

AVT-339 Research Workshop on Robotics and laser/plasma – paint interaction in paint removal

Lessons Learned from Two Decades of Laser Testing across the US Air Force

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29 – 30 April 2020



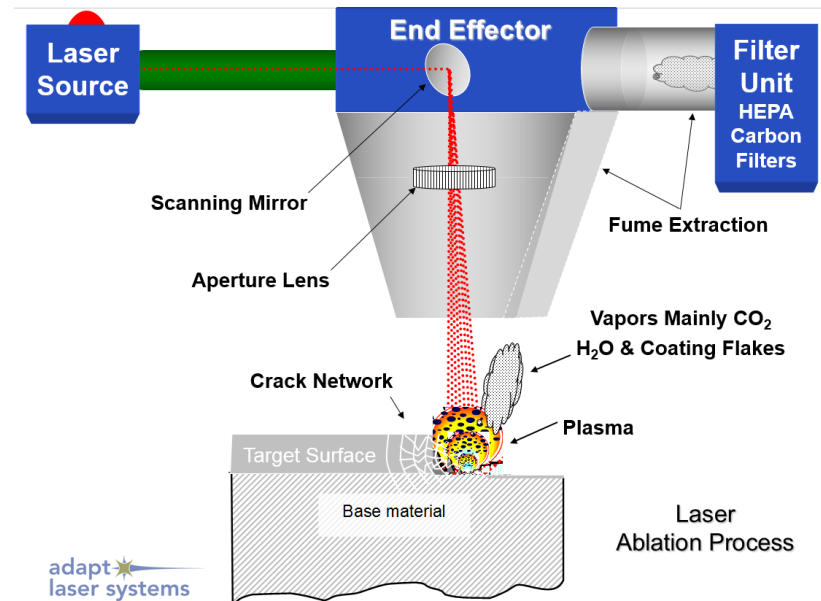
Why the Interest in Lasers?

- Corrosion prevention and control (CPC) on aircraft is a nasty process!
- Many chemicals used in CPC are carcinogenic
 - Hexavalent chromium (Cr^{6+})
 - Cadmium
 - Isocyanates
 - Chemical strippers, such as methylene chloride
- These carcinogens mandate the use of personal protective equipment (PPE)
 - Full face respirators
 - Gloves
 - Tyvek suits
 - Tyvek boots
- These chemicals create large waste streams and mandate confinement of operations to certain facilities



How the Lasers Work

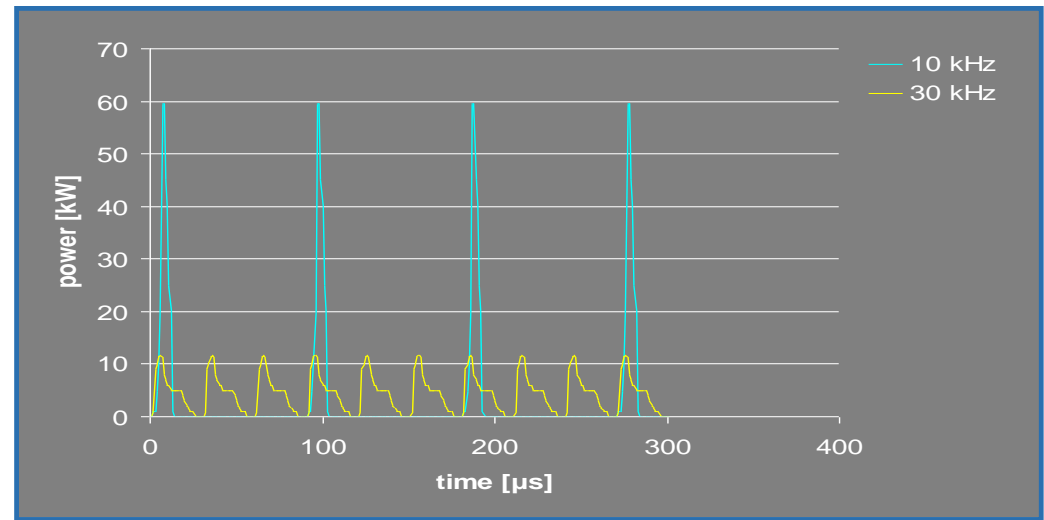
- Lasers remove coatings through ablation (essentially solid to gas vaporization or sublimation)
 - Chemicals such as strippers don't need to be captured
 - Sanding/blasting = airborne contaminants...major facility and PPE requirements!
- All contaminants are captured at the substrate...only laser safety glasses required!
- Lasers can be used outside of controlled facilities as long as all personnel are wearing the appropriate eye protection
 - This allows simultaneous maintenance operations to occur while corrosion maintenance is taking place



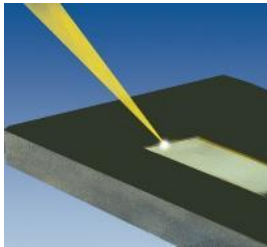
How the Lasers Work

Laser Ablation = Sublimation

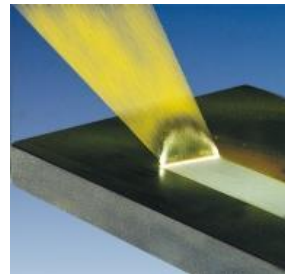
- Convert Solid To Gas
 - With Laser Energy
- Nanosecond Pulses Of Laser Energy Create
 - High Energy
 - Very Little Thermal Effect
- Metal Can Reflect The Energy
 - With Correct Parameters
- 2 Processes of Cleaning
 - Sublimation
 - Induced Pressure



PULSE



SCAN



MOVE



Health and Safety Testing Performed

- Testing by the federal government performed for nearly 2 decades
- Air sampling by 3rd party lab (MACTEC) funded by ESTCP performed 8/2002, 10/2003, 9/2004, and 2/2005; additional testing by AF Institute for Operational Health 3/2005
 - Acid gases (nitric acid, sulfuric acid, etc.)
 - Hydrogen cyanide
 - Heavy metals (hexavalent chromium, chromates, lead, etc.)
 - Cyanides and diisocyanates
 - Nitric oxide
 - CO and CO₂
 - O₃
 - SO₂
 - Organic coating VOCs
- Air sampling also performed by USAF School of Aerospace Medicine (USAFSAM)
 - April 2017 (Report available)

ALL SAMPLING WELL WITHIN OCCUPATIONAL EXPOSURE LIMITS

Health and Safety Testing Performed

- Noise sampling performed by MACTEC in 2002 - 2005
 - Below OSHA's TWA exposure limit of 90 dbA and action level of 85 dbA
 - Additional noise sampling performed in April 2017 by USAFSAM
 - Consult with local bioenvironmental to determine if hearing protection required based on other sources of noise in work area
- UV/IR exposure sampling performed by MACTEC
 - Prolonged use (up to 3 hours) could result in skin irritation
 - Never reported by USAF or commercial users
 - Easily eliminated by wearing long sleeves (or sunscreen) and gloves
- Flammability testing conducted by Science Applications International Corp. in 2004
 - Testing conducted on artificial cavity (representative of fuel tank) & contaminated surfaces
 - MIL-L-23699 lubricating oil
 - MIL-PRF-7808 lubricating oil
 - MIL-PRF-83282 hydraulic fluid
 - MIL-H-5606 hydraulic fluid
 - Skydrol LD-4
 - JP-8 Turbine Fuel

**THE LASERS WERE NOT ABLE TO
PRODUCE A FLAME OR EXPLOSION**

Health and Safety Testing Performed

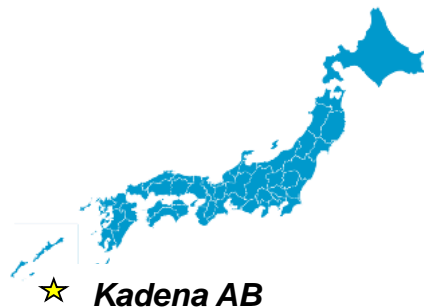
- Ergonomic assessment accomplished by AF Institute for Operational Health (Apr 2004)
 - Essentially the same as other tools in profession
 - Weight of end effector easily supported by resting fiber optic cable and vacuum hose on shoulder
 - Wheel mechanism developed to support weight of end effectors (~3 lbs for CL300 and ~7 lbs for CL1000)



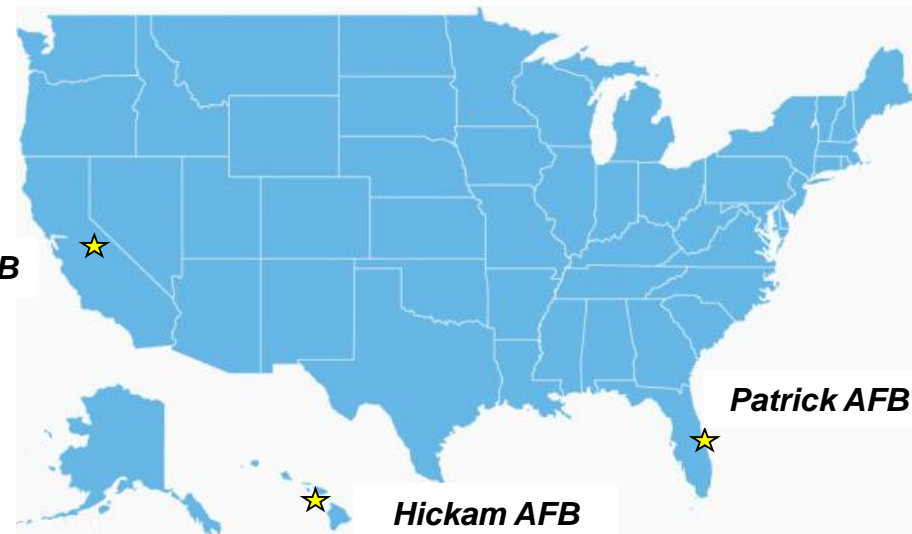
Demonstration on Ground Support Equipment

Demonstration Overview

- **Two lasers per location for field tests on ground support equipment (GSE)**
 - CleanLASER 300 W (CL300) and 1000 W (CL1000)
- **Lasers installed for demonstration at**
 - Travis AFB, CA (April 2017)
 - Patrick AFB, FL (May 2017)
 - Kadena AB, Japan (Aug 2017)
 - Hickam AFB, HI (Aug 2017)



Travis AFB



HHL Implementation for GSE

- Standard operating procedures created
- AFLCMC worked with USAFSAM to create safety and bioenvironmental guide for field
- Air Force specific training video and procedures were created
- MIL-HDBK-529 published



Laser Safety Curtains, Signs, and Beacons



HHL Training In Progress

GSE Applications

Corrosion/Coatings Removal



GSE Corrosion Examples from Patrick AFB, FL

Laser Stripped Equipment



GSE De-Painted with HHL

Aircraft Specific Testing

Aircraft Process Controls for CL300

- Electronic Margin Shielding (EMS)
 - Surpasses edges of scan path to prevent over processing surface
- Nozzle with Wheels
 - Maintains standoff distance to ensure laser is in focus
- Motion/Distance/Thermal Sensor
 - Ensures minimum sweep speed is maintained
 - Ensure laser is in focus



Aircraft Material Testing – Coating Adhesion

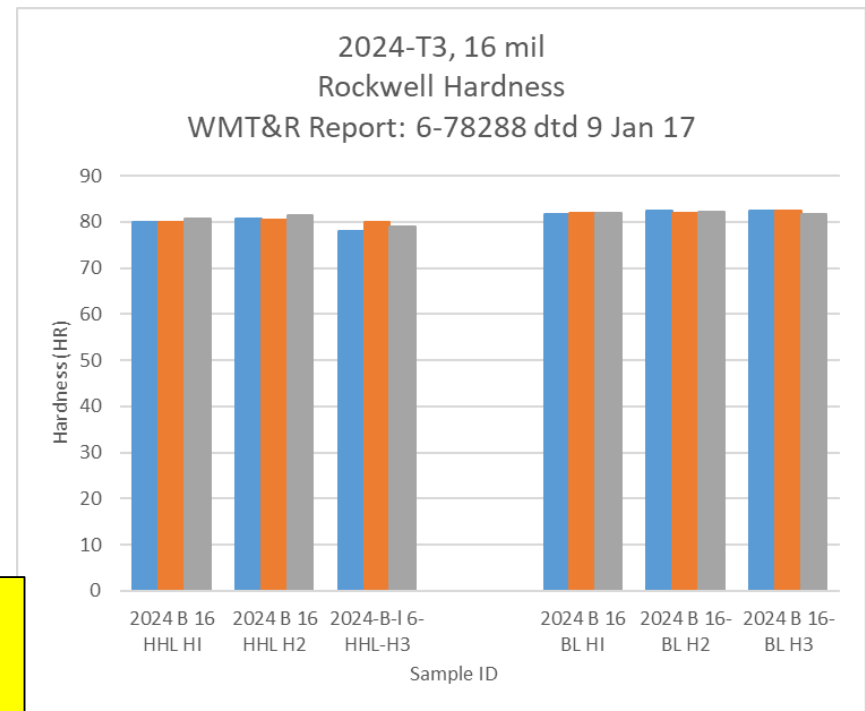
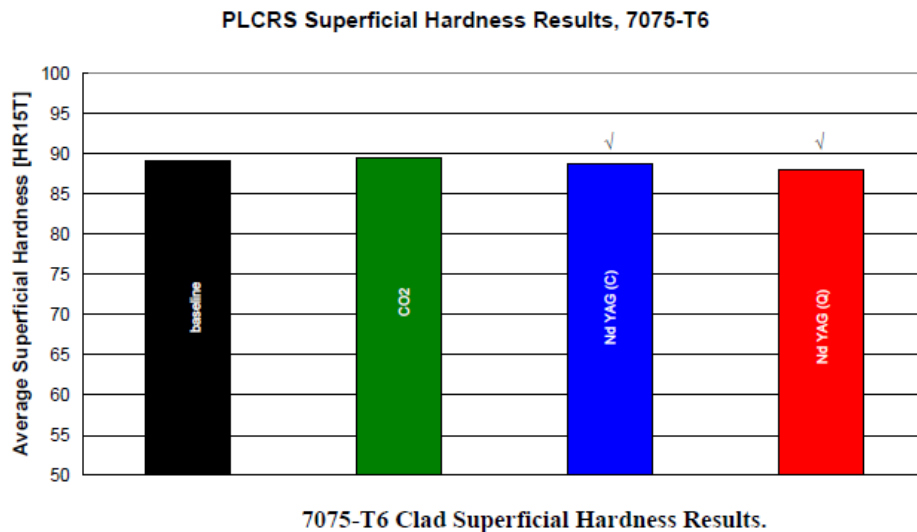
- Adhesion testing post lasing
 - A rating over 4 is considered a pass

Adhesion Ratings – Modified X.

Substrate	Coating System	Rating (Avg. of 5 Panels)	Laser Used
2024 T3 Clad	MIL-PRF-23377 + MIL-PRF-85285	4.0	40 watt Nd:YAG
		4.2	120 watt Nd:YAG
		4.8	250 watt CO ₂
2024 T3 Bare	MIL-PRF-23377 + MIL-PRF-85285	4.8	250 watt CO ₂
		4.4	40 watt Nd:YAG
		4.6	120 watt Nd:YAG
2024 T3 Bare Chromic Acid Anodized	MIL-PRF-23377 + MIL-PRF-85285	5.0	40 watt Nd:YAG
		5.0	250 watt CO ₂
		5.0	120 watt Nd:YAG
4130 Steel	MIL-PRF-23377 + MIL-C-46168 CARC)	4.4	120 watt Nd:YAG
		5.0	250 watt CO ₂
		3.4	40 watt Nd:YAG

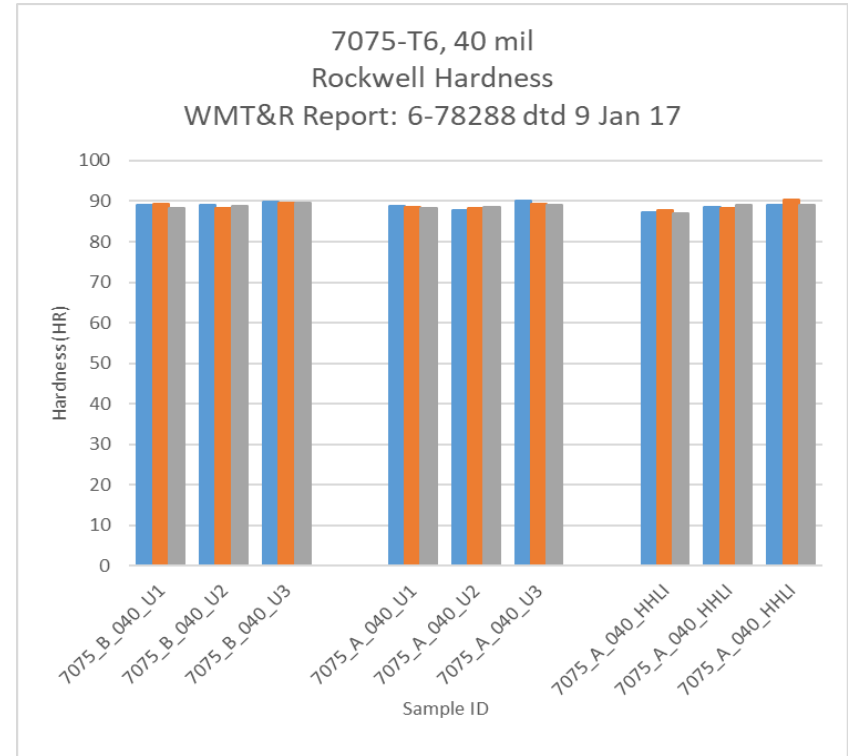
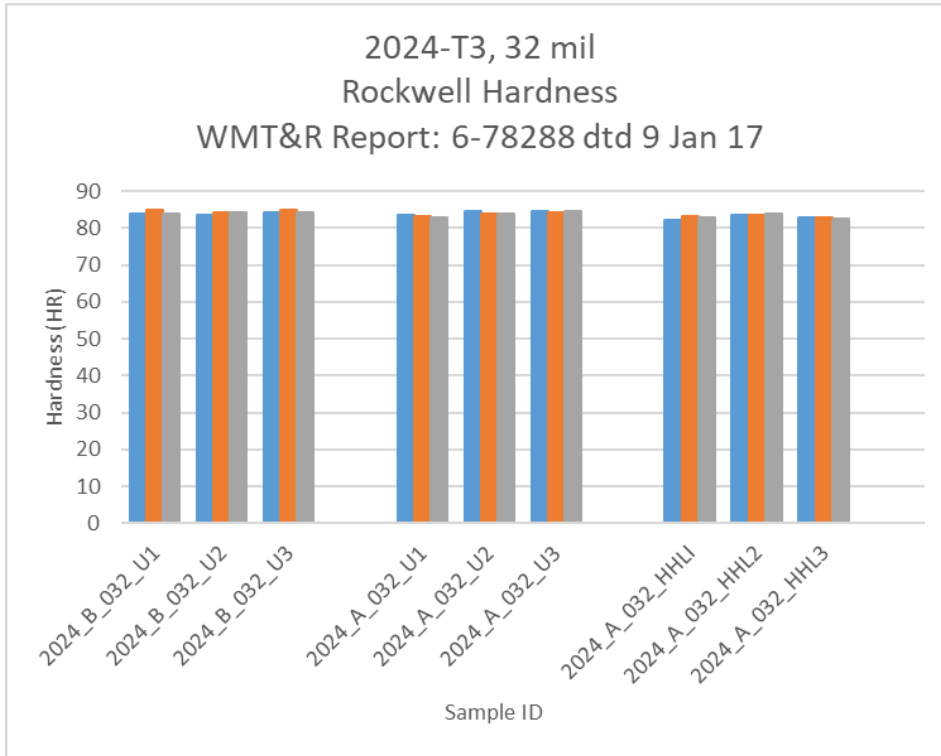
Aircraft Material Testing - Hardness

- Extensive testing has been performed by the USAF over the past 2 decades
 - Hardness testing performed by CTIO/UDRI revealed no significant impact to substrate hardness
 - (Westmoreland Mechanical Testing and Research, Jan '17)



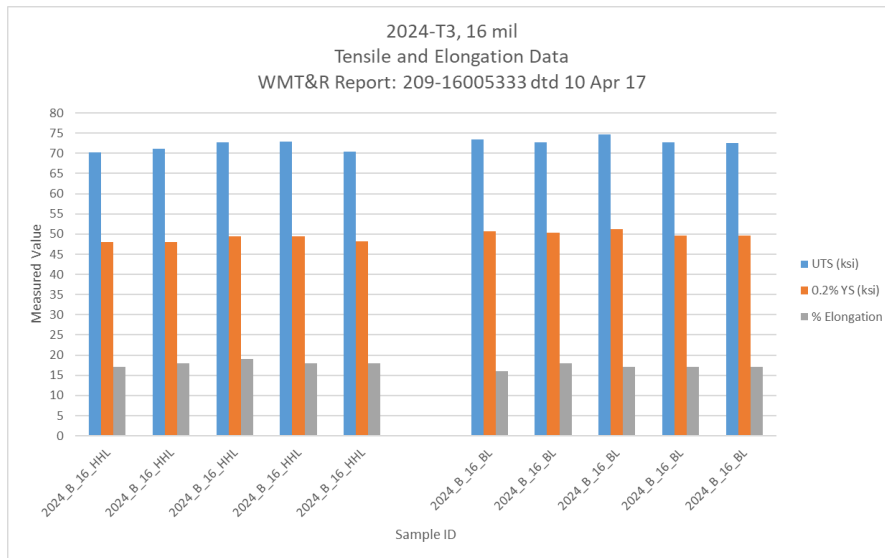
NO STATISTICALLY SIGNIFICANT CHANGE FROM UNPROCESSED BASELINE

Aircraft Material Testing - Hardness

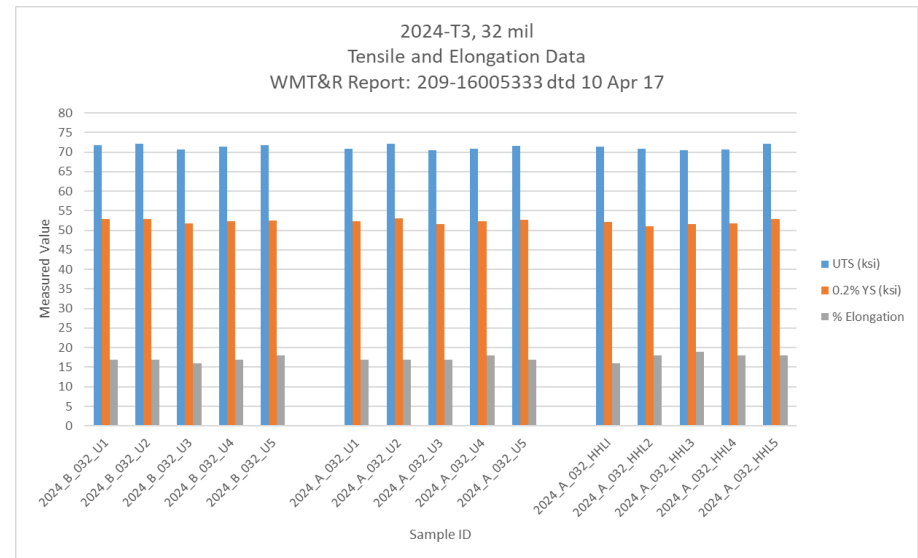


NO STATISTICALLY SIGNIFICANT CHANGE FROM UNPROCESSED BASELINE

Aircraft Material Testing - Tensile



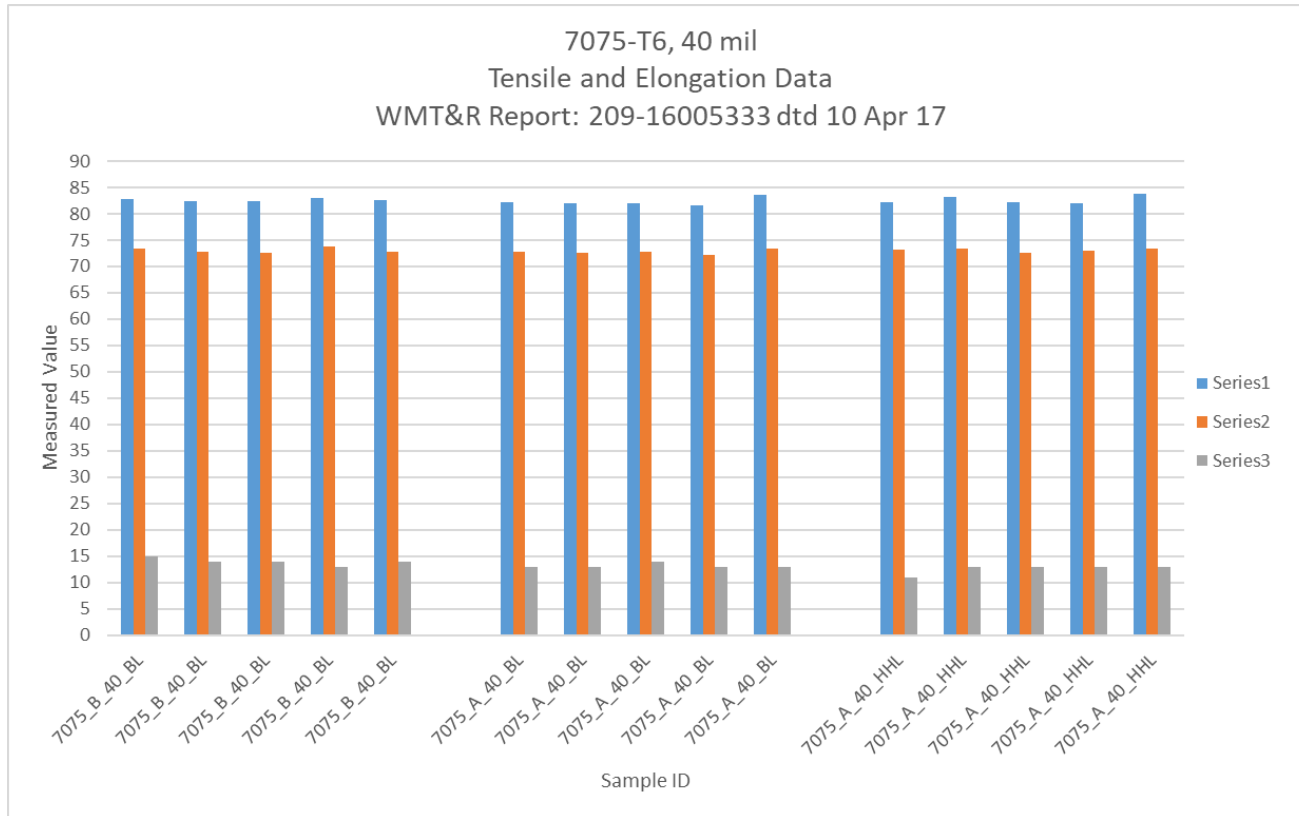
2024-T3 @ 0.016" in thickness



2024-T3 @ 0.032" in thickness

NO STATISTICALLY SIGNIFICANT CHANGE FROM UNPROCESSED BASELINE

Aircraft Material Testing - Tensile



7075-T6 @ 0.040" in thickness

NO STATISTICALLY SIGNIFICANT CHANGE FROM UNPROCESSED BASELINE

Future Aerospace Testing

- Axial fatigue testing being accomplished by UDRI on 2024-T3 @ 0.050" and 7075-T6 @ 0.080"
- 7075-T6 fatigue testing complete; analysis being conducted
- 2024-T3 fatigue testing will complete in Mar 2020
- Pending positive results, USAF will move to qualify CL300-AF on all 7075 (0.080" and thicker) and 2024 (0.050" and thicker) substrates USAF wide
- Pending positive results, insertion into TO 1-1-8, "*Application and Removal of Organic Coatings, Aerospace and Non-aerospace Equipment*" expected in 2020

300W HHL Aerospace Qualification Testing Completed

- **Substrates:**

- 7075-T6 substrate at 0.080" thickness
- 2024-T3 substrate at 0.050" thickness
- Control (un-painted and un-lased) and laser processed samples for each

- **Tests Performed to date:**

- Backside temperature: didn't exceed 150 °F
- Rockwell Hardness 15TW: no significant difference between control and laser specimens
- Tensile tests: no significant difference between control and laser specimens
- Tensile-Tensile Fatigue on 7075-T6:
 - Weibull analysis shows no significant difference for R0.1, S = 37.5 ksi ; additional analysis underway for S = 40 ksi and S = 73 ksi
 - Weibull analysis shows no significant difference for R0.5, S = 55 and S = 60 ksi ; additional analysis underway for S = 82 ksi
 - Kitagawa analysis pending additional test results (fatigue crack growth)



300W HHL and HEPA Vacuum

Current Aerospace Usage

- Coating stripping for electrical grounding points for UH-60s
- Used by Lockheed for stripping U-2 in Palmdale, CA during depot
- Used by Lockheed for improved nut plate bonding during F-35 build
- Used by USAF to demilitarize F-22 canopy transparencies
- Airbus using for coating stripping for grounding contacts
- Inbar stainless steel tooling cleaning for composite manufacture

NORTHROP GRUMMAN



US DoD Approvals

- HHL as a coating/corrosion removal tool added to USAF TO 35-1-3 on 18 Mar 2019
 - *“Corrosion Prevention and Control, Cleaning, Painting, and Marking of USAF Support Equipment (SE)”*
- HHL as a coating/corrosion removal tool added to USAF TO 36-1-191 in March 2020
 - *“Technical and Managerial Reference for Motor Vehicle Maintenance”*
- HHL as a coating/corrosion removal tool added to USAF Metals Technology Office TO 34W4-1-5 in March 2020
 - *“Welding Theory and Application”*

Questions?

