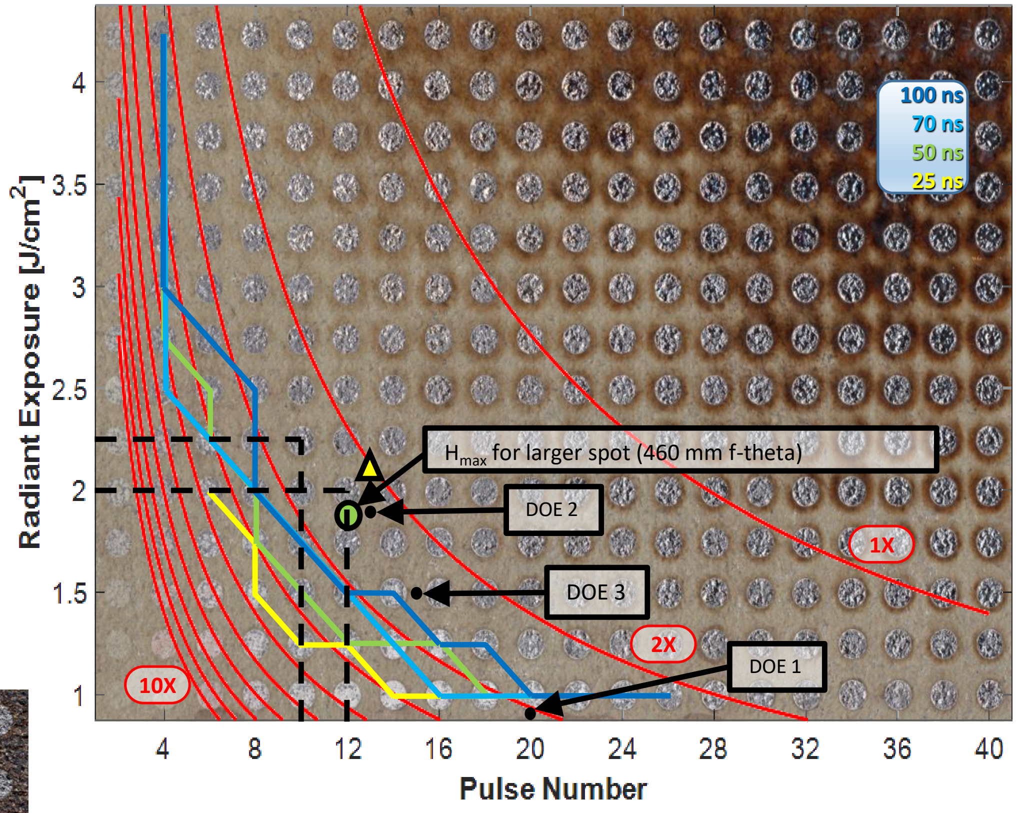
% Jump Overlap Images

- Recommendation: Avoid % Jump Overlap < 20%

Background: Developing LA Parameters

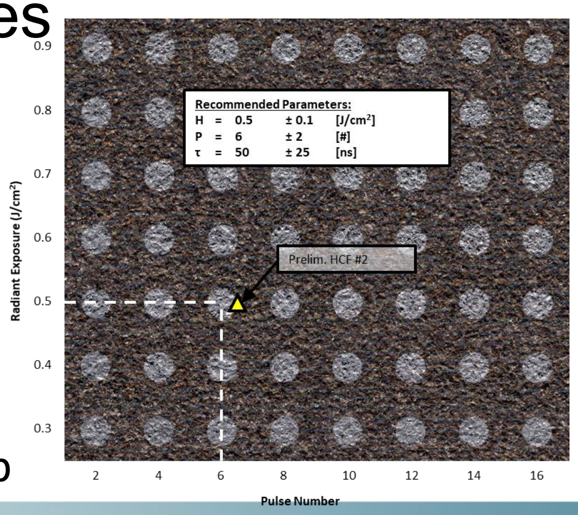
- Continued experimentation to develop optimal processing rate for LA with new lens
  - Trialed 25, 50, 70 and 100 ns (sample experiment image below [100 ns] with DOE 1-3 overlaid)
  - Red curves indicate maximum possible processing rates compared to est. media blast rate (2.5 in²/s)
  - Nominal Parameter Array led to these recommended parameters (right) for further optimization
- Optimized "clean-up" passes
  - All ranges resulted in fairly good clean-up
  - LA Rate "isolines" (not displayed) were not uniform in clean up as are in Stage 1 stripping

Nominal Parameter Array



Stage 1 Stripping

Recommended Parameters:				
H	=	2.0	± 0.1	[J/cm²]
P	=	12	± 2	[#]
τ	=	50	± 25	[ns]
Or, if higher energy is req'd:				
H	=	2.25	± 0.1	[J/cm²]
P	=	10	± 2	[#]
τ	=	50	± 25	[ns]



Stage 2: Clean Up

Goal and Objectives

- Goal:
  - Develop pulsed laser comparison tool (processing map overlays) to enable SYs to:
    - Shorten the duration and expenses associated with qualifying alternate LA systems for similar applications.
    - Leverage data already developed for an approved use-case.
- Objectives:
  - Identify high priority laser systems-of-interest for shipyard use
    - Handheld and automated
  - Review dominant factors influencing strip rate, completeness of stripping, and degradation to materials.
  - Determine best methods to compare systems
    - Identify best variables to include in developing a comparative processing tool/map.
  - Develop processing tool/map based on previous data and new testing conducted under this project.
  - Gain support from Technical Warrant Holders
    - Work to better understand TWH requirements for LA use on ship steel.

Proposed Timeline

• *PULSED-LASER COMPARISON TOOL*	*Est. Schedule*
○ Task 1: Program Management	Month 1-12
○ Task 2: Select Laser Systems to Trial	Month 1-2
○ Task 3: Identify Targeted Testing	Month 1-3
○ Task 4: Identify Dominating Parameters Through Testing	Month 4-10
○ Task 5: Overlay Maps and Correlate Characterization Data	Month 9-11
○ Task 6: Complete Final Report	Month 12

Proposed Approach

- Task 1: Project Management (Month 1-12)
  - Throughout project, team will create/update a Project Plan, Quarterly Reports, and briefing materials to disseminate project information.
- Task 2: Select Laser Systems to Trial (Month 1-2)
  - Gather input from partner SYs (NNS, BIW, and HII-Ingalls) on high priority hand held laser ablation (LA) systems.
  - Collaborate with Maritime Industrial Base (MIB) to leverage plans for LA implementation across SYs.
    - MIB is to procure mobile 500W and 1000 W laser systems for SY trials; examining leveraging options.
  - Examine power level, energy delivery, pulse frequency, spot size, and scan overlap/frequency for candidate LA systems.
    - Compare variable ranges to 1 kW pulsed fiber laser (NNS in-line).
    - Review unique LA features to determine applicability or the need for unique approaches for process overlays.

Proposed Approach

- Task 3: Identify Targeted Testing (Month 1-3)
  - Develop test matrix
    - Coordinate development with NNS (and BIW and HII-Ingalls, if available) and TWHs.
      - Seek TWH direction regarding primary tests to obtain their approval of processing maps.
      - Key: Reduce overall testing requirements to qualify like LA systems for use in similar applications.
        - ✓ Define "like LA systems" and "similar applications" with TWHs to outline boundary conditions.
    - Additional system examination and testing (outside existing NSRP funds) will be outlined for future consideration.
    - Identify substrate type, condition (e.g., pristine or oxidized), and profile, as well as coating materials.
- Task 4: Identify Dominating Parameters Through Testing (Month 4-12)
  - Determine if process variables permit matching energy density of the 1 kW pulsed in-line laser, and identify if the secondary defining parameter may produce similar removal rates and resulting material conditions.
    - Identify laser parameters – variable and fixed .
      - Example: Laser energy and power (peak and average), spot size/geometry, laser stand-off distance from the substrate (depth of focus tolerance), and scanning technology/pattern(s), spot overlap, etc.

Proposed Approach

- Task 4: Identify Dominating Parameters Through Testing (Month 4-12)
  - Two-fold or single approach may be taken, depending on TWH test requirement input and funding needs and success at initially tested approach meeting project needs.
    - Approach 1: Modify variables to tweak energy density to approximate in-line 1 kW pulsed fiber laser.
    - Approach 2: Conduct best effort process optimization independently evaluate processing parameters that best strip the coating and mirror the surface obtained using optimal in-line 1 kW pulsed fiber laser (as on HSLA steel) parameters.
  - Reveal dominant secondary parameter through stripping action/rate and a surface characteristics.
    - Perform limited characterization to determine the similarity in stripping completeness and base material condition (e.g., damage).
  - Breadth of examination is based on funding constraints
    - Up to 4 lasers may be considered under planned NSRP (includes in-line 1 kW pulsed fiber laser) funds.
    - Desire to examine both crude, gross paint removal using more intense settings and less intense parameter set to removed the light oxide byproduct of the first process (clean up pass).
    - Expansion of investigation is desirable.

Proposed Approach

- Task 5: Overlay Maps and Correlate Characterization Data (Month 9-11)
  - Generate process maps for evaluated lasers
    - Review characterization/test data against process data.
    - Identify parameters (in addition to energy deposition) that appear to best refine LA with each laser trialed.
  - Overlay process maps between LA systems
    - Determine necessary adjustments to align processes/surface outcomes when dominating parameters are similar.
    - Determine best means to compare processing maps of LA systems when secondary dominating factors differ.
      - Focus on achieving similar material condition results with a high degree of confidence vs. maximum processing rate.
    - Discuss results with the TWHs.
      - Seek TWH direction on usefulness of results and need to expand examination or alter maps within NSRP project or with augmented funding.
    - Deliver process maps, provided a successful correlation between LA tools is found.
    - Coordinate future process development and map expansion with NSRP, NNS (and BIW and HII-Ingalls, if available), TWHs, and other interested parties (e.g., MIB).
- Task 6: Develop Final Report (Month 12)
  - Compile documentation of project activities, findings, recommendations and results into a final report.
    - Expect to include testing matrix, test results and analysis, process maps and indication of ability to overlay process parameter maps of different LA systems to achieve similar material conditions.

Next Steps

- Execute Contract then Focus on Milestones and Technical Progress
- Near-Term Milestones to be Addressed
  - Develop Project Plan.
- Technical Progress to be Accomplished
  - Initiate technical work.
- Risk Reduction Items to be Addressed
  - Develop sufficient data with existing funds.
    - Leverage existing processing data generated under ManTech Project.
  - Ensure usefulness of data generated.
    - Consider imminent plans for hand held laser ablation use in the SYs and leverage MIB activities, where possible.

Acknowledgements: NSRP Team

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  - Mr. Colin Dunlop – NSRP Program Manager, NAVSEA
  - Mr. Mark Smitherman – Program Administrator NSRP
  - Mr. Conlan Hsu – NSRP Surface and Coatings Preparation Chair
  - Ms. Angel Zepeda - NSRP Surface and Coatings Preparation Vice Chair
  - Mr. Kevin Roossinck – NSRP Welding Chair
  - Mr. Cody Whitely – NSRP Welding Vice Chair
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  - Mr. Luke Lyndaker – Member, GD Bath Iron Works
  - Mr. Scott Wellens – Member, Fincantieri Marinette Marine
  - Mr. John Kooienga – Member, HII – Ingalls Shipbuilding

<u>NSRP Project Team</u>

- Newport News Shipbuilding – Active Participant
  - Mr. James Brooks – NNS Technical Lead
  - Mr. Elmer Dickens – NNS NSRP Manager
- General Dynamics Bath Iron Works - Participant
  - Mr. Gregg Buczkowski – BIW Technical Lead
  - Mr. Andy Blackman – BIW NSRP Manager
- Huntington Ingalls Shipbuilding (HII) - Participant
  - Ms. Haley McGee – HII Technical Lead
  - Ms. Ambre Cauley – HII NSRP Manager
- Penn State Applied Research Laboratory
  - Dr. Melissa Klingenberg – Principal Investigator (PI)
  - Mr. Stephen Brown – Co-PI
  - Mr. David Rearick – Co-PI

Acknowledgements: ONR and MIB

ONR ManTech Team Members

- ONR: Mr. Paul Huang – iMAST Program Officer
- PMS 379: Mr. Russell Knowles – PEO Aircraft Carriers, ManTech/ NSRP Representative
- NAVSEA Technical Authorities: NAVSEA 05
    - Mr. John McGrorey – TWH, Metallic Hull Materials, Welding and Fabrication Processes Used in Surface Ship Structures
    - Mr. Chris Rodgers – TWH, Structural Integrity – Aircraft Carriers and Large Deck Amphibious Ships
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    - Dr. Dan Finke – Technical Director, Penn State ARL
    - Mr. Steve Brown – Primary Investigator (PI), Penn State ARL
    - Dr. Melissa Klingenberg – Co-PI, Penn State ARL

ONR ManTech Team Members

- Newport News Shipbuilding
    - Ms. Tammy Rossi – NNS ManTech Manager
    - Mr. Mike Cunneen – NNS Lead Mfg. Engineer
    - Mr. Eugene Saunders – Director of Mfg. 2
    - Mr. Luke Kumler - Welding Engineer
    - Mr. Chris Norris – Welder

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- Maritime Industrial Base Laser Ablation /Coatings Removal Leads
    - CMDR John Hill –MIB Industrial Base Acceleration, Coatings Removal PM
    - Mr. Deniz Ferrin – IMF PMG WA
    - Mr. Nick Bankus – NUWC-Keyport
    - Mr. John Albrecht – TRF-Bangor

Contacts

Dr. Melissa Klingenberg
Penn State Applied Research Lab
Primary Investigator, R&D Engineer
Phone: (814) 424-1209
Email: mxk311@arl.psu.edu

Mr. James Brooks
Newport News Shipbuilding
R&D Engineer
Email: James.Brooks@hii-nns.com

Mr. Stephen W. Brown
Penn State Applied Research Lab
Co-PI, R&D Engineer
Phone: (814) 441-6685
Email: swb143@arl.psu.edu

Mr. Dave Rearick
Penn State Applied Research Lab
Co-PI, R&D Engineer
Phone: (724) 496-2631
Email: djr243@arl.psu.edu

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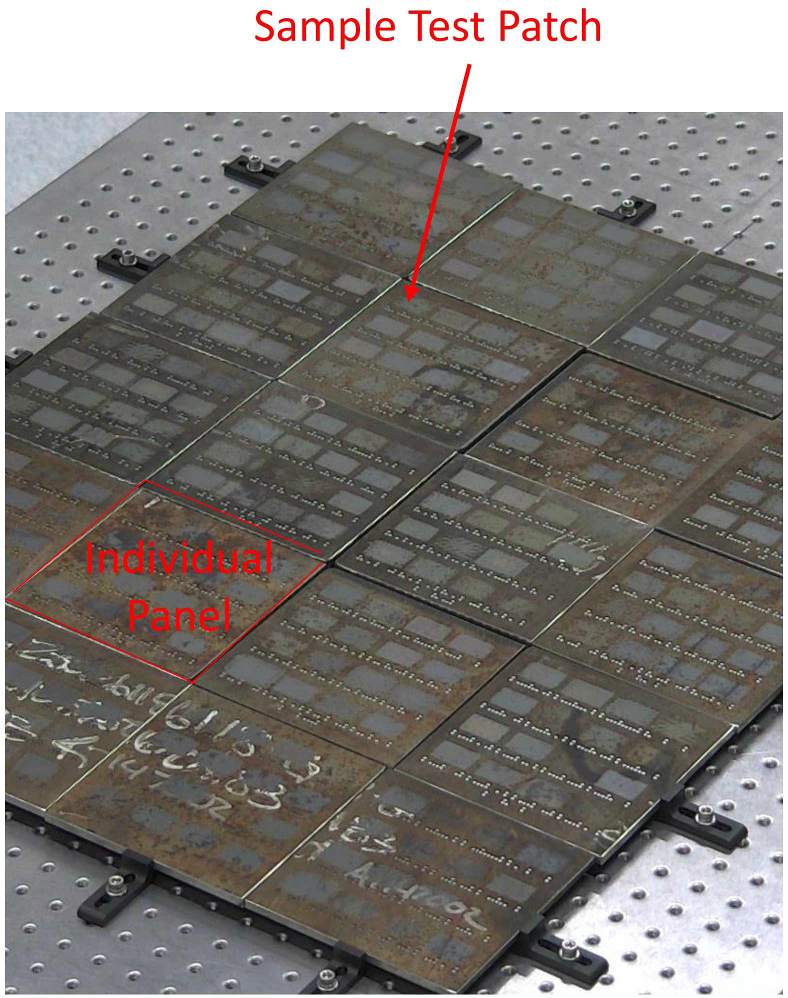
Background: Previous LA Experimentation

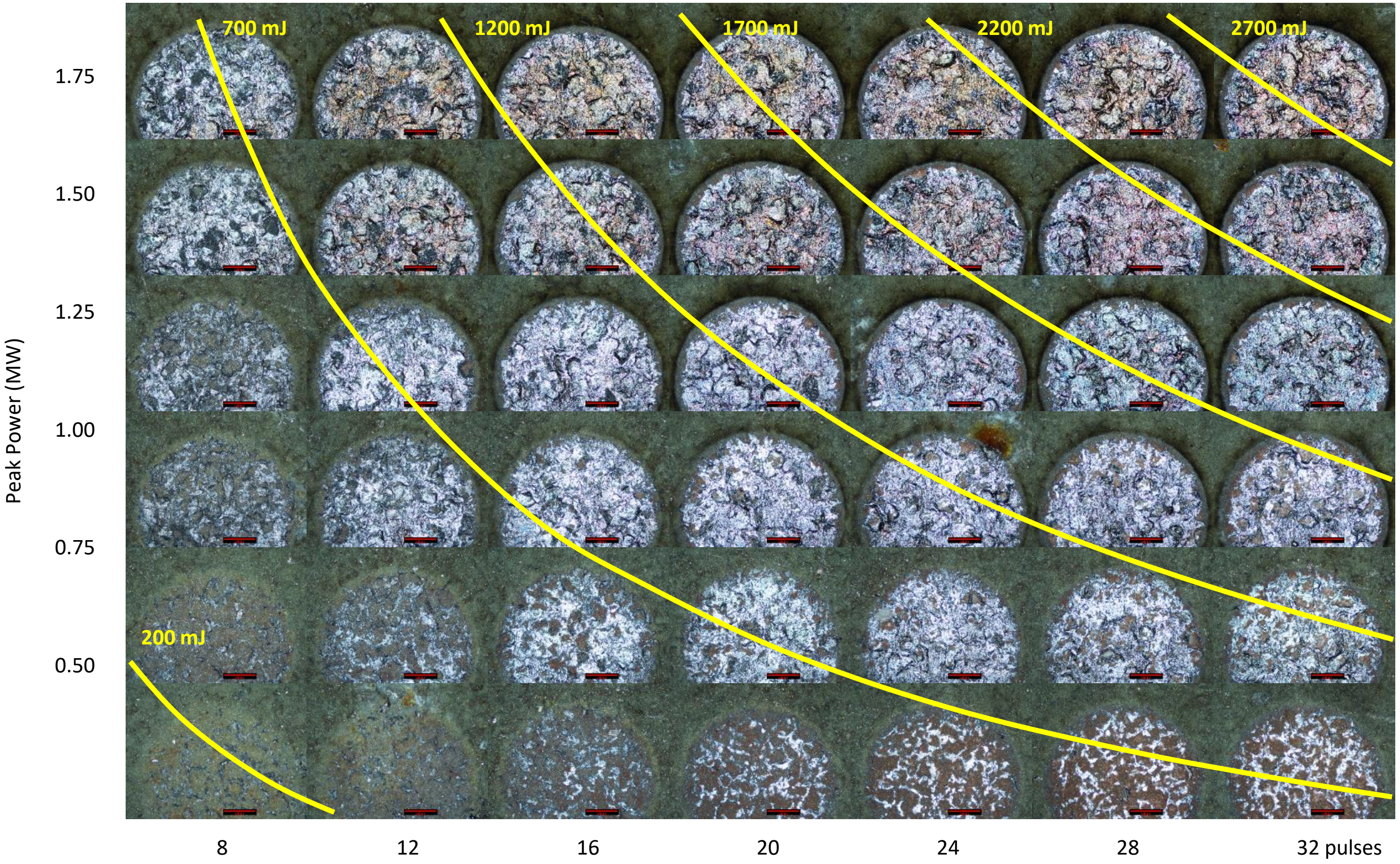
- Conducted 1000+ stripping trials to optimize green primer removal on HSLA steel
  - DOE 1 = applied 320 unique parameter sets to 640 test patches
  - Developed isoenergy contours and overlaid processing bands
    - Enabled quick reduction of processing variables
      - Useful for more difficult to remove coating systems
  - Improved system program to enable clean up
    - Removed oxidation while improving completeness of stripping
  - Determined optimal parameters for weathered IOZ PCP
  - Learned unweathered primers and new primer colors would be encountered eventually



Rusted samples with test patches

Background: Energy Deposition Consideration

- Nominal Parameter Array overlaid with iso-energy contours
  - Evaluated Peak Power vs. Number of pulses
    - Overlaid (yellow) energy contours show increasing levels of average energy input
    - Avg. E input is proportional to Radiant Exposure (pulse energy divided by spot size)
  - *Radiant Exposure affects potential for ablation*
  - *Pulse Number affects thoroughness of ablation*
  - *Total Energy affects onset of melting*

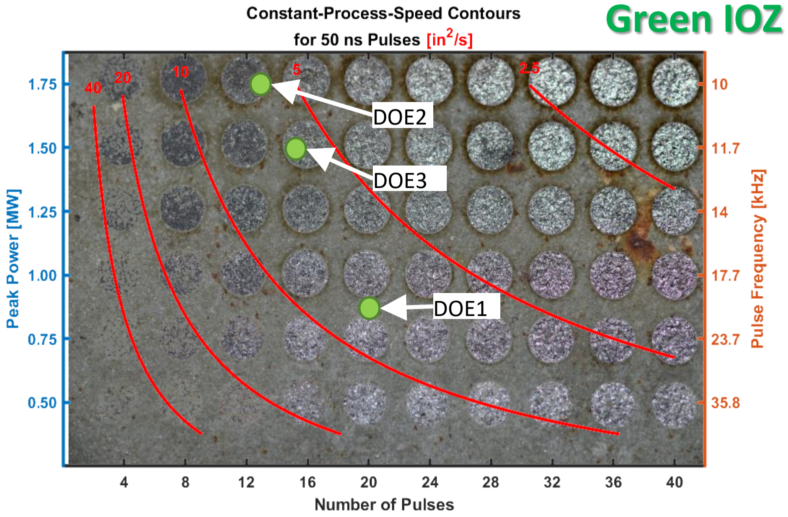


Isoenergy Contours

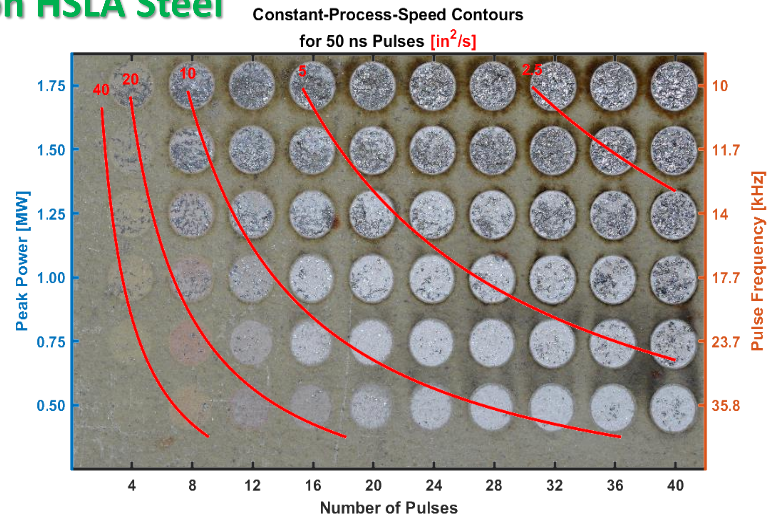
Background: Weathered vs. Unweathered Paint

Green IOZ Primer (0.8 – 1.2 mil) on HSLA Steel

Weathered Green: Consistent Ablation

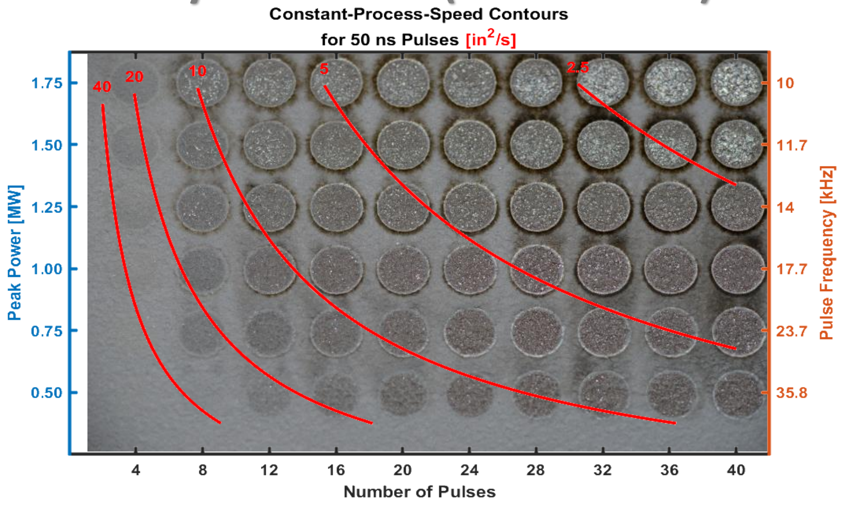


Newly applied green: Inconsistent / Patchy Ablation

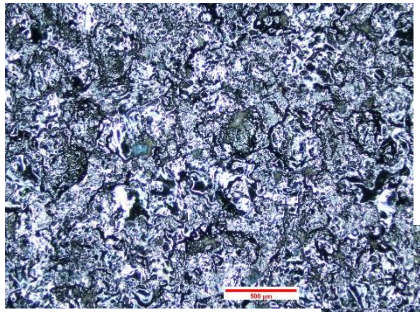


Gray IOZ Primer (0.7 – 1.2 mil) on OSS

Newly applied gray: Incomplete ablation at uppermost energy density



Weathered Green: Consistent ablation



Unweathered Green: Inconsistent ablation