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Laser Removal of TSN color-top for Refurbishment

NRL Code 6138

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Work Funded by Paint Center of Excellence, NAVSEA

NAVSEA NAVAL SEA SYSTEMS COMMAND Painting Center of Excellence PCoE

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Outline & Abstract

OUTLINE

1) Overview and Executive Summary
2) Benchtop T&E of Color-top Removal Methods
3) Ship Demonstration and Validation
4) Costing for Maintenance Planning
5) Laser Safety and Operation
6) Summary and Next Steps

ABSTRACT

NRL completed a one year project that evaluated four alternative technologies to remove color-top coatings from thermal spray nonskid (TSN) to maintain system performance and extend service life. TSN is a high-performance deck coating system that is essential to successful operations of U.S. Navy ships and as such maximizing system service life is essential. To maximize TSN service life, the Paint Center of Excellence (NAVSEA 05P) funded NRL to evaluate four different technologies to determine efficacy for removing color-top coatings from TSN. NRL determined, based on laboratory testing and evaluation, that two of the four technologies effectively removed the coating and did not adversely impact the TSN substrate (i.e., low mass loss, negligable reduction in coefficient of friction (CoF), and no adverse effect on subsequent color-top coating adhesion). Currently, of these two technologies that can effectively remove color-toppings, only laser ablation can be fielded in a shipyard environment. NRL demonstrated that a laser could be used to remove and refurbish critical flight deck color-top coatings on a deck coated with TSN. As a result, NRL is developing equipment requirements and operating procedures for laser ablation of color-top coatings in a format that can be incorporated into a future update of the TSN applications requirements document.

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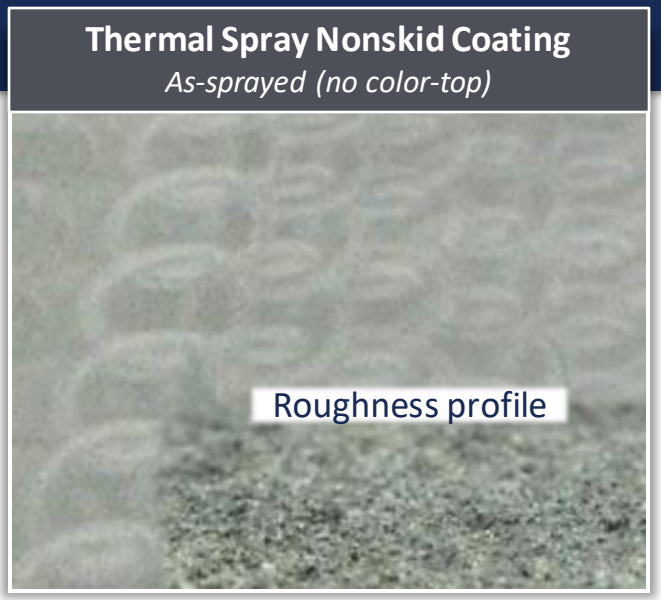
Project Overview

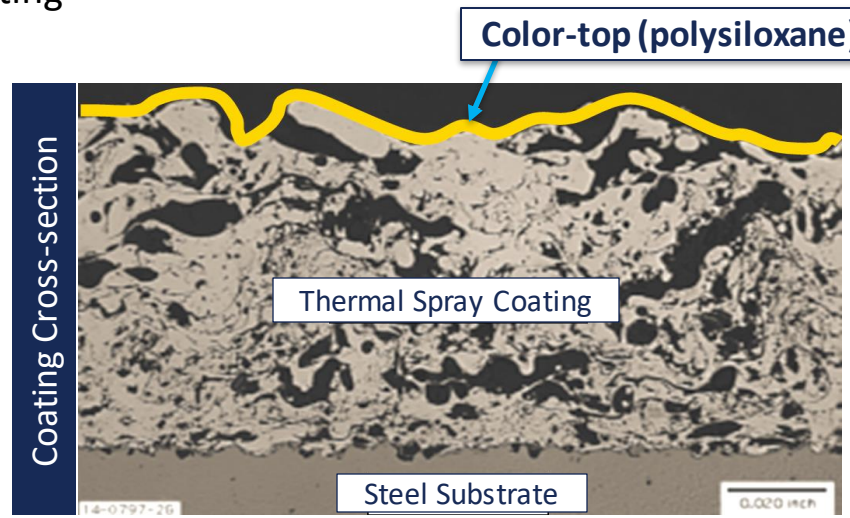
Background

- Thermal spray nonskid (TSN) is used in landing spots of certain amphibious class ships for its high temperature resistance
- Because TSN is a metalized coating, a color-top is applied to hide the metallic finish and meet dark gray and VLA (visual landing aid) requirements
- TSN flight decks are subject to soot and hydrocarbon staining, especially in the VLA areas, and require recoating to maintain the required visual contrast



Problem Statement

- TSN inherently does not have the same ridges as traditional nonskid so color-top can build up and degrade the deck's coefficient of friction
- As a new deck coating system, there is no established process for removing color-top without damaging the underlying TSN



The goal is to remove the polymer color-top without damage to the underlying thermal spray

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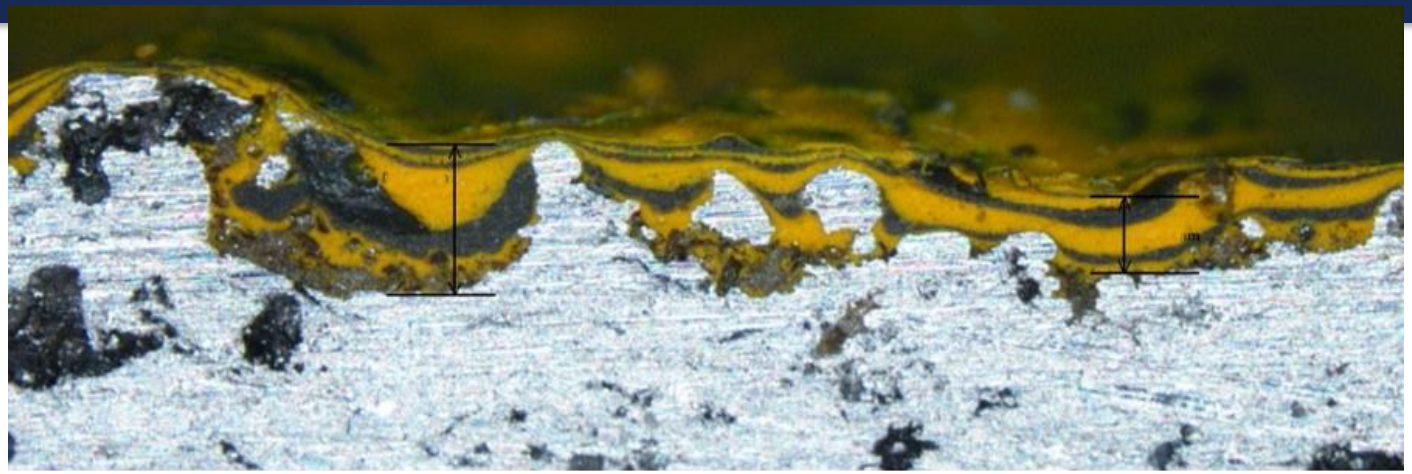
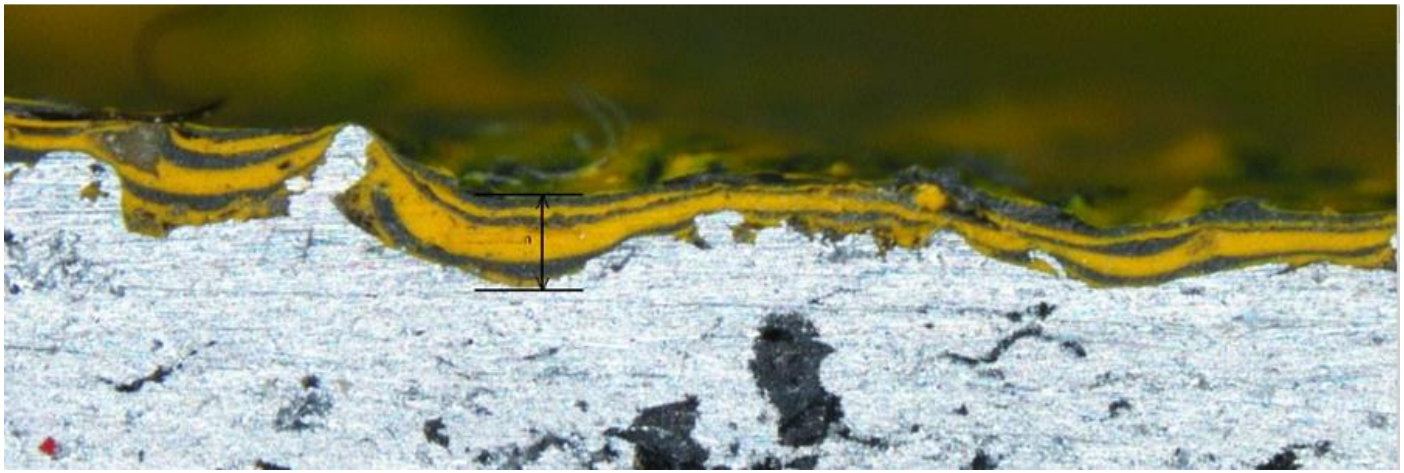
Impact of Multiple Recoats on TSN Profile





- 7 coats of the flat finish, singl-component, siloxane color-top to be qualified to TT-P-28J
- Color-top is low viscosity and tends to settle in the valleys
- ***Begins to fill in TSN profile after 2-3 coats***

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Executive Summary of Testing

Removal Method	Removal Efficiency	Removal Rate (ft^2/hr)	Static COF (before/after removal)	% TSN loss*	Notes
200W Laser	60-65%	5-6 [yellow] 25 [gray]	1.24 ± 0.12 [before] 1.25 ± 0.10 [after]	-1.3% *(**7** removal iterations)*	Multiple cleaning directions needed to overcome shadowing effects of profile roughness
1000W Laser	55-60%	31 [yellow] 60 [gray]	1.24 ± 0.10 [before] 1.28 ± 0.13 [after]	0% *(**7** removal iterations)*	
Atmospheric Plasma	5%	n/a	n/a	n/a	Process was not able to sufficiently remove color-top
Pulse waterjet	95%	38	1.20 ± 0.12 [before] 1.24 ± 0.12 [after]	-2.2% *(**1** removal iterations)* -6.4% *(**3** removal iterations)*	Rate based on single nozzle; production
Acrylic grit	49%	2.5	n/a	0 *(**2** removal iterations)*	60-80 psi blast pressure
Walnut shell	46%	3.6	n/a	0 *(**2** removal iterations)*	60 psi blast pressure
Corn cob	49%	3.2	n/a	0 *(**2** removal iterations)*	60 psi blat pressure

Based on a coating weight of 0.8 lb/sqft;* ***max allowable loss for "Resistance to Wear" (MIL-PRF-32577) is 5%*

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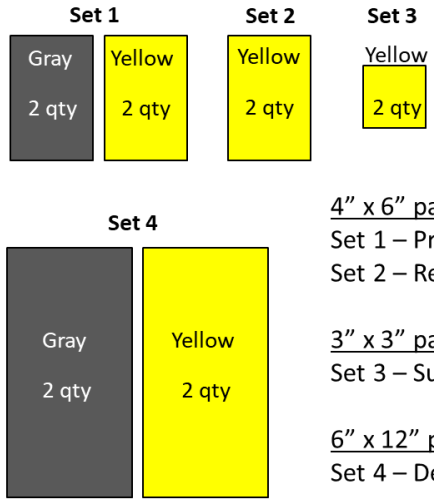
Removal Evaluation: 200W laser

Observations

- Testing was performed by the vendor using a 200W
- Removal efficiency was highly dependent on direction of cleaning
- Pulse marks were visible in the metalized TSN layer
- ***Recommend second round of testing to optimize settings and reduce visible pulse pattern***

Test Matrix



4" x 6" panels:
Set 1 – Practice panels
Set 2 – Re-coat adhesion

3" x 3" panels:
Set 3 – Surface topography check

6" x 12" panels:
Set 4 – Determination of removal rate[i]

Color	No. of Coats	Removal Rate	Removal Efficiency
Gray	1	25.7 ft^2/hr	n/a
		30.0 ft^2/hr	n/a
Yellow	1	6.0 ft^2/hr	61%

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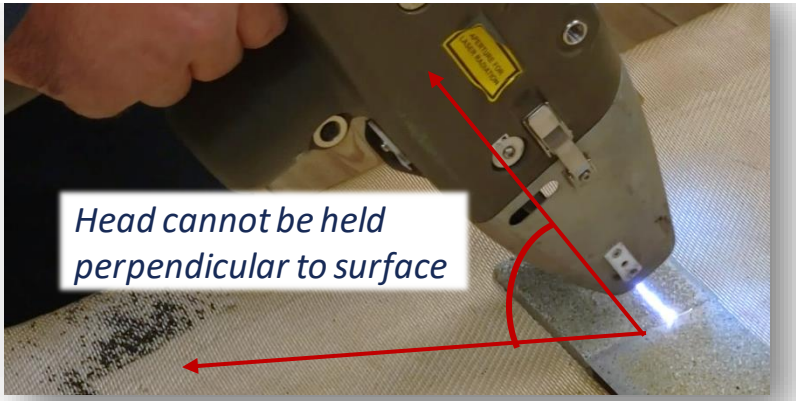
Removal Evaluation: 1000W laser

Observations

- Performed testing with manufacturer
- Beam intensity set to “high” (24 kHz) for all runs
- Cross-hatch pattern required for more thorough removal
- Removal efficiency highly dependent on angle of attack
- Produced no visible damage to the TSN



Color	# of Coats	# of passes	Removal rate (ft^2/hr)	Removal efficiency
Yellow	1 or 2	4	**31**	**56%**
Gray	1	2	**60**	--
Gray	2	4	**32**	--

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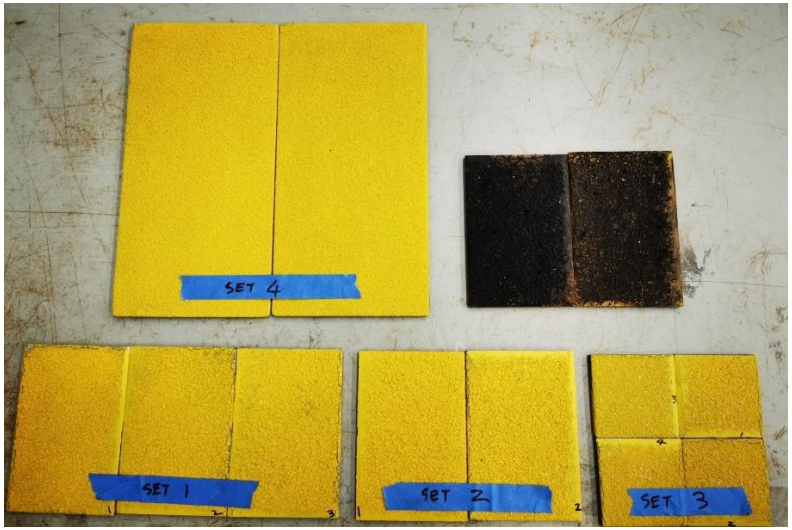
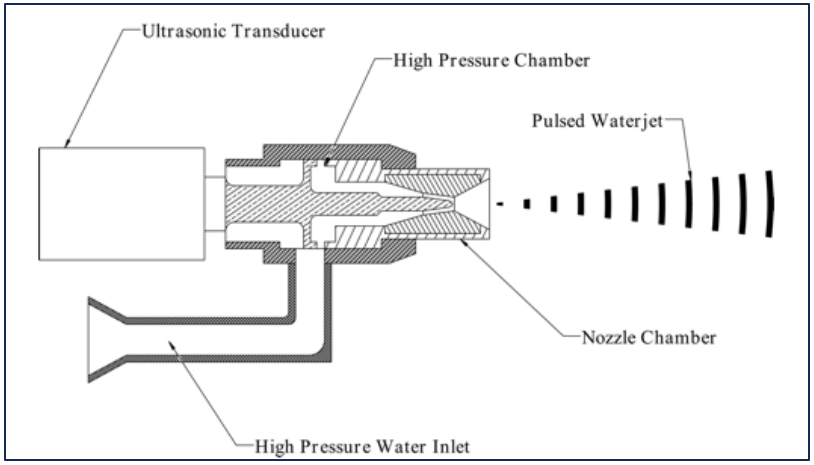
Removal Evaluation: forced-pulse waterjet

Single – Nozzle FPWJ





Source: http://www.vln-tech.com/

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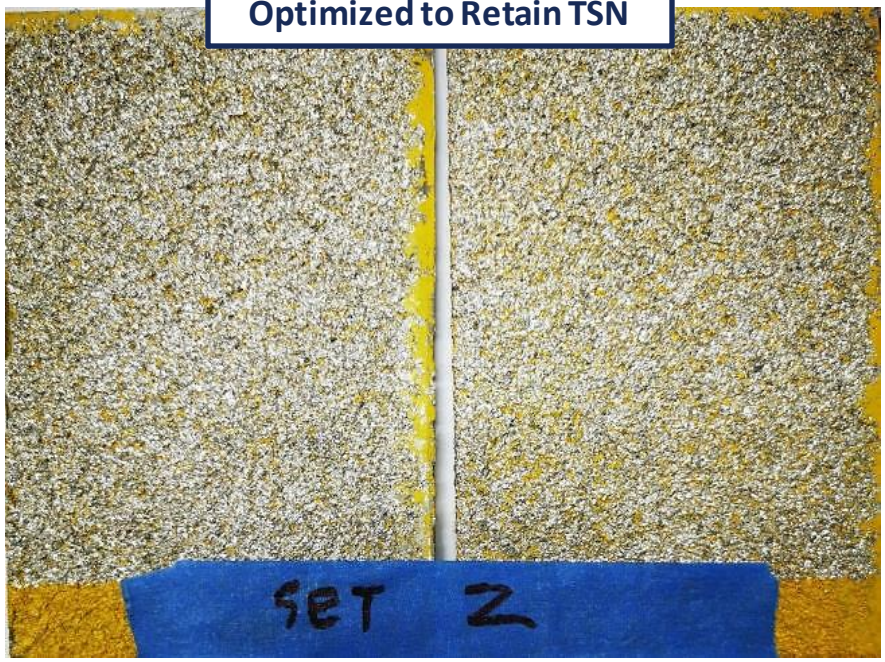
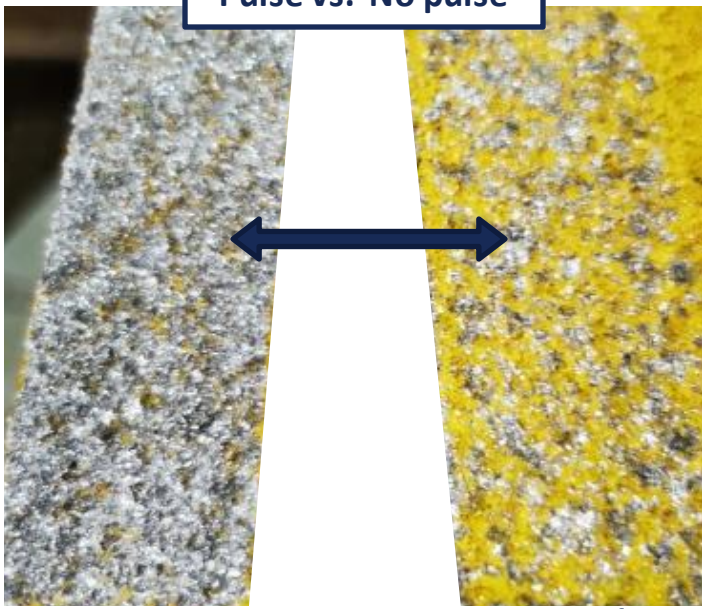
Removal Evaluation: forced-pulse waterjet (cont.)

Optimized to Retain TSN



Pulse vs. No pulse



Pulse ***No pulse***

- The goal was minimize the energy input required for removal so as to not damage the TSN
- Paint flecks left after removal provided a visual indication that removal energy was being minimized

Transverse Speed	Pressure	Flow	Standoff	Removal Rate*
39.4 in/s	6 ksi	3 gpm	1.75 in	**38 ft^2/hr**

Note: industrial version will likely contain 3 nozzles, which would bring production to **114 ft^2/hr*

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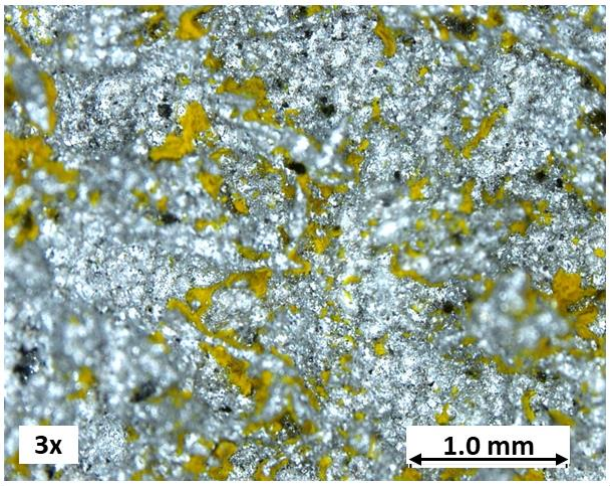
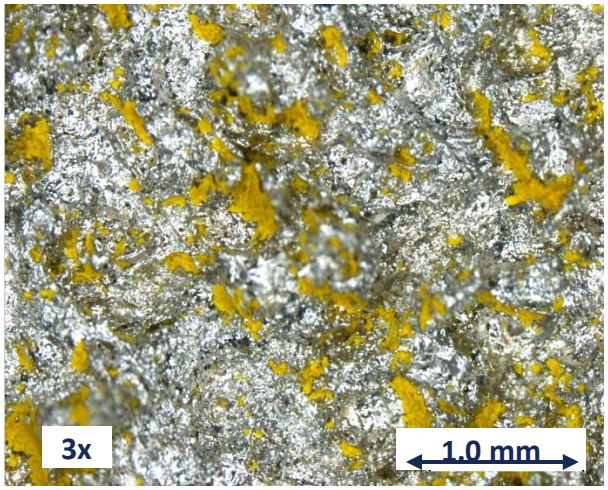
Visual Results for Downselected Methods

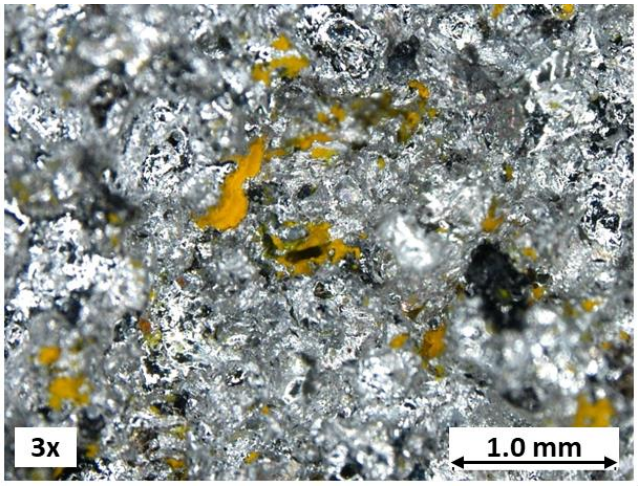
200W Laser

1000W Laser

Forced-pulse waterjet







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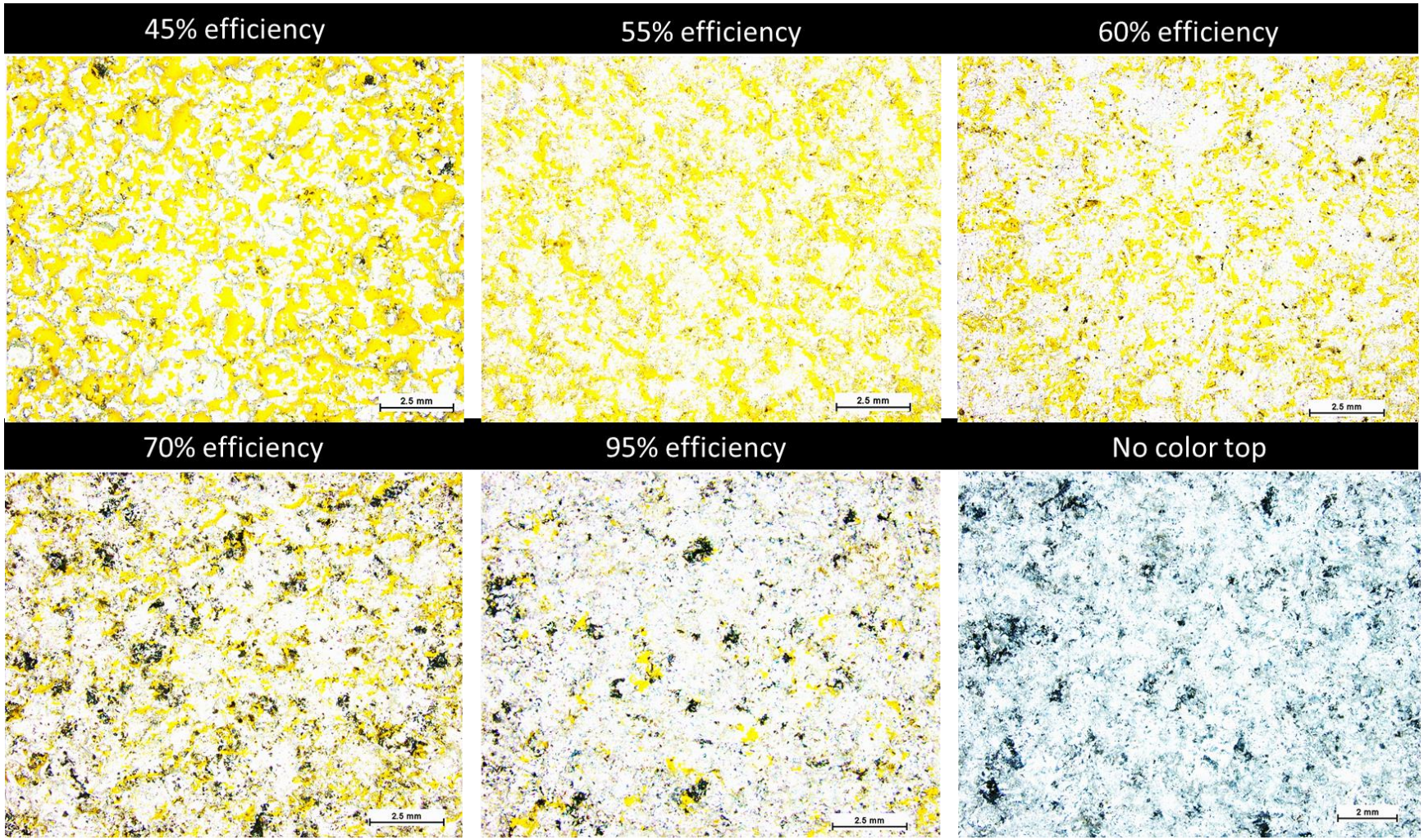
Visual Reference Guide



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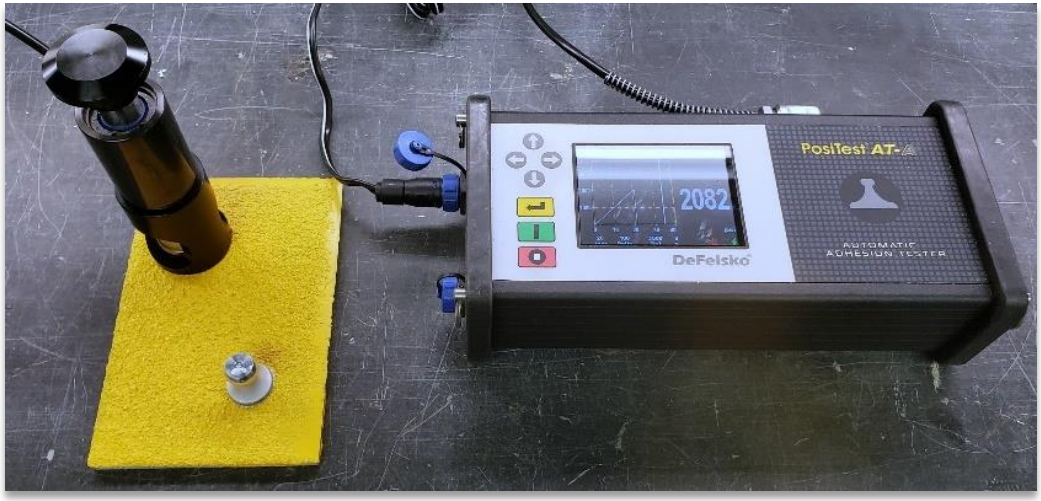
Re-coat Adhesion Performance



Removal method	Average adhesion (psi)		Failure b/w color-top & TSN?
	No soil	*Synthetic deck soil**	
200W Laser	1,591	--	No
1000W Laser	1,087	1,064	No
Pulse waterjet	1,898	1,856	No, for pulls less than 1,800 psi

**MIL-PRF-32177 synthetic soil is comprised of grease, JP-5, hydraulic fluid, and carbon black*

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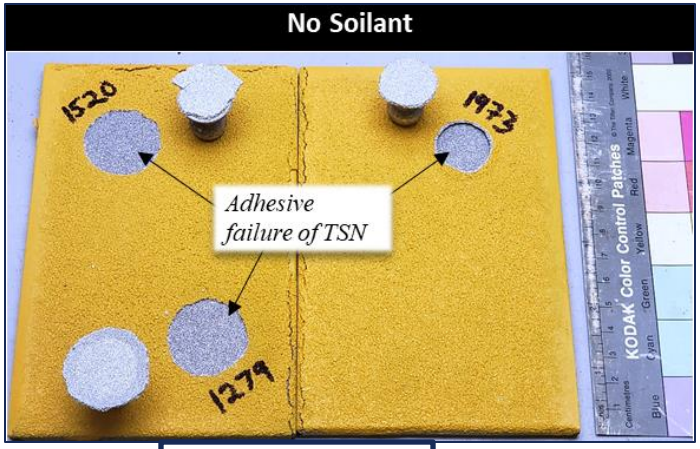
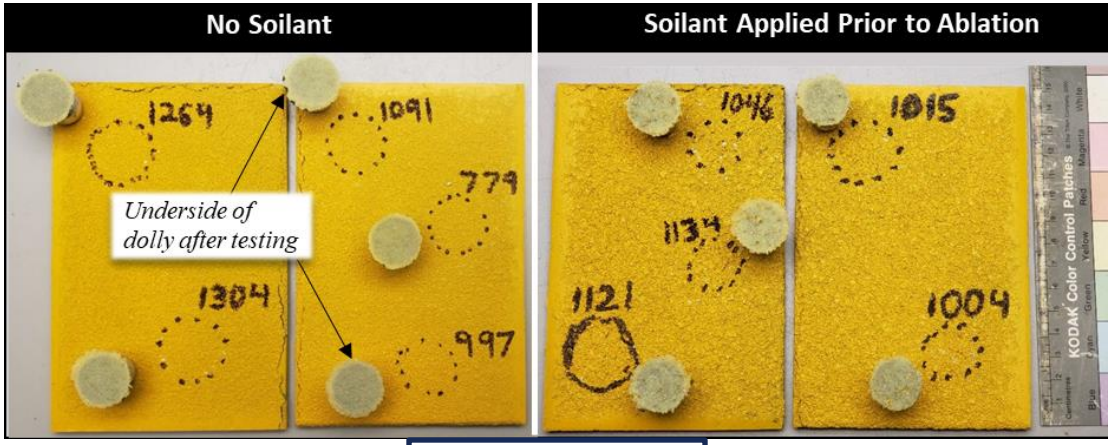
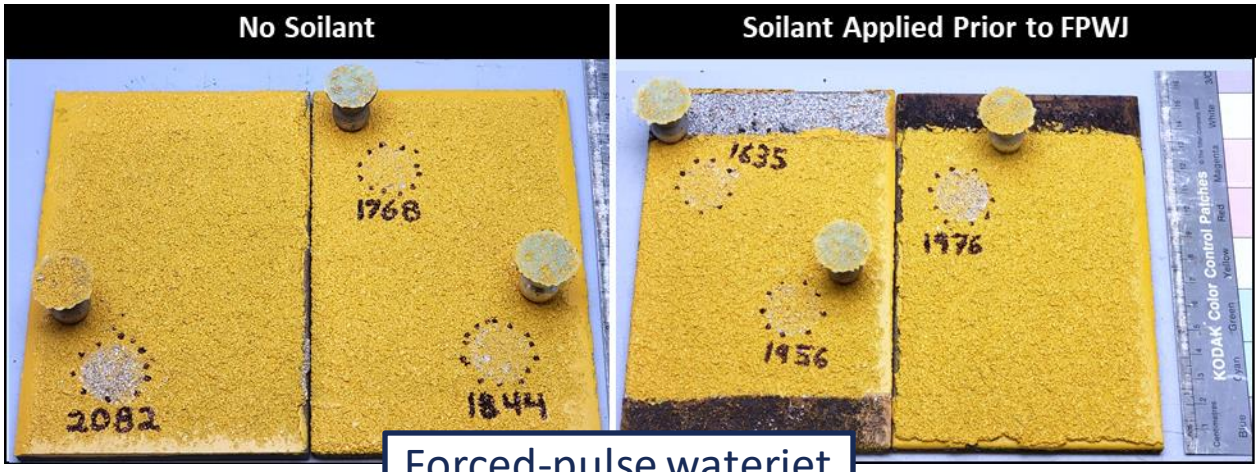
Re-coat Adhesion (cont.)



200W Laser



1000W Laser



Forced-pulse waterjet

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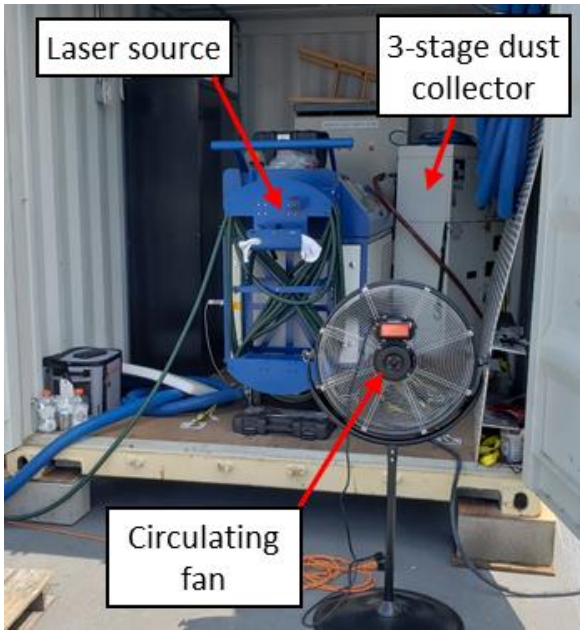
Ship Demonstration Overview

Ship VLA Line Refurbishment

- Rented a single 1000W Laser
- Laser manufacturer trained waterfront contractors
  - Training developed by **Naval Undersea Warfare Center Division Keyport** and laser manufacturer
- Laser safety curtains used around operator
- Used three stage filtration and vacuum to capture vaporized coating



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Ship Demo: laser ablation of color-top

Peak rate 30 ft²/hr

VLA after Color-top Removal

Total area removed 830 ft²

- Laser "on-time" average 6.1 hours of an 8 hour shift
- Removal rate averaged 15.1 ft²/hr with a peak removal rate of 30 ft²/hr
- Better trigger ergonomics or mounting the laser head to a crawler should boost production by at least 200%

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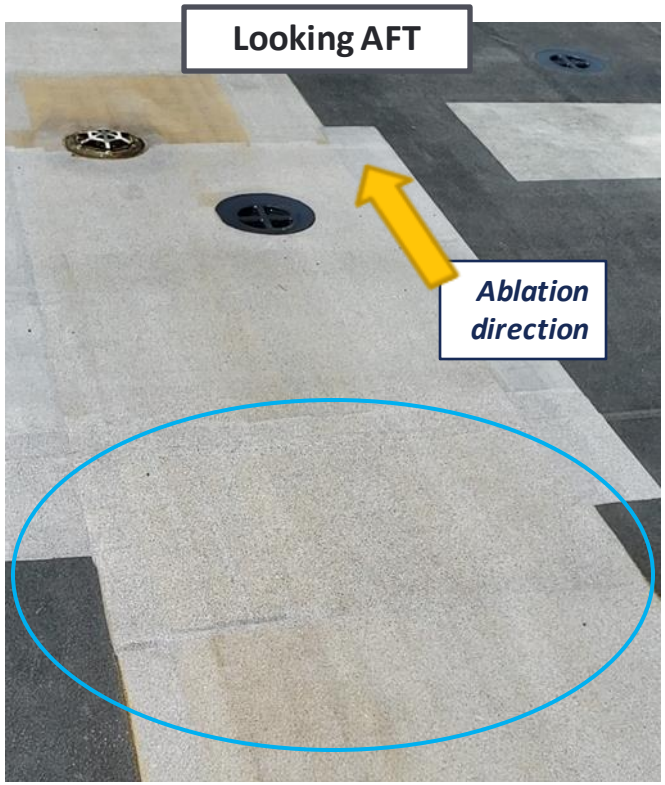
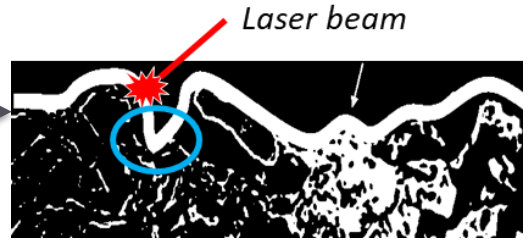
Ship Demo: shadowing effects

Same spot looking from 3 different vantage points



- The laser works by "line-of-sight", so multiple approach angles are needed to reach recesses/crevices
- Multiple cleaning directions can improve efficiency



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Ship Demo: re-application of color-top

Lessons Learned

- Integrate double containment or interlocks to enhance safety
- Ventilation and shade is required to keep laser source cool
- Cooling and air circulation is needed to keep operator in laser containment comfortable
- Mounting the laser head to a crawler should boost production by at least 200%>

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Ship Demo: coefficient of friction (CoF)

Dynamic, Rotating-ball Coefficient of Friction

Area	At time of original install (Jan 2016)	Before color-top removal*	After re-coat*
1	--	1.53	1.54
2	--	1.37	1.51
3	--	0.97	1.26
4	--	1.11	1.3
5	--	1.25	1.6
6	--	1.11	1.52
7	--	1.3	1.45
AVG	***1.24***	***1.23***	***1.45***
Stdev	*0.05*	*0.19*	*0.13*

*CoF taken in the same approximate location before color-top removal and after re-application

Dynamic coefficient of friction shows an increase of 18% following color-top refurbishment

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Laser Ablation Costing

1. Actual Cost Breakdown for Ship Demonstration

Man hours*	$ 34,840	Generator rental	$ 2,000	Color top paint	$ 2,000
Laser rental	$ 24,500	Fuel	$ 500	Waste disposal	$ 2,500
Green clean	$ 8,000	Crane lifts	$ 8,000	Misc.	$ 560
Total refurbishment cost: $82,900 or $100/ft^2					

**Labor to remove and reapply color top*

2. Projected Cost Model for 1000W and 2000W Lasers

	VLA lines (only) 1,000 sqft		Entire TSN coating 12,000 sqft		[u]
	1000W	*2000W*	*1000W*	*2000W*	
Projected Laser Removal Cost	$8,450	$4,225	$67,600	$33,800	
Laser color-top removal	$8.45	$4.23	$5.63	$2.82	/sqft
Laser removal duration	5.4	2.7	32.5	16.3	days
Low Pressure Wash (green clean)	$30,573	Not needed	$88,560	$63,560	
Color Top Recoat	$3,649	$3,649	$25,070	$25,070	
Color-top application	$3.65	$3.65	$2.09	$2.09	/sqft
Re-coat duration/time	1.3	1.3	3.4	3.4	days
Support Equip./Miscellaneous	$30,369	$29,903	$55,393	$53,573	
Refurb cost (w/o laser rental)	**$73,041**	**$37,778**	**$236,623**	**$176,003**	
Cost/sqft	$73	$38	$20	$15	
Laser rental ($12K/wk)	**$24,000**	**$24,000**	**$168,000**	**$96,000**	
Cost/sqft	$24	$24	$14	$8	
Total duration	**3.4**	**2.8**	**9.8**	**6.6**	wks

Two refurbishment options:
1. **VLA lines only**
2. **the entire TSN patch**

- The 2000W laser is the most economical chose for VLA refurbishment
- Business case for VLA is in very good agreement with the actual costs from the ship demo

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Safety, Training, and Operation References

Industry Safety Standards

ANSI Z136.1 Series – "Safe Use of Lasers"

OSHA 29 CFR 1910 for general industry

***ANSI Z136.1** is the primary reference for safety*

Government Safety Program

Laser Radiation Program (PSNS OSH Manual Vol. III Ch. 19)*

- ANSI Z136.1 – "Safe Use of Lasers"
- 21 CFR 1040 – "Performance Standards for Light-Emitting Products"
- NMCPHC-TM OM 6260 – "Medical Surveillance Procedures Manual"
- BUMEDINST 6470.23 – "Medical Management of Non-Ionizing Radiation Casualties"

DoD Process Instructions

USAF Handbook (MIL-HDBK-529) – "Use of Handheld Lasers to Remove Coatings and Corrosion from Aerospace Ground Equipment"

NNSY Industrial Process Instruction – "Laser Ablation Removal of Coatings from Metallic Materials"

Third-party Training

Laser Officer and General Industrial Trainings offered by third party entities based on ANSI Z136

**Bankus, N., Binsfield, M., Niemeier, T. Industrial Laser Ablation Coating Removal & Cleaning Training Course. NUWC Division Keyport C42.*

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Summary and Next Steps

Project Summary

- Benchtop T&E proved laser ablation and forced-pulse waterjet are capable of efficiently removing color-topping without damaging the TSN layer, while achieving reasonable throughput
  - ***Minimal TSN mass loss*** – laser ablation (0-1.1%), and FPWJ (2.8%)
  - ***CoF*** – No loss in static CoF after color-top removal and re-application for laser ablation and pulse waterjet
  - ***Microscopy*** – Under magnification, no damage to the TSN was noted for the 1000W laser and FPWJ
  - ***Recoat adhesion*** – Pull-off strength of panels recoated after laser or pulse-waterjet was >1,000 psi

  Note: FPWJ was most efficient (95%) at removing color-top; however, a deck crawler does not yet exist

- Ship demonstration validated that the 1000W laser system was able to effectively remove the VLA lines (830 ft^2) while operating in a shipyard environment:
  - CoF measurements detect no loss in slip resistance
  - Multiple lasers and/or a higher power laser is recommended for areas >1,000 ft^2 in order to complete the work in a reasonable timeframe

- Drafted Standard item 009-124 attachment for process and reviewed with NAVSEA Tech Warrant

Next Steps

- Incorporate additional safety controls such as double containment and safety interlock
- Develop a lawn-mower-style chassis to improve ergonomics, productivity, and safety
- Perform additional ship demonstration(s) to validate safety and operational process for in future inclusion in Standard-Item 009-124

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