Competitive Academic Agreement Program

Laser Peening for Preventing Pipe Corrosion and Failure

DTPH56-14-S-N000006

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Main Objective

The **goal** of the proposed work is to investigate and develop laser peening to improve the corrosion resistance of carbon and stainless steels used for pipeline construction.

Project Team & Other Sponsors

- PI: Yongfeng Lu
- Graduate Res Assistant: Chenfei Zhang
- Postdoc: Dr. Leimin Deng

- University of Nebraska-Lincoln,
- Nebraska Center for Materials and Nanoscience
- Laser-assisted Nano-Engineering Lab.

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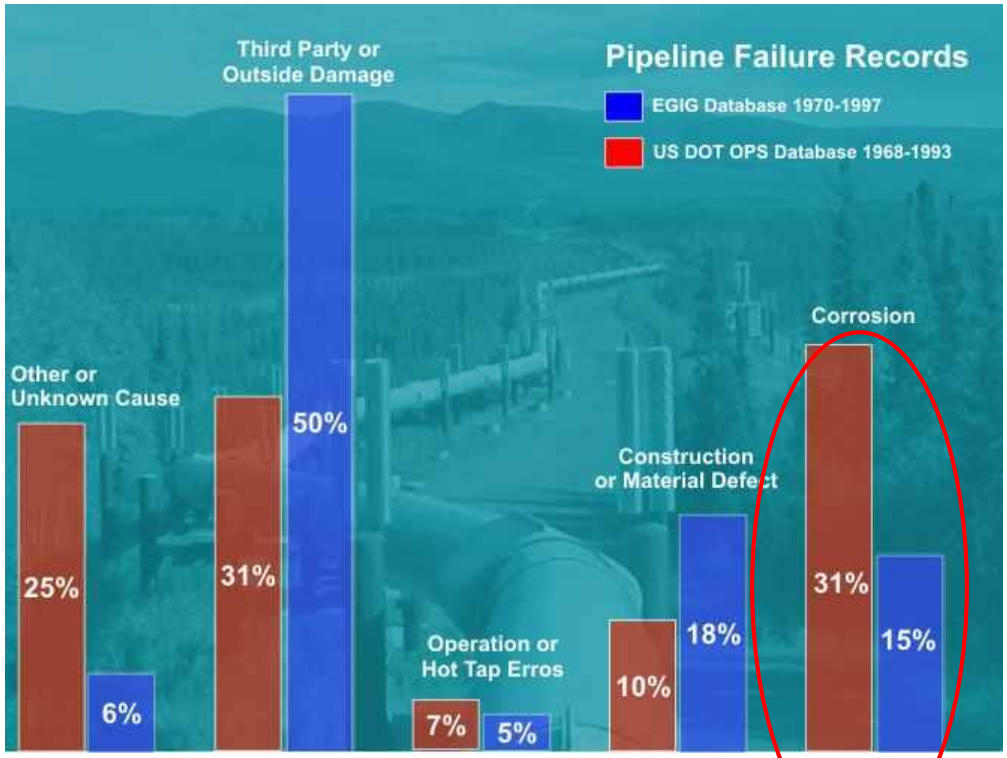
- Introduction
- Laser shock peening of pipeline steels
- Development of portable laser shock peening system
- Summary

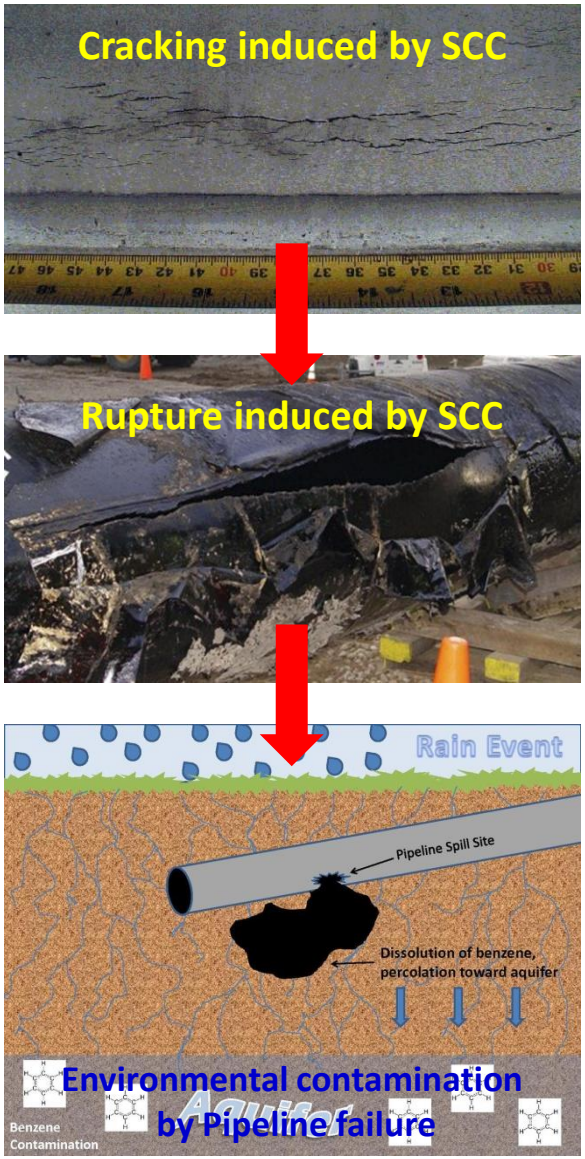
Introduction

Pipeline failure records from European (1910-1997) and US (1968-1993)



Nearly One-thirds of the pipeline failure were induced by corrosion;

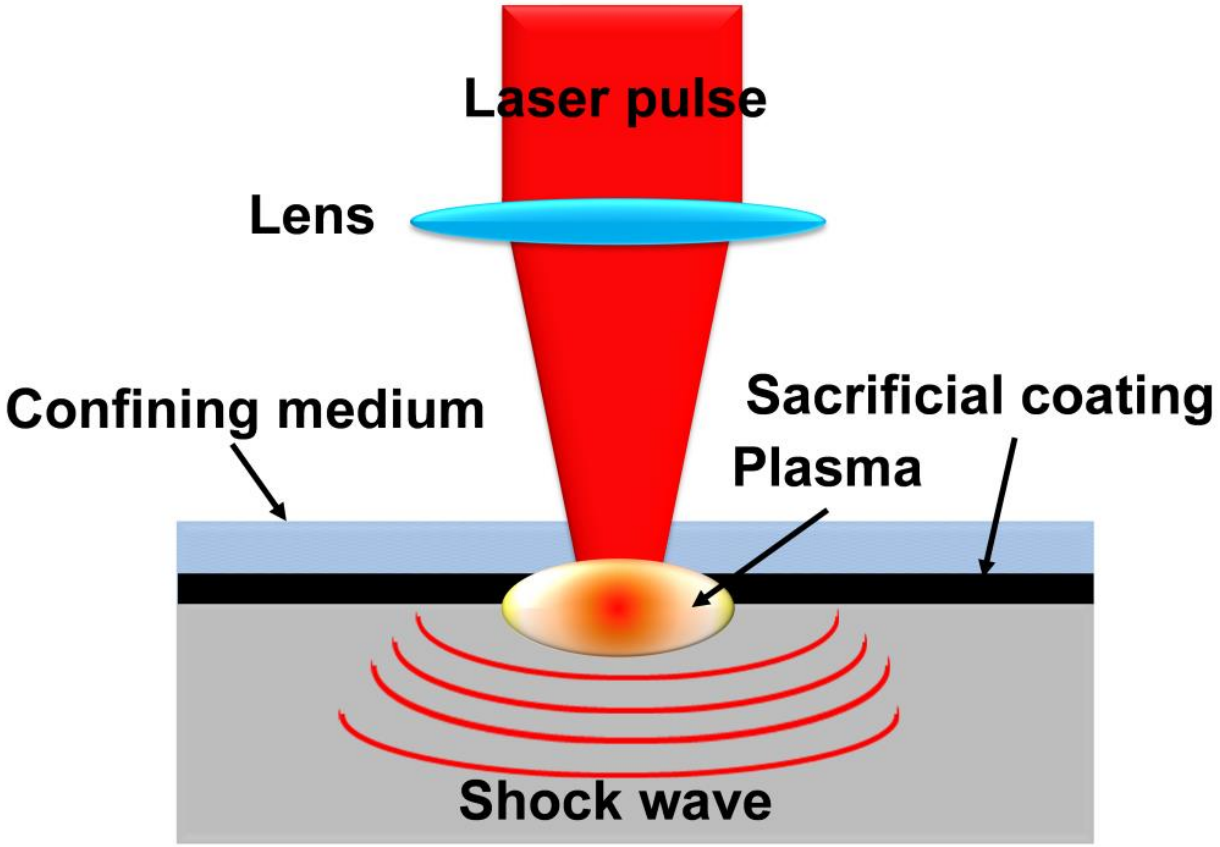
Stress Corrosion Cracking (SCC) contributes significantly among all corrosion mechanisms



Laser shock peening for pipeline steels

Laser shock peening

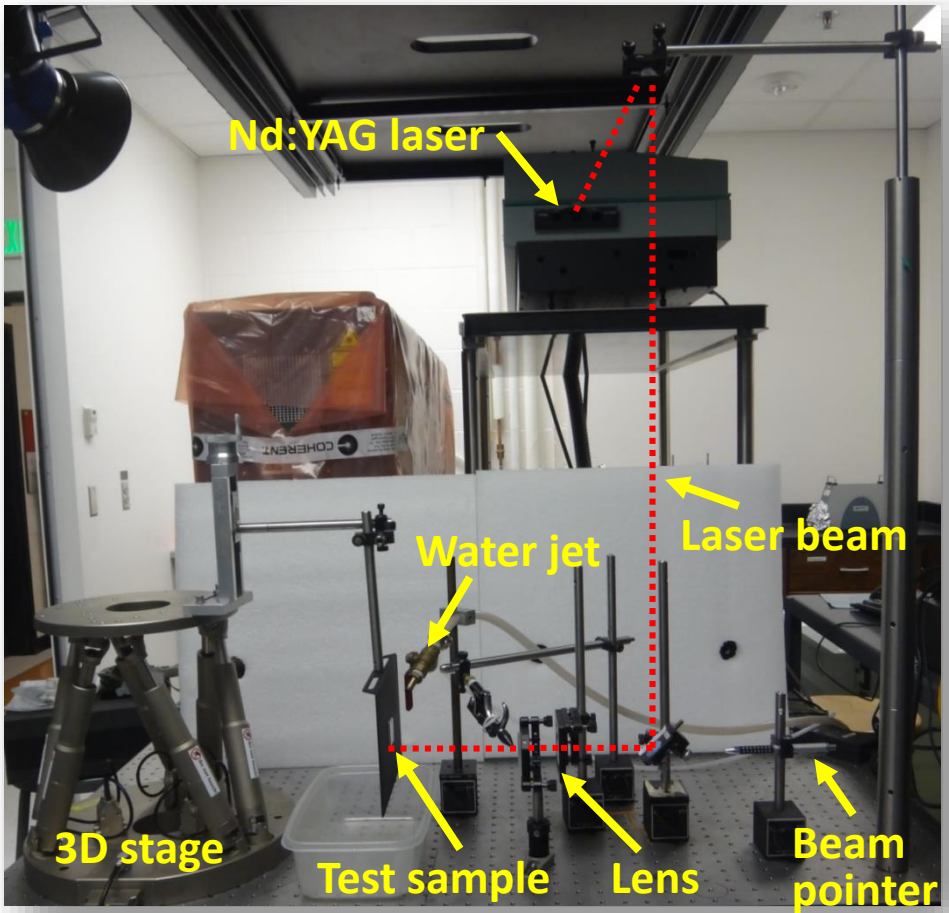
Fundamental mechanism



Schematic for the principle of laser shock peening (LSP)

Laser shock peening

LSP setup



Type	Value
Laser model	Continuum Nd:YAG PR II 8010 laser
Wavelength (nm)	1064
Pulse energy (mJ)	750
Pulse duration (ns)	6-8
Frequency (Hz)	1-10
Beam size (mm)	~ 6

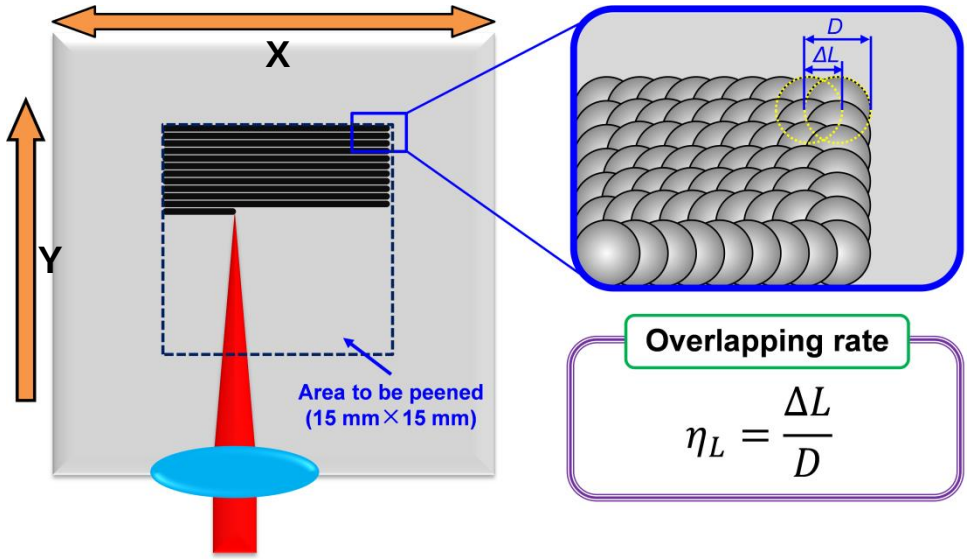
LSP system in LANE lab

Laser shock peening

Experimental procedures

❖ **Two different LSP experiments**

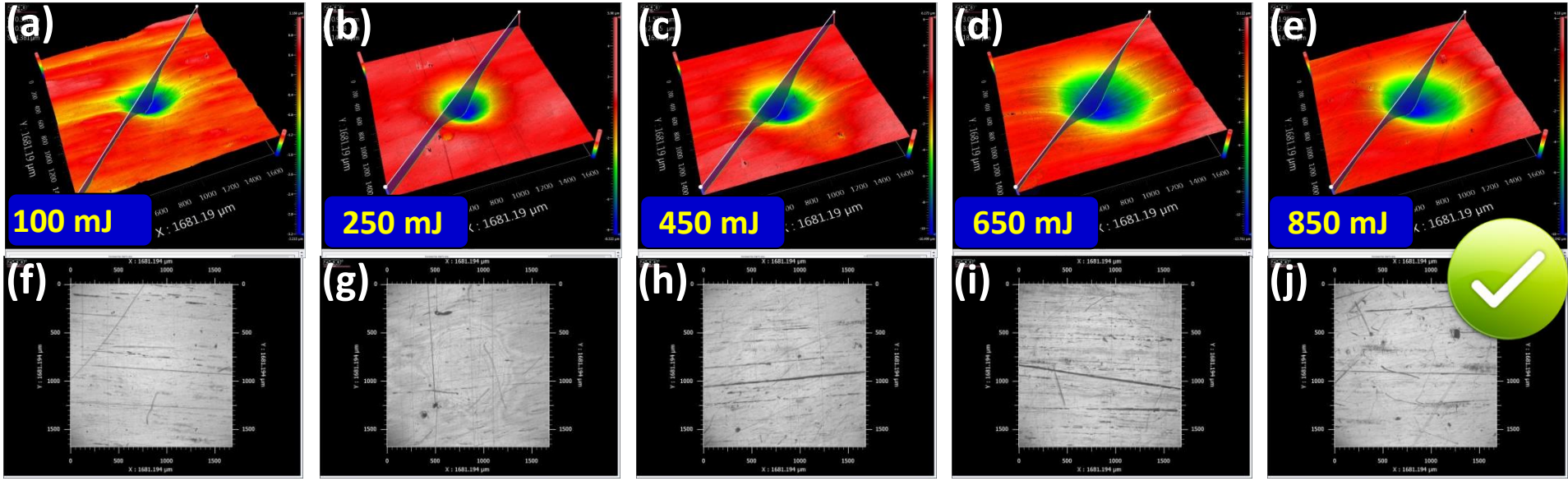
1. **Single-spot LSP:** **single laser pulse**.
2. **Large-area LSP:** laser repetition rate **10 Hz**.



- ***ΔL*: overlap between two adjacent laser spots**
- ***D*: laser spot diameter**

Laser shock peening of 5456 Al alloy

Laser pulse energy



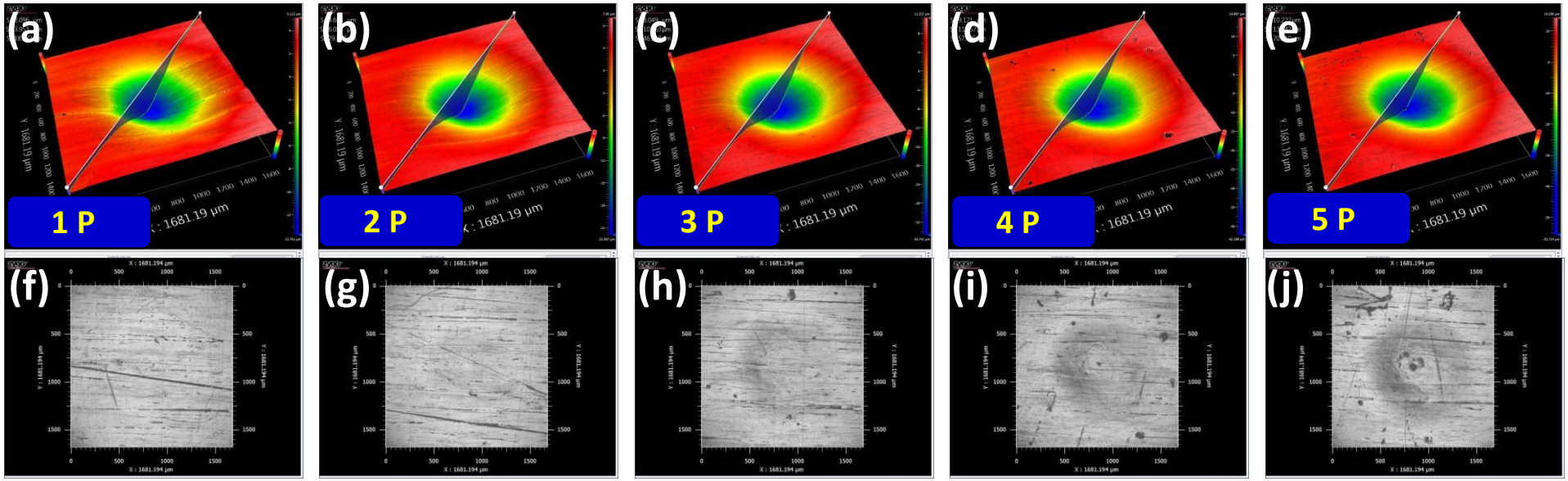
(a-e): 3D surface topographies of Al-Mg alloy after single LSP with different laser energies

(f-i): Corresponding optical images of Al-Mg alloy shown in (a-e).

- Dent depth increased with high laser pulse energy.

Laser shock peening of 5456 Al alloy

Impact times



(a-e): 3D surface topographies of Al-Mg alloy after single LSP with different impact times

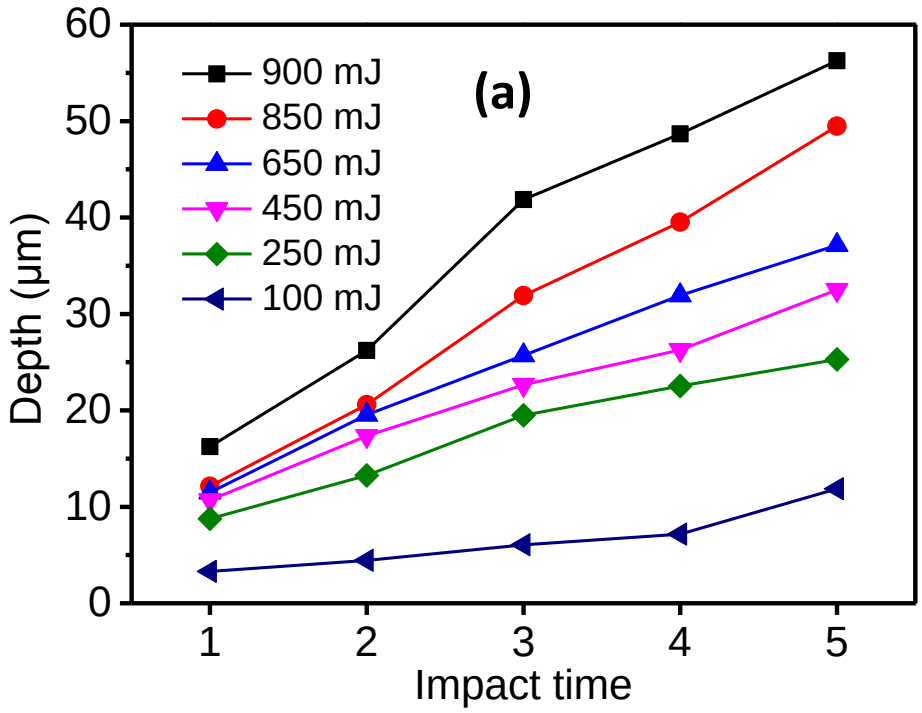
(f-i): Corresponding optical images of Al-Mg alloy shown in (a-e).

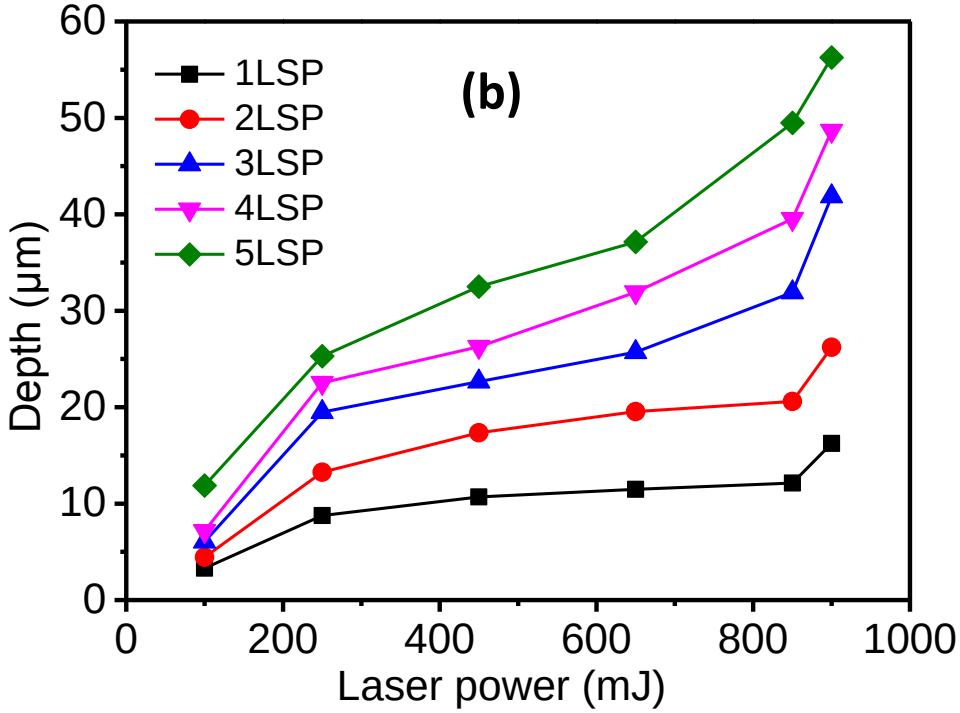
- Dent depth increased with increasing impact times.

Laser shock peening of 5456 Al alloy

Laser pulse energy/impact times

Systematic optimization

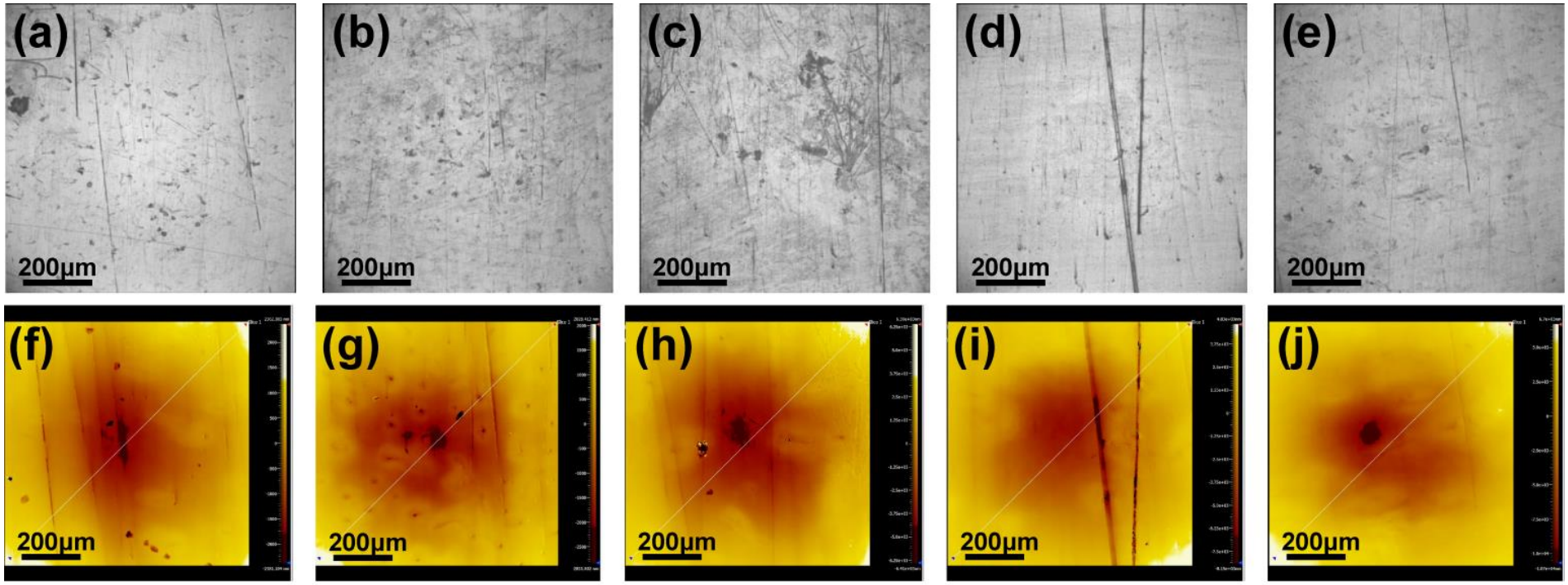




- **Laser pulse energy is a key parameter;**
- **Multi impact accumulation with low pulse energy has similar effect as large pulse energy.**

Laser shock peening of 304 SS

Impact times

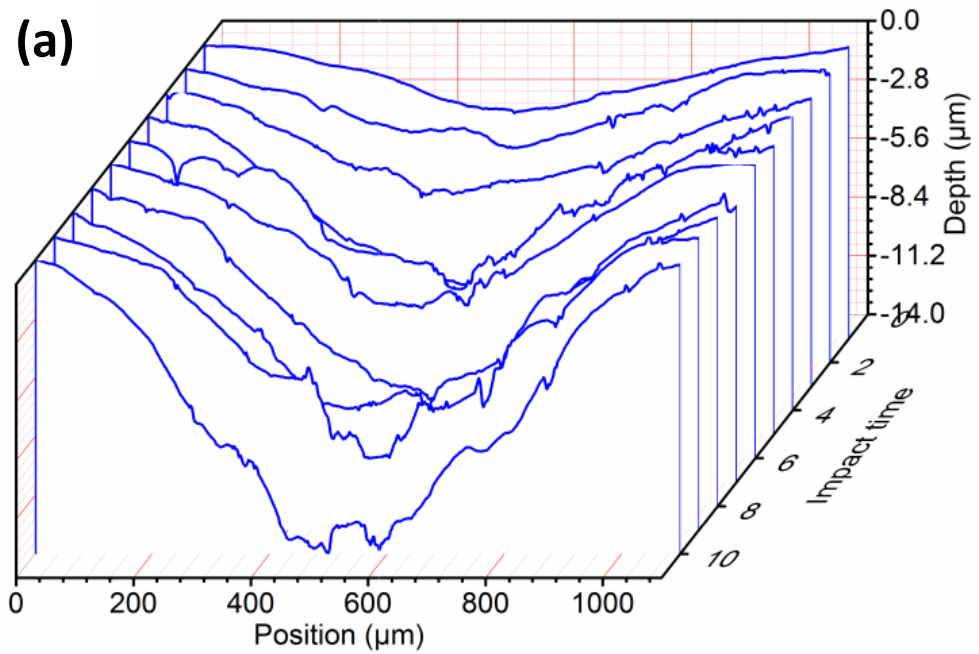


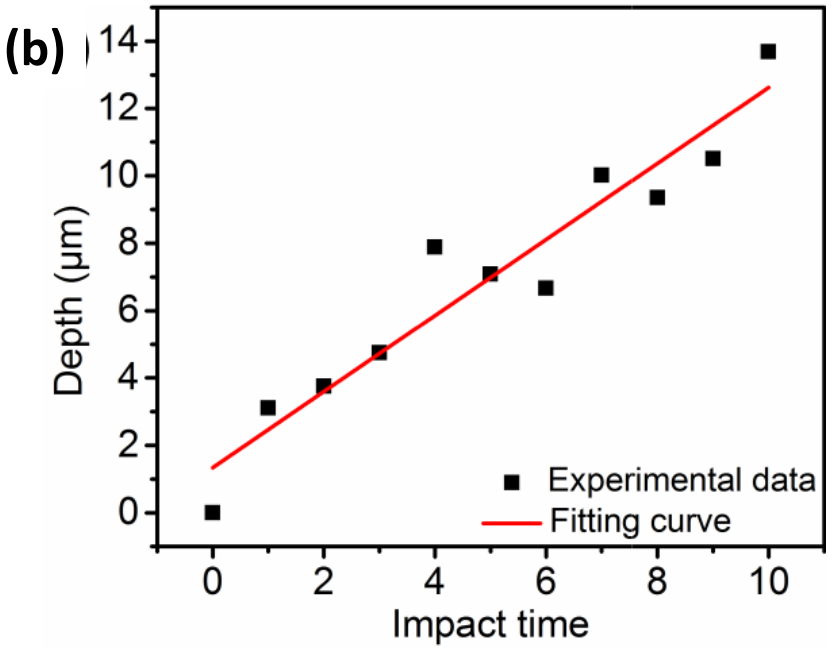
(a-e): optical images of the 304 stainless steel treated by single-pulse LSP with 1, 2, 4, 7, 10 impacts times; (f-j): Corresponding 3D surface topographies

- The stainless steel can endure more laser impacts without surface damage;
- The deformation of stainless steel is lower than Al alloys.

Laser shock peening of 304 SS

Impact times



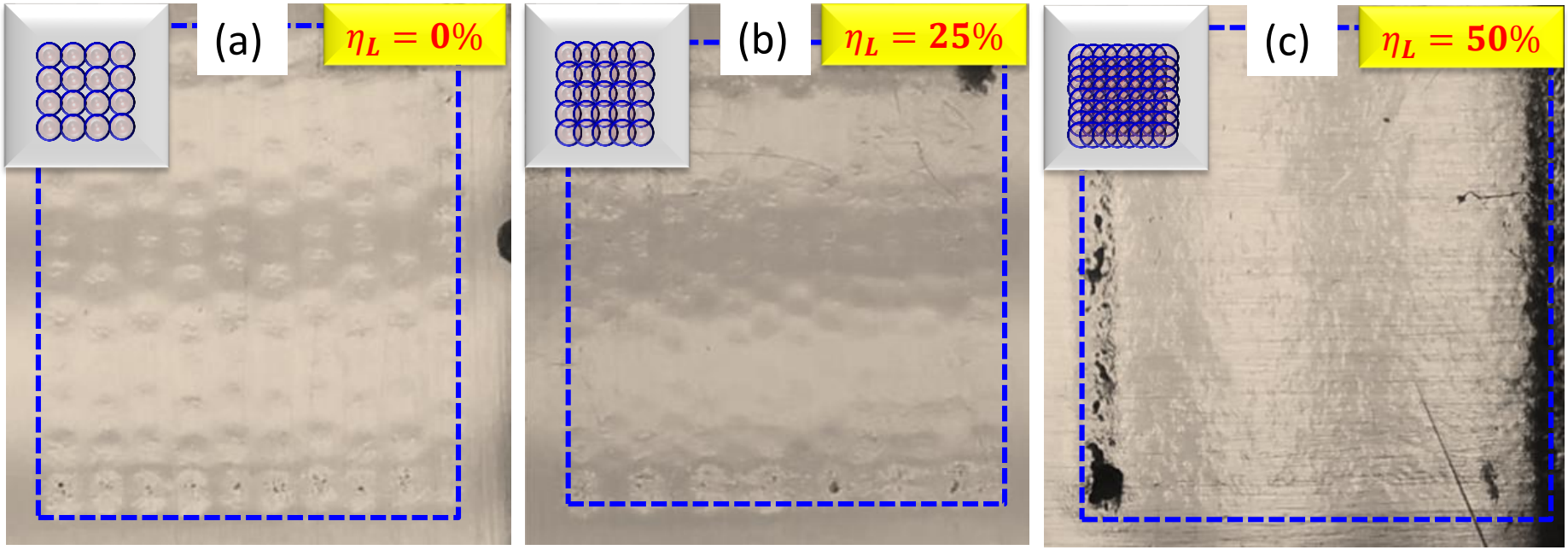


(a) The topography and (b) dent depth of peened dent with different impact times

- **Increasing impact times can improve peening effect significantly;**
- **Multiple impact times will produce rough surface.**

Laser shock peening of 304 SS

Overlapping rate



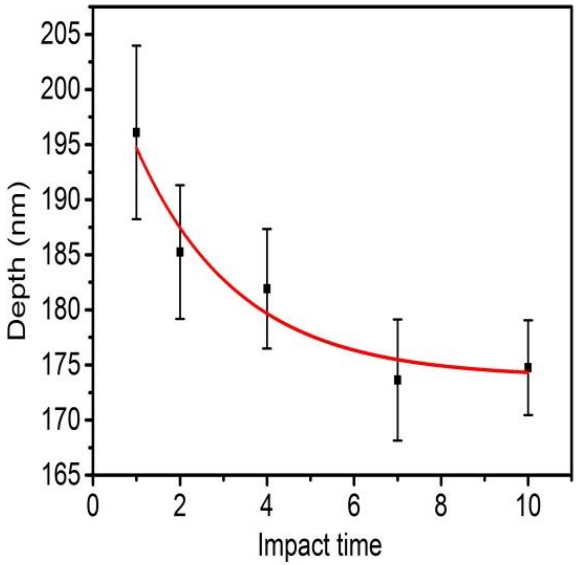
Optical images of the 304 SS surfaces after LSP with different overlapping rates

- **The stainless surface is undamaged even in high overlapping rate.**

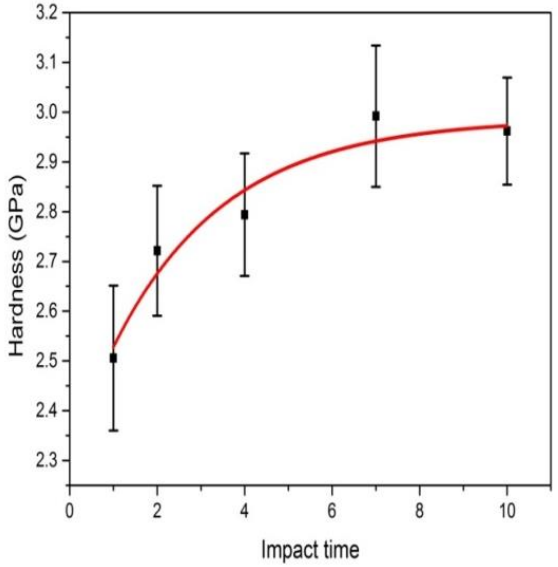
Laser shock peening of 304 SS

Surface nanohardness/elastic modulus

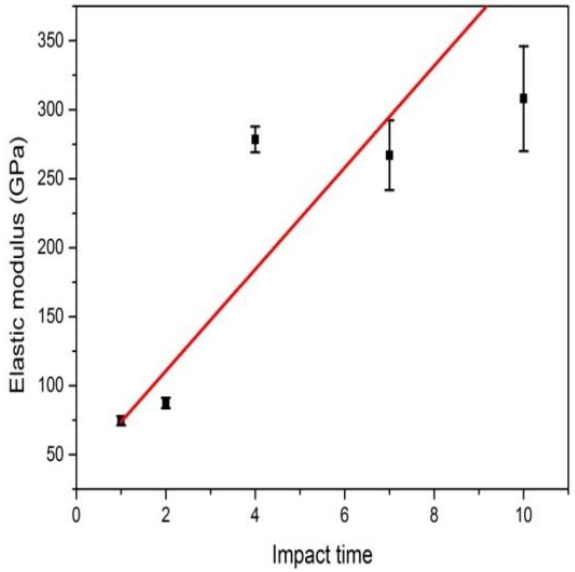
Contact depth



Surface nano-hardness



Elastic modulus

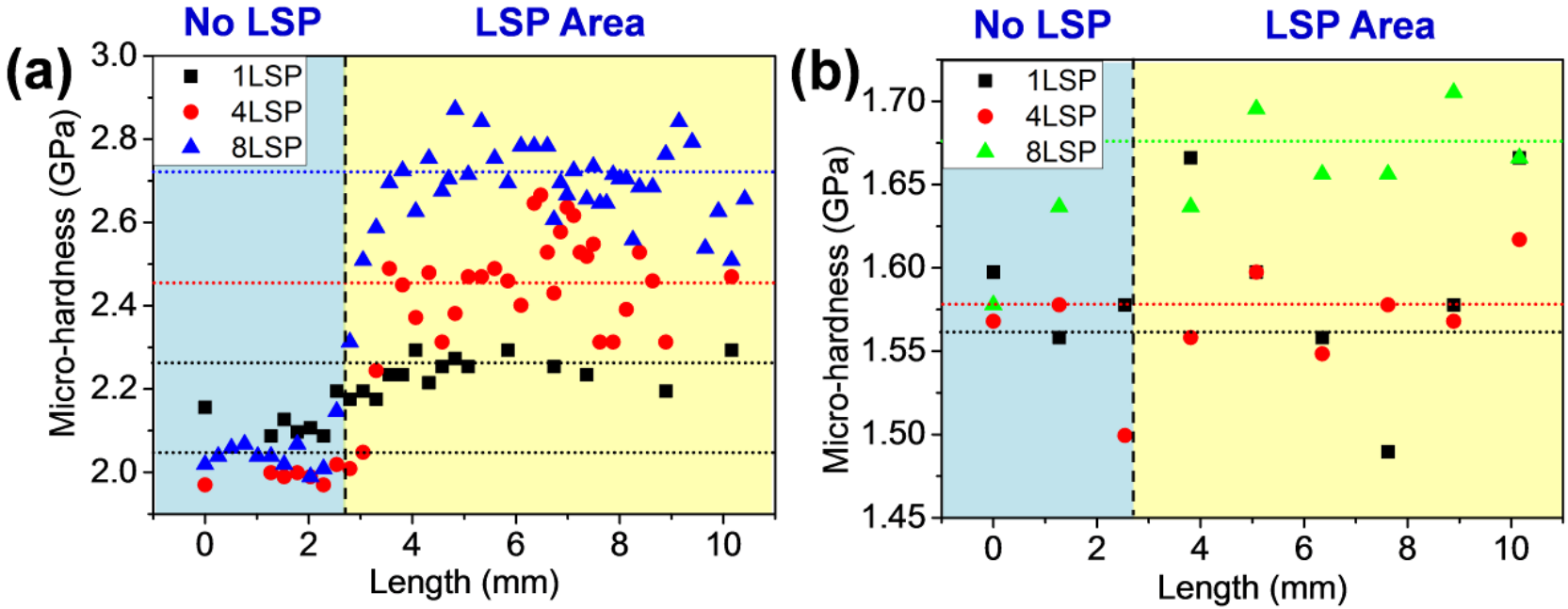


Mechanical property ~ impact times.

- **Both nanohardness and elastic modulus increase with more impact times.**

Laser shock peening of 304 SS/1018 CS

Surface microhardness



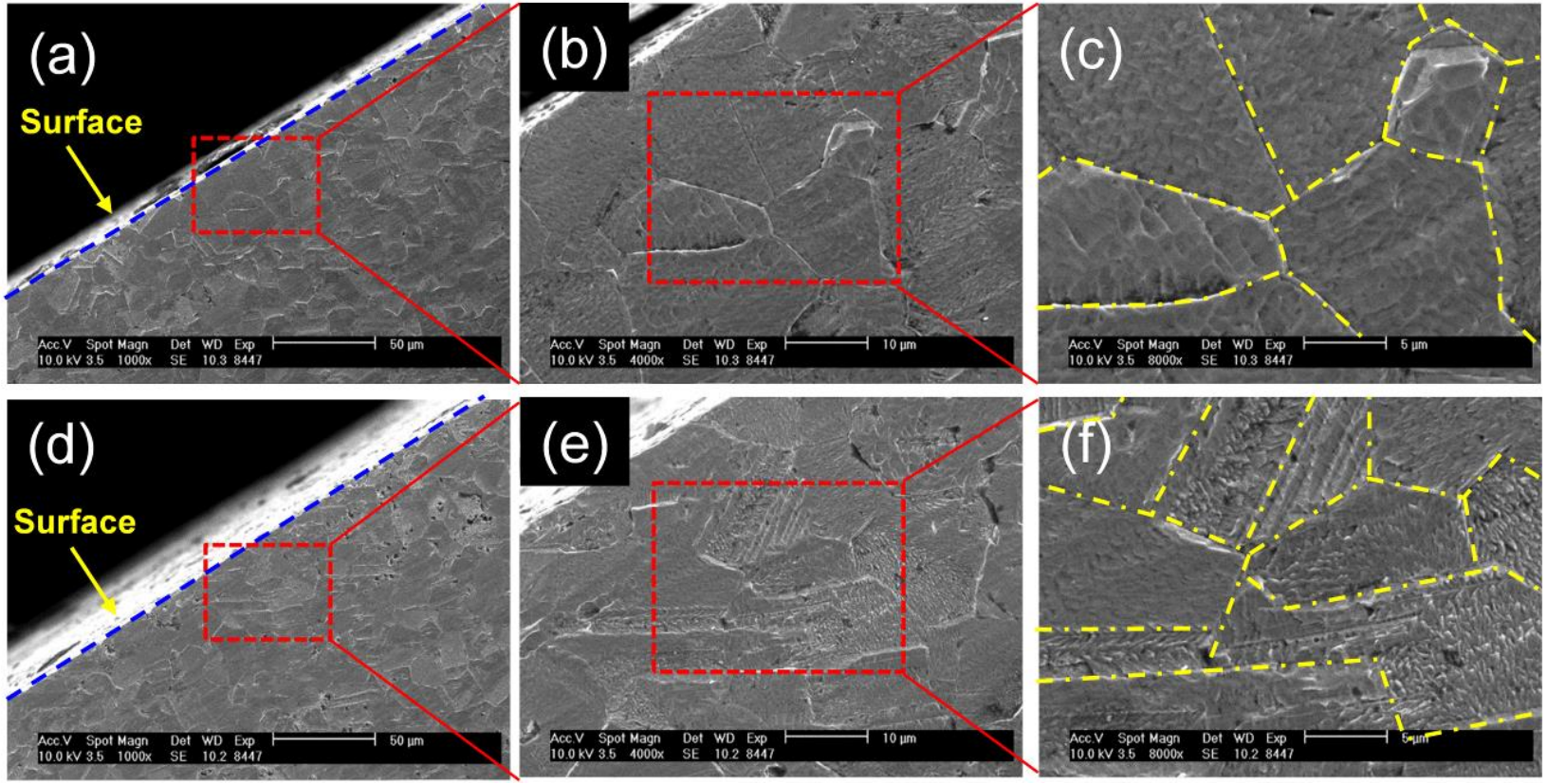
(a) 304 stainless steel;

(b) 1018 carbon steel

- More microhardness increase in 304 stainless steel;
- Less microhardness increase in 1018 carbon steel.

Laser shock peening of 304 SS

Metallographic imaging

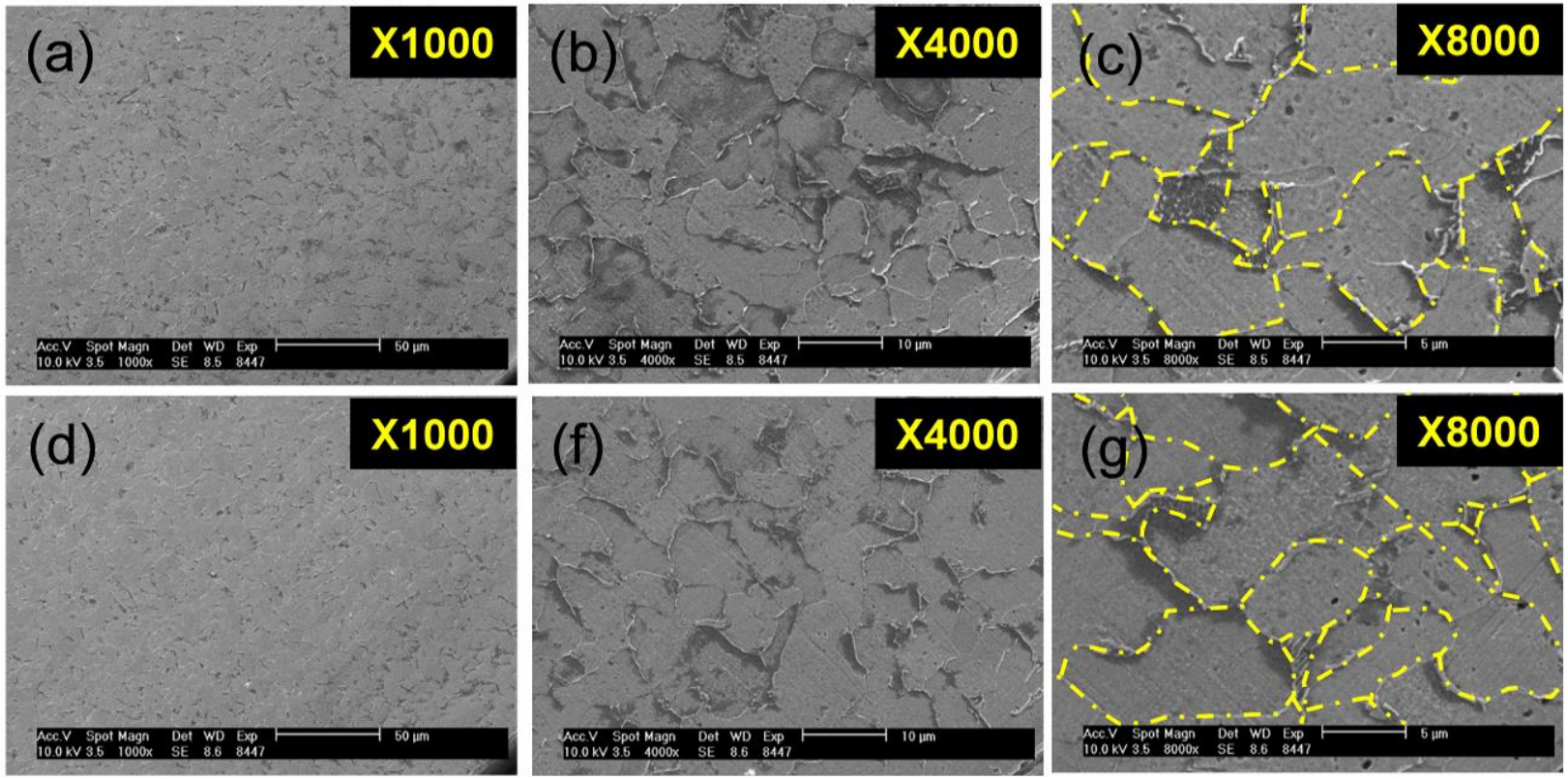


The microstructure of 304 stainless steel before (a-c) and after (d-f) LSP

- **Surface grain size of 304 SS decreased a little after laser peening.**

Laser shock peening of 1018 CS

Metallographic imaging

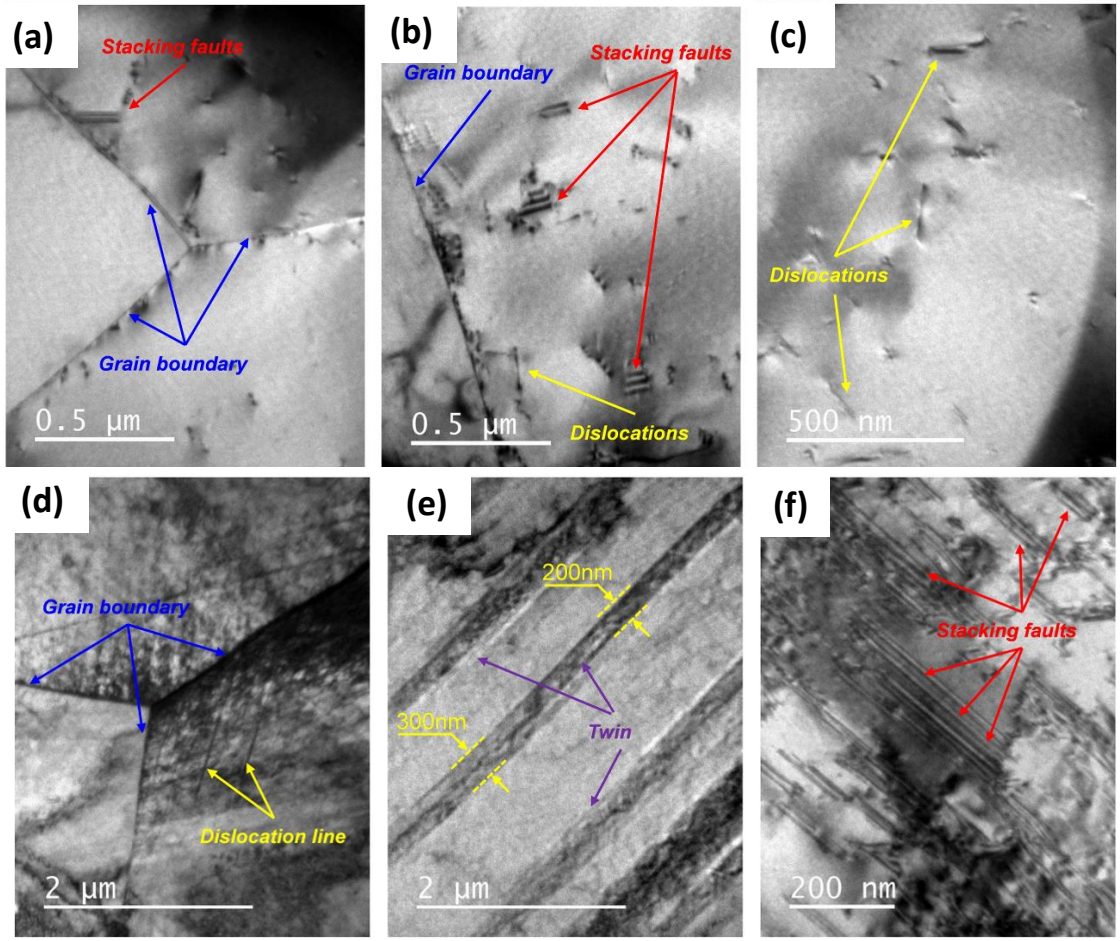


The microstructure of 1018 carbon steel before (a-c) and after (d-f) laser shock peening

- **No obvious grain size decrease in 1018 CS after laser peening.**

Laser shock peening of 304 SS

TEM investigation

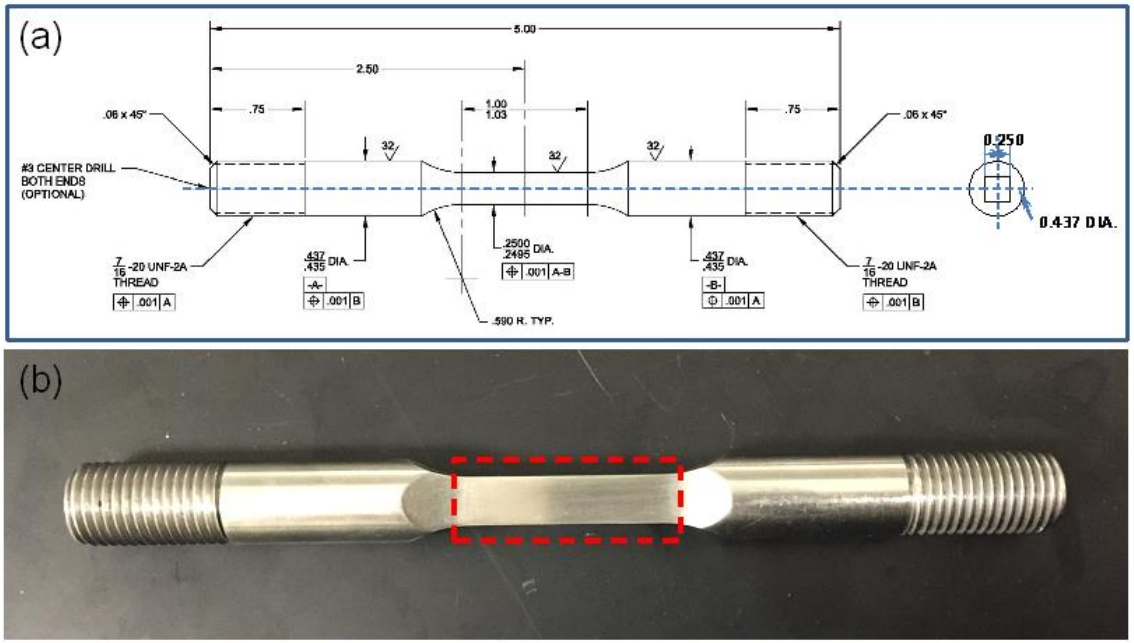


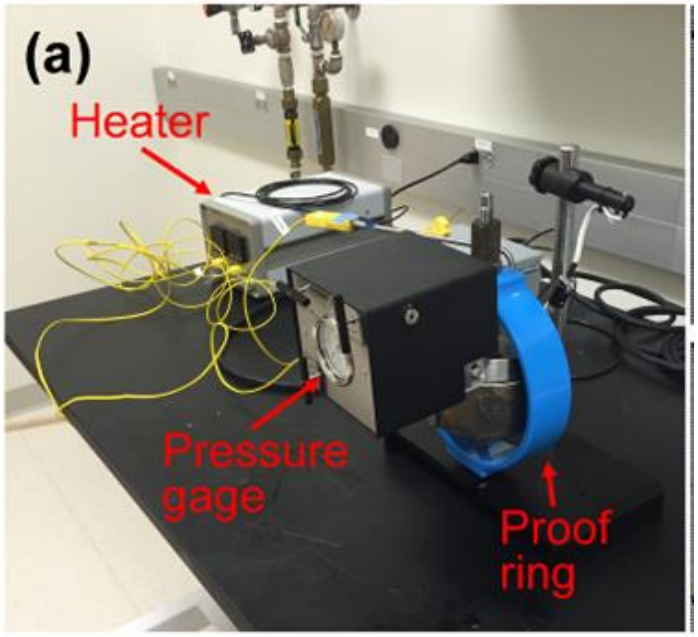
TEM images of 304 stainless steel before (a-c) and after (e-f) laser peening

- More dislocations, twins, and stacking faults observed after laser peening
- Increase in hardness and compressive residual stress

Laser shock peening of 304 SS

Stress cracking corrosion (SCC) test

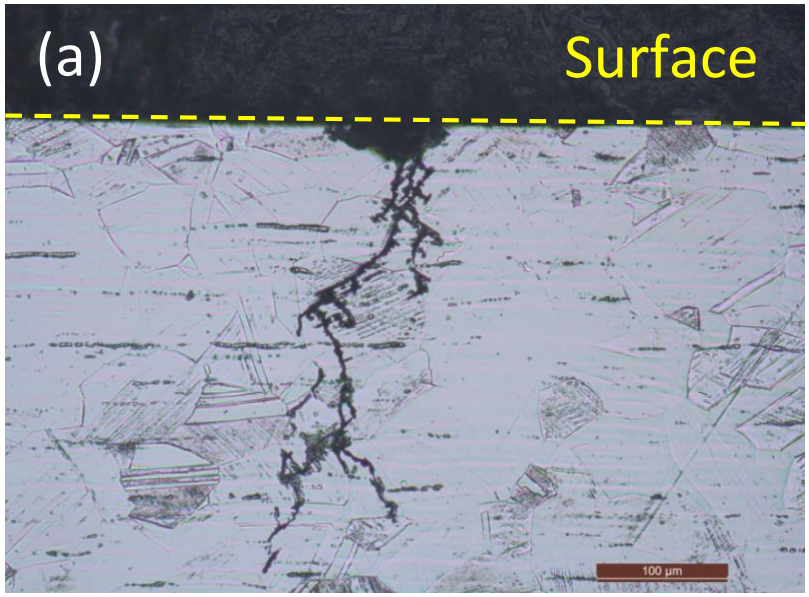


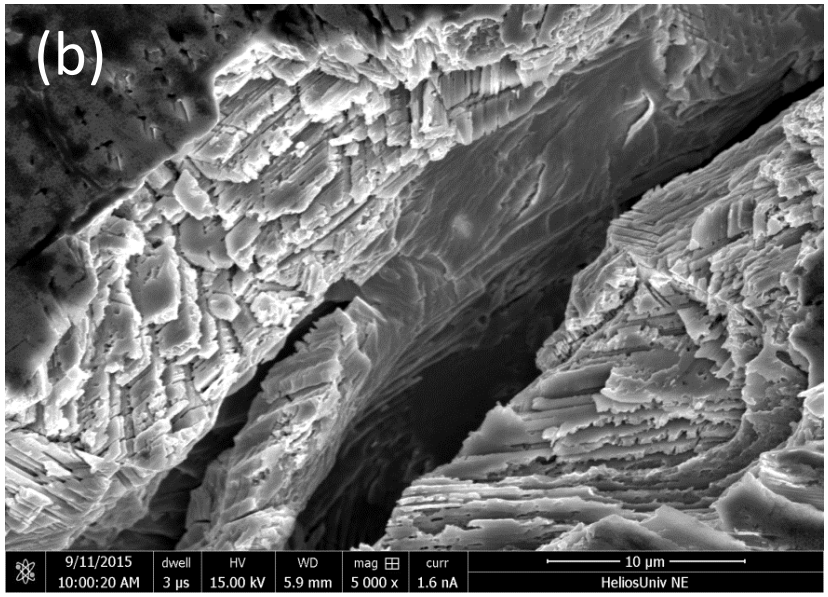


The stress corrosion cracking (SCC) test sample and equipment

Laser shock peening of 304 SS

SCC test



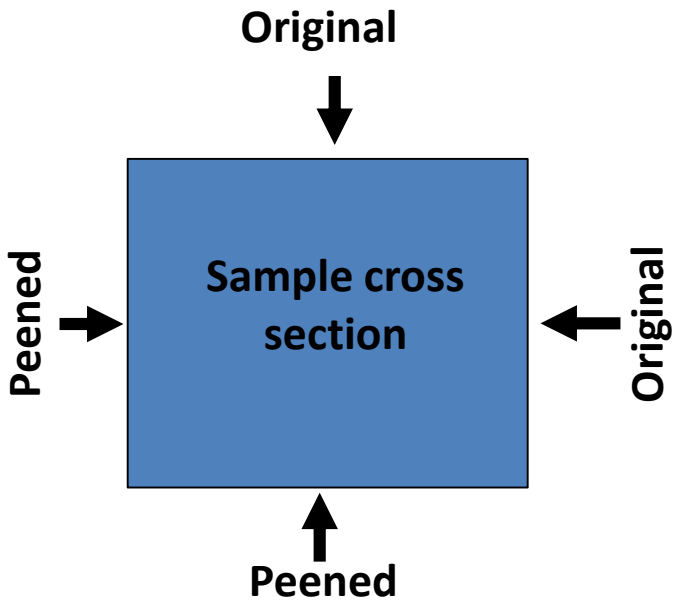


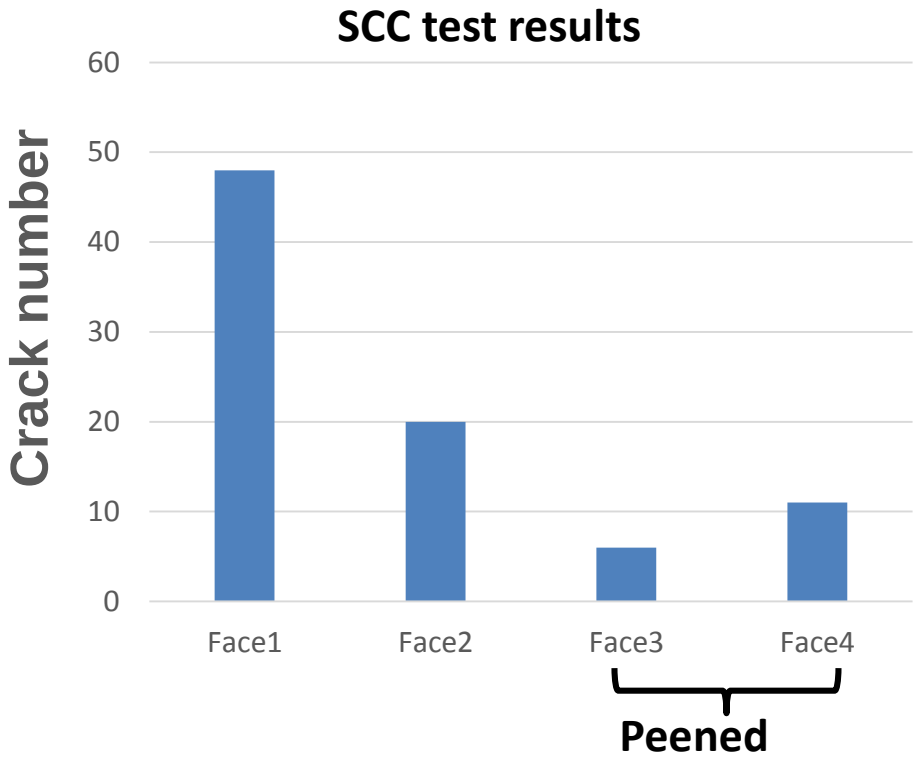
(a) Cross section view of a typical crack and (b) microstructure of the crack.

- **The crack shows clear intergranular microstructure.**

Laser shock peening of 304 SS

SCC test





Peening parameters: 850mJ, 50%, 4 times;

Test solution: $MgCl_2$, 144°C; Load: 300 MPa, 96 hours

- **The crack number of peened surface is lower than original surface;**
- **Most of the cracks on peened surface are expanded from original surface.**

Portable laser shock peening prototype development

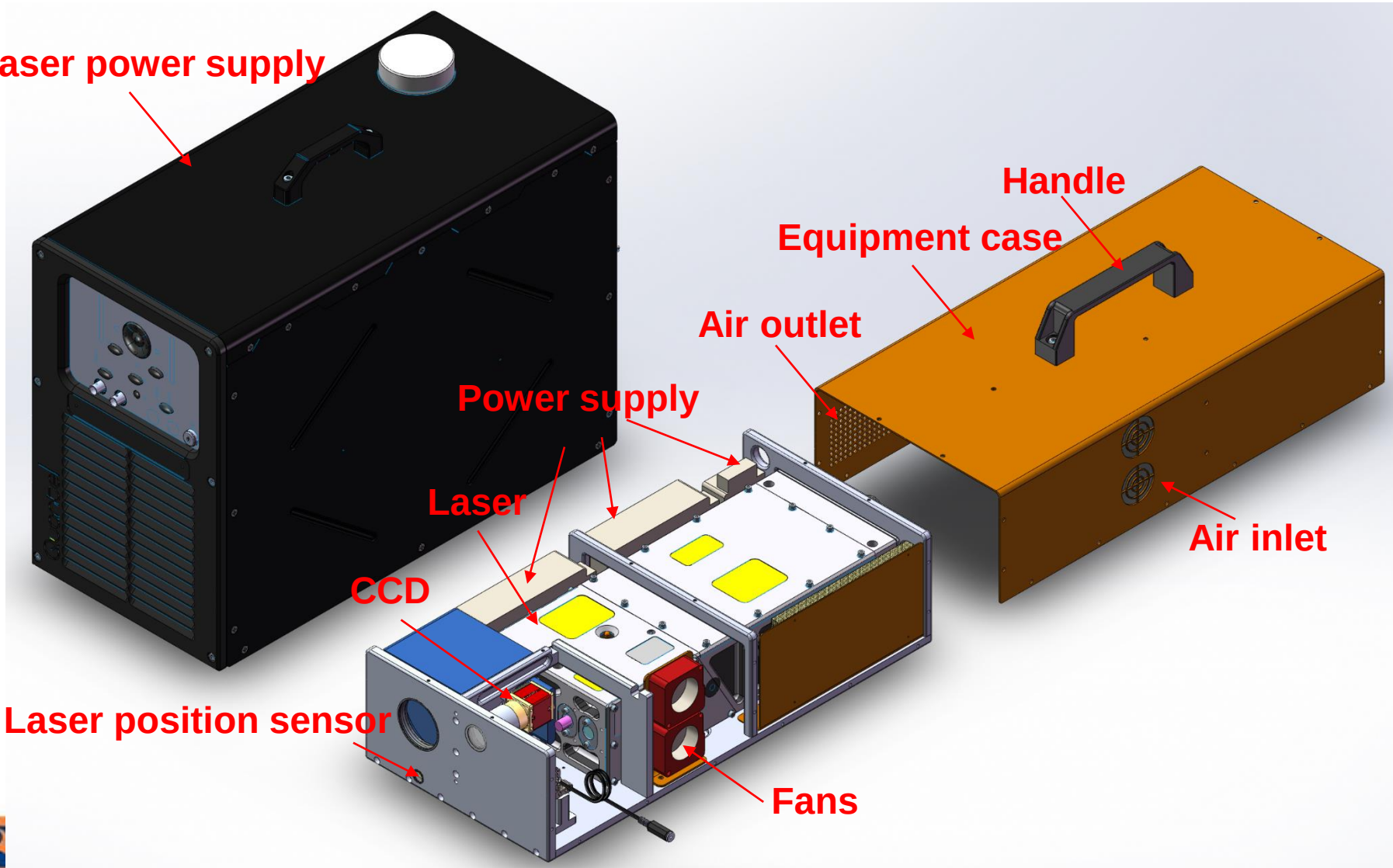
Laser shock peening

Portable LSP system – laser comparison

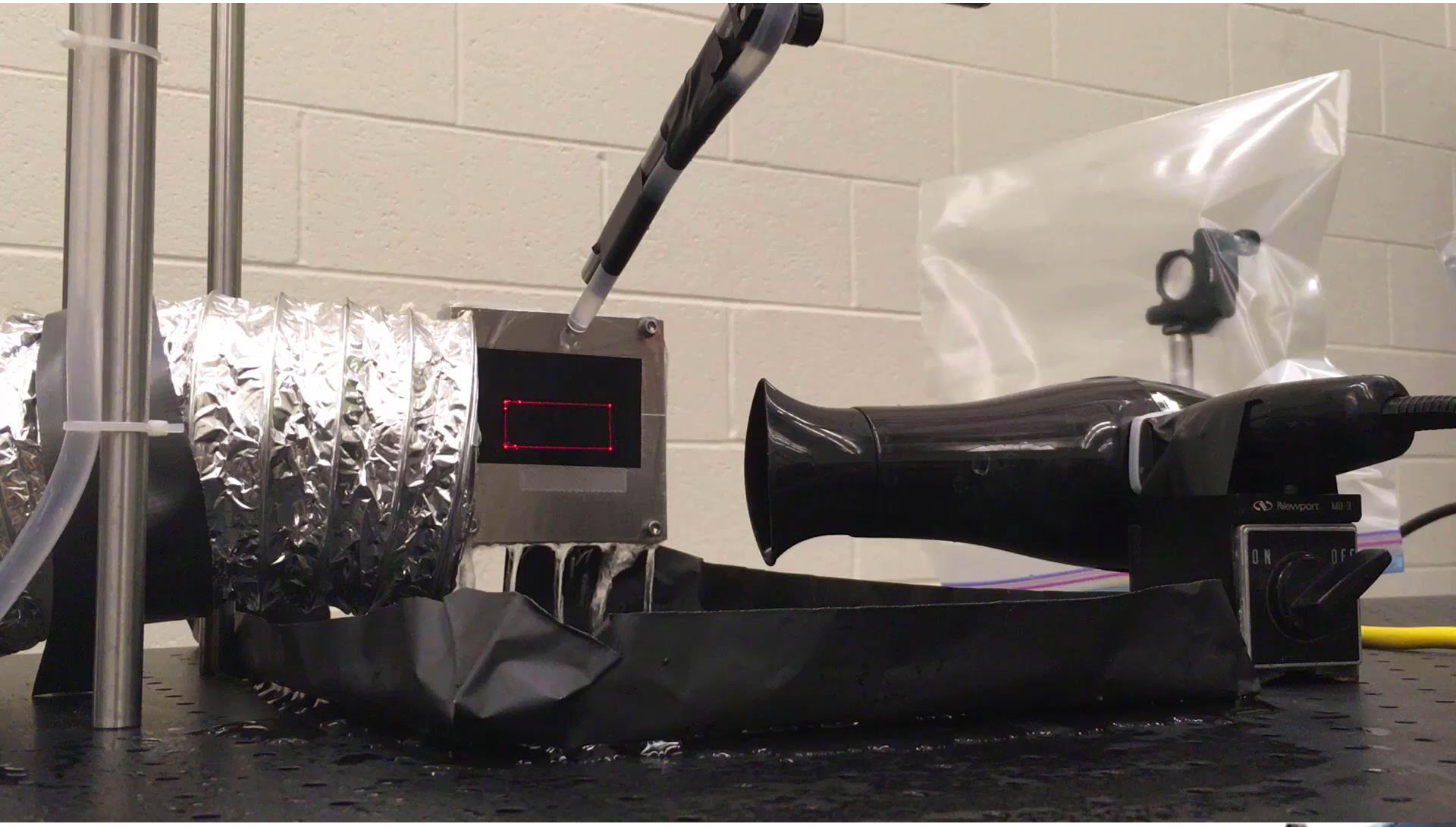
Laser model	Continuum Nd:YAG	Quantel DRL 650
Size(mm)	1189 × 457 × 298	432 × 160 × 94
Wavelength (nm)	1064	1064
Pulse energy (mJ)	850	650
Pulse duration (ns)	6 ~ 8	< 15
Frequency (Hz)	1 ~ 10	1 ~ 30
Spot size (mm)	1 ~ 2	1 ~ 2
Weight (kg)	>50	6.4
Portability	Large / heavy / delicate Sensitive to humidity and vibration	Compact / light / rigid Resist to humidity and vibration

System Design and Integration

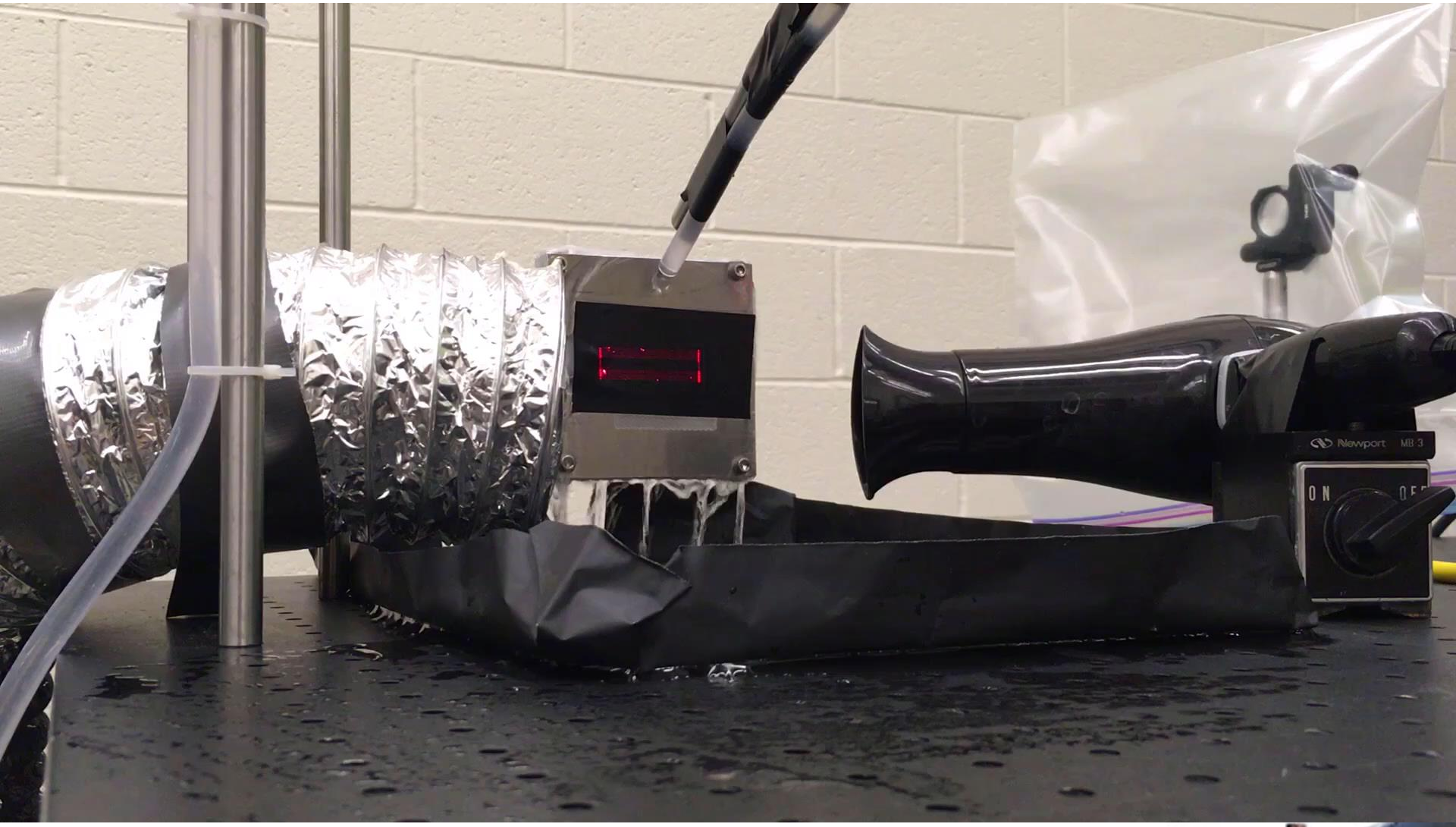
Portable laser repairing system – design



System Design and Integration



System Design and Integration



Project Reporting

- Final Reporting and any student poster papers are available from:

"insert project URL - example"

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=570

THANK YOU!