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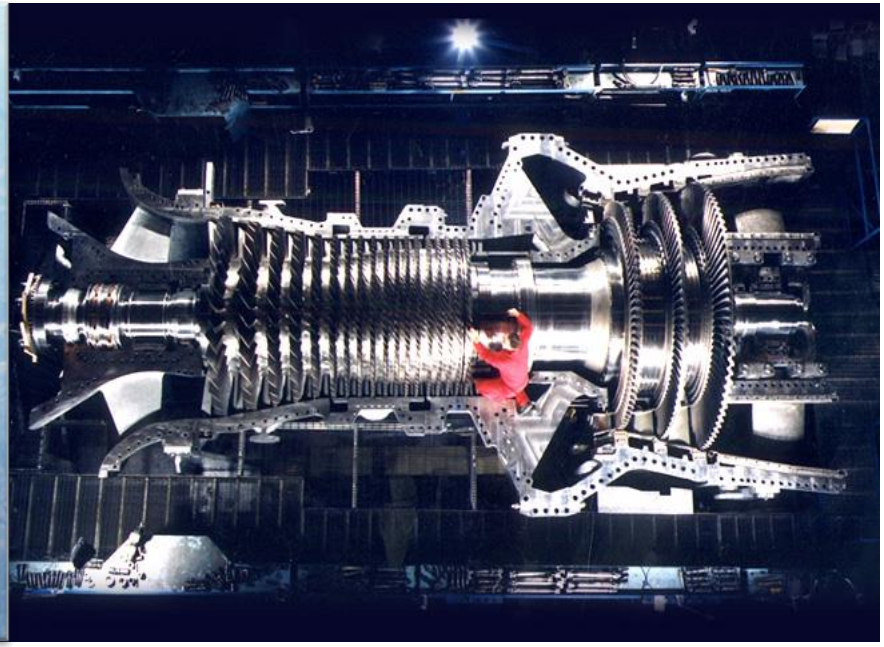
Introduction to Laser Peening
March 20, 2019

LSP Technologies, Inc.

Laser Peening benefits

- Extends the fatigue life and Enhances metallic parts properties
- Saves end users on maintenance costs
- Increases safety



Outline

- LSP Technologies Inc. background and leadership
- LSP process and the material response
- Material properties enhancement by LSP
- LSP Application Development

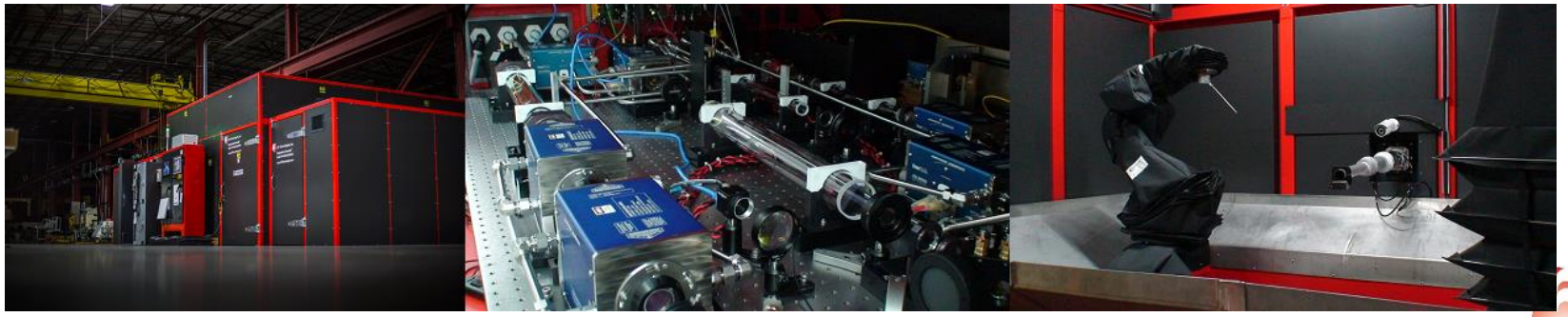
LSP Technologies Inc. Background and Leadership

Global Presence

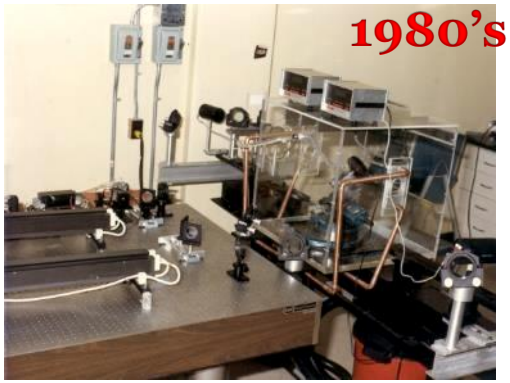
Collaborative Partnerships

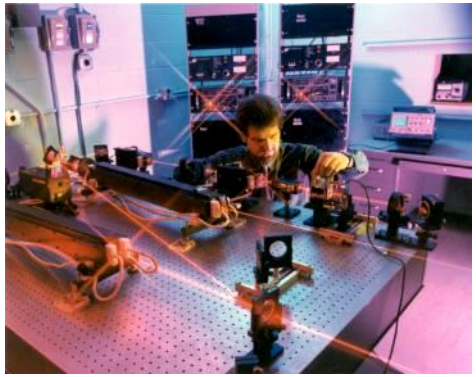
LSPT Background

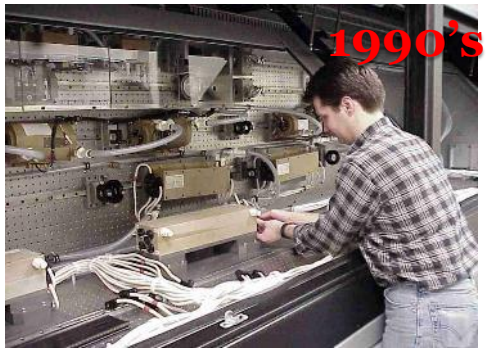
- LSP Technologies Inc. (LSPT) was founded in 1995 to commercialize Laser Shock Peening (LSP)
- Original business model – all parts laser-peened at our facilities.
- Expanded to include laser peening equipment sales to integrate with customer production lines.
- Today, LSPT is the world's premiere provider of laser peening services, technology, and equipment.



Growing with Technology







LSPT Background

- In early 2015, LSPT introduced the Procudo® LSP System, offering next-generation laser peening systems for customer production lines.

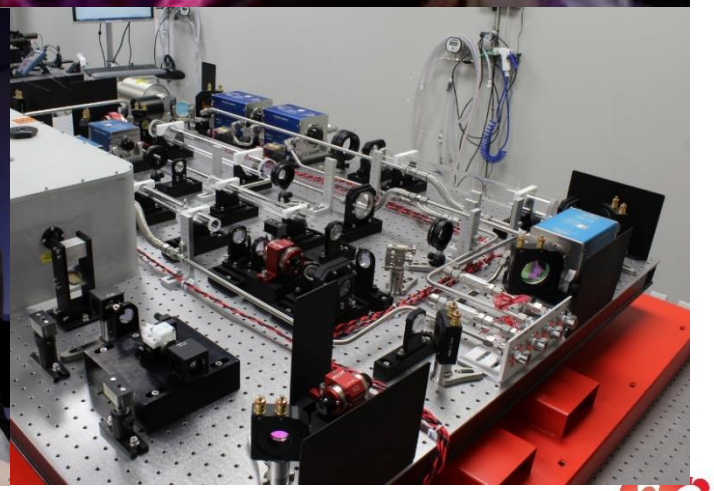
LSPT Leadership

LSPT was the first to provide:

- Production LSP services
  - First aerospace application
- Production LSP equipment
  - Sold first LSP System to General Electric in 1997
- Diode-pumped production LSP Systems
  - Procudo® 200 LSP System
- Commercial Laser Peening Cells
  - Production for industry
- Laser Bond Inspection (LBI) Systems
  - Sold first LBI system to Boeing in 2012

LSPT Leadership

LSPT leads the industry with high energy laser technology, precision modeling of metal part stress, and optimized laser peening patterns.



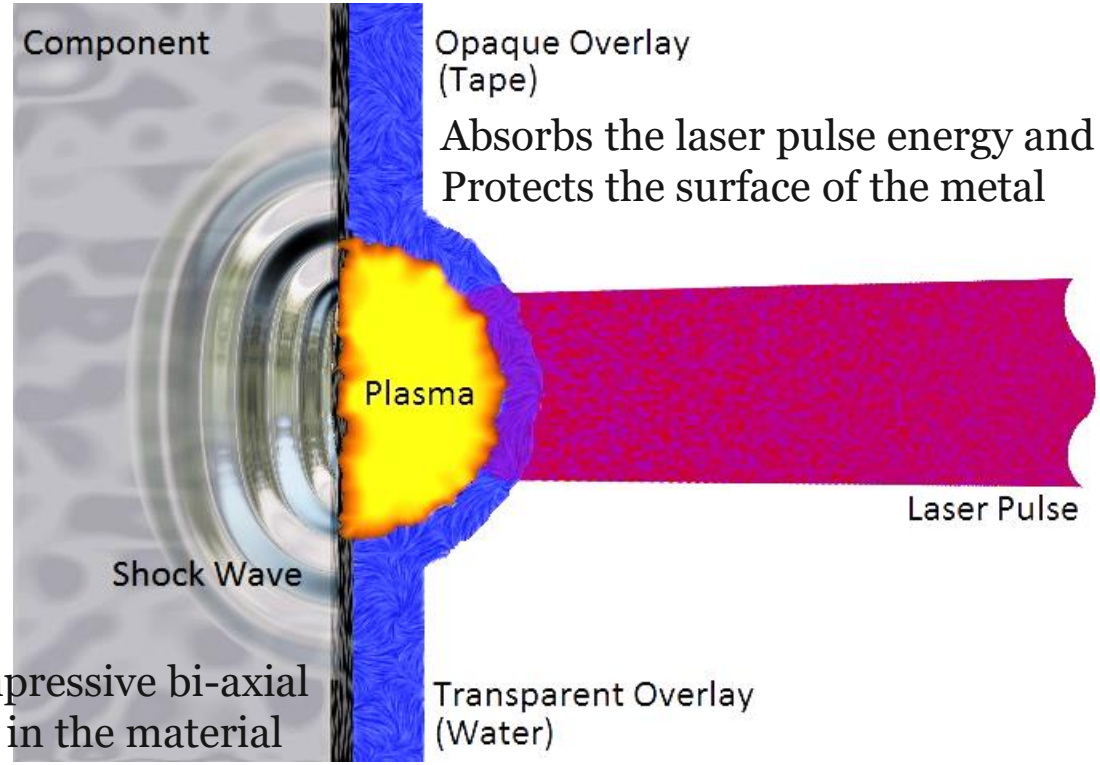
Continuous Technology Development

- LSPT has the dominant intellectual property position in the laser peening industry.
  - 61 issued patents
  - 9 patents pending
  - 5 patents in preparation
  - LSPT can leverage its extensive know-how and trade secrets for you, our customer

- LSPT has cross-licensed patent portfolios with GE
  - LSPT has rights to 72 GE-issued patents
  - LSPT has right to sub-license GE patent portfolio
  - GE has extensive know-how and trade secrets

LSP process and the material response

The Laser Peening Process

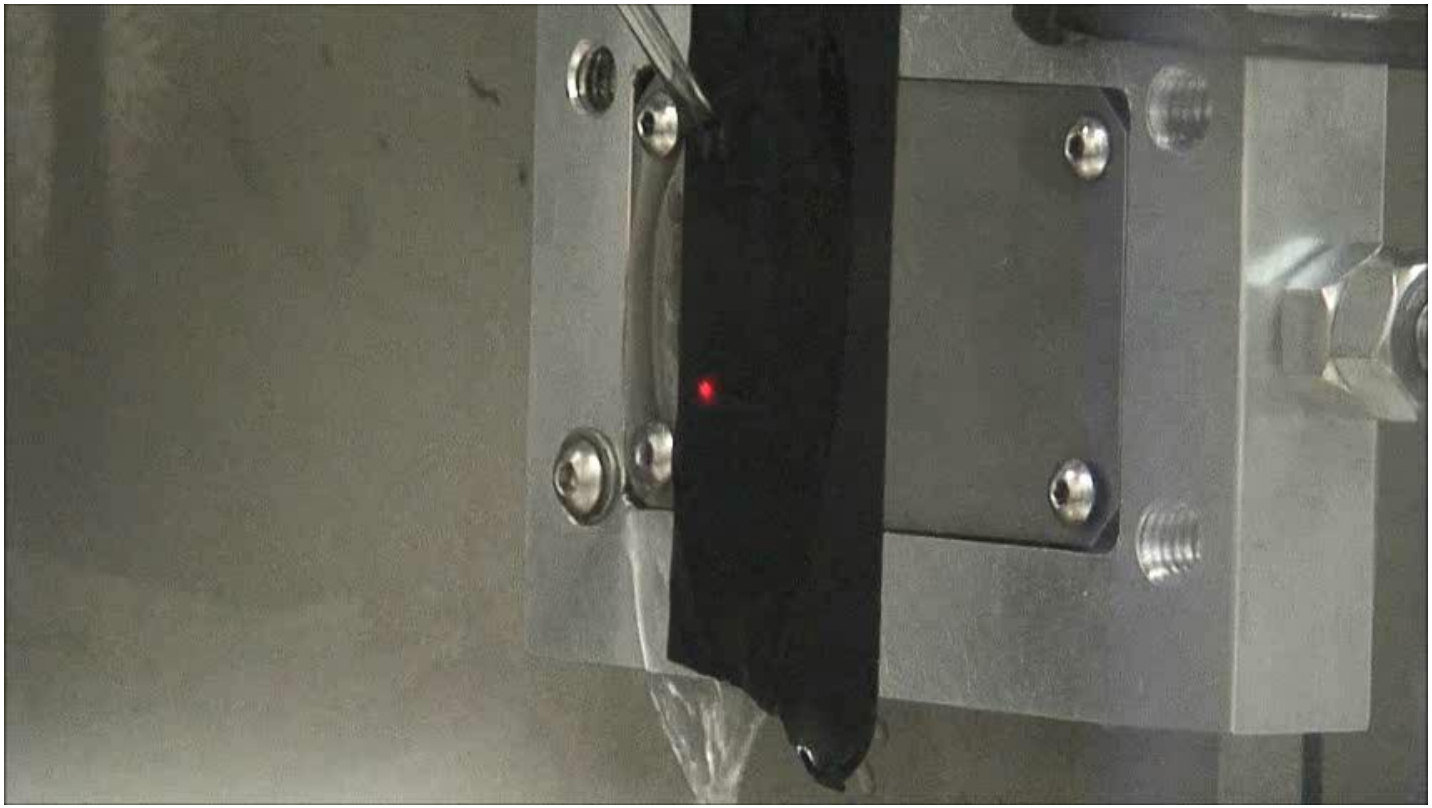


Absorbs the laser pulse energy and create plasma
Protects the surface of the metal

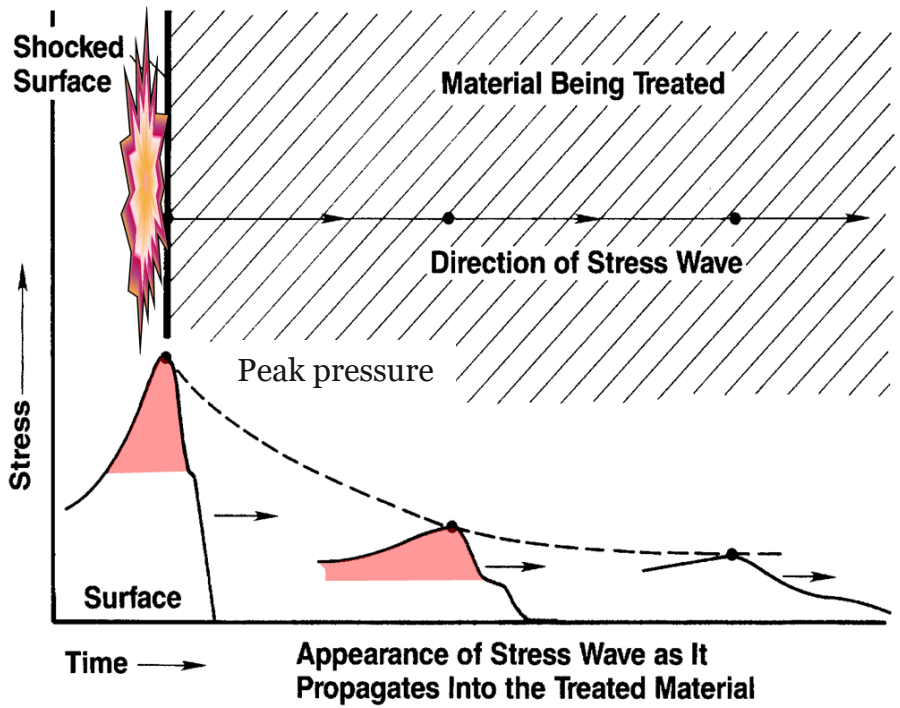
Creates a compressive bi-axial state of stress in the material

Transparent since it needs to pass the laser pulse, then it confined the plasma forcing the energy to propagate into the material

The Laser Peening Process



Shock wave attenuation



Two significant changes occur in the shock wave as it travels into the material from the surface

- ✓ The peak pressure decreases
- ✓ The width of the shock wave increases

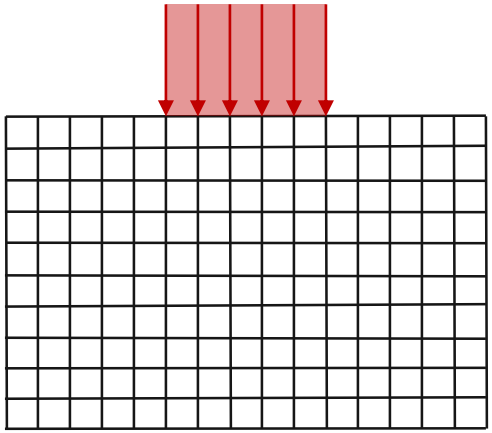
Attenuation of the shock wave has important consequences

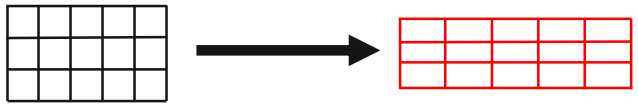
- ✓ At some distance below the surface the peak pressure drops below the HEL and no longer produces plastic strain
  - Plastic strain creates the residual stresses
- ✓ In thinner sections it affects the magnitude of the peak pressure when it reflects off the opposite surface

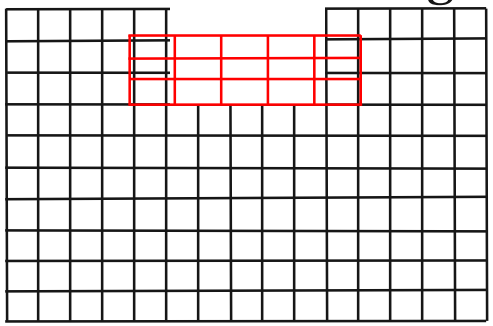
Material Response to Surface Treatments (Continuum)

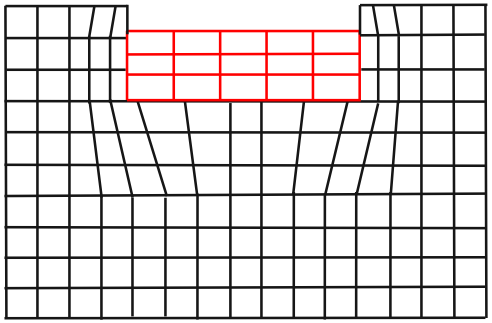
Plastic strain drives elastic response

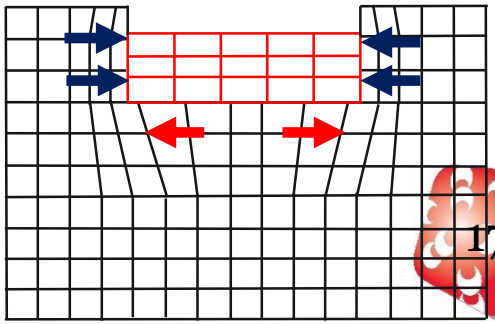
STEP 1	STEP 2	STEP 3
Surface enhancement applied	Processed volume plastically deformed (cold worked)	Surrounding material elastically adapts to plastic strain volume
	Plastically deformed material has different dimensions than original	Elastic strain leads to creation of residual stress











The Laser Peening Process Parameters

Intensity/Power density: Maximum power density on the order of 10 GW/cm^2.

Energy: Amount of energy carried by each laser pulse hitting the surface.

Pulse Width: Longer pulse widths lead to increased treatment depth. Shorter pulse widths can increase surface magnitude.

Spot Size: Determined by laser capability and target requirements. Spot size at the highest repetition rate determines the processing speed. Spot size can impact treatment depth.

Example: 20 J/20 ns laser delivers 10 GW/cm2 in 3.5 mm spot diameter

Layers of Coverage/overlap: Is the number of layers of 100% coverage that needs to be used on a specific area. More layers provide improved residual stress profiles up to a saturation point. Alternatively, the spacing between the consecutive shots in a row and consecutive rows can be controlled to provide the desired number of shots in a specific area.

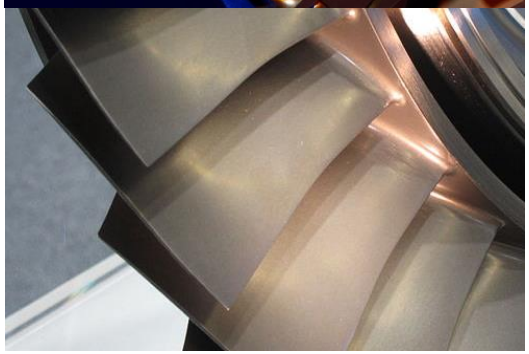
Overlays: Overlays impact shock pressure transmittance.

Material properties enhancement by LSP

Applications

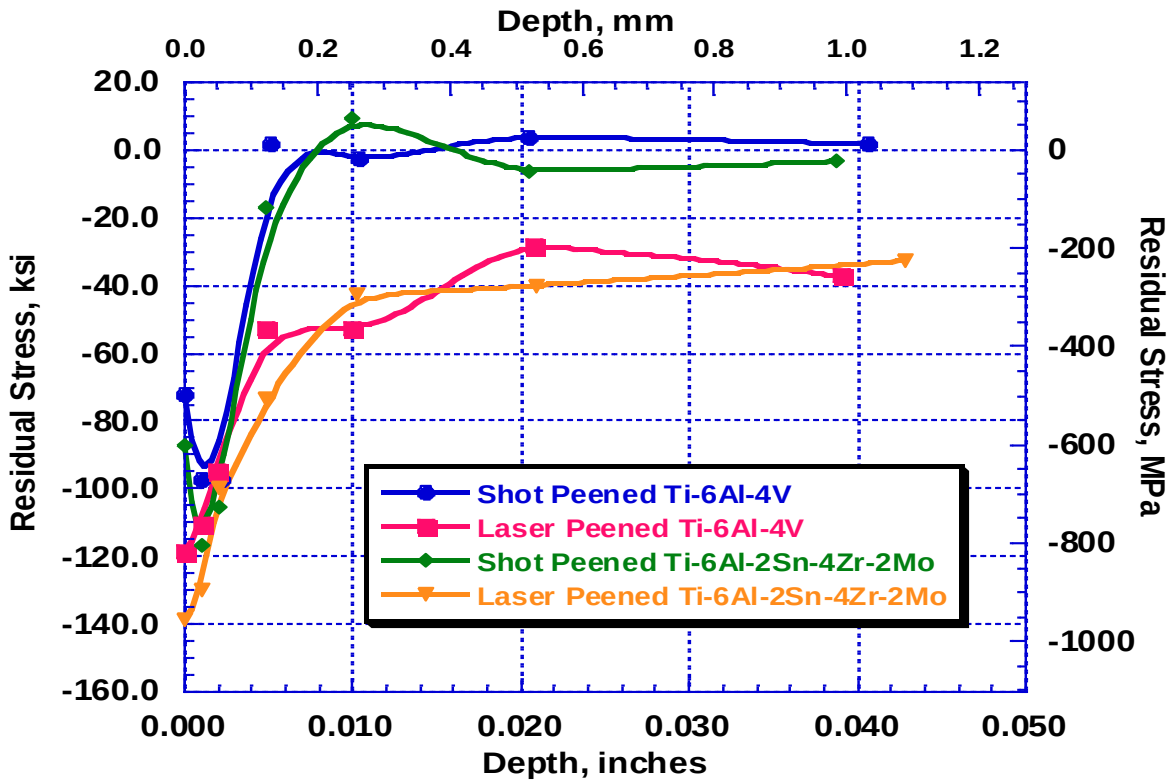
- Works on all metallic materials
  - Steel
  - Titanium
  - Aluminum
  - And More……

- Production Parts
  - Fan and Compressor airfoils
  - Gas & Steam turbine blades
  - Gears, crankshafts, valves
  - Landing gear assemblies
  - Tools & Metal forming dies
  - Weldments
  - And More…..



Residual Stresses profile LSP vs SP

Shot Peening vs. Laser Peening



Shot Peening:
Residual stress depth 0.1 mm (0.004 in)

Laser Peening:
Residual stress depth 1 – 1.5 mm (0.040 – 0.060 in)

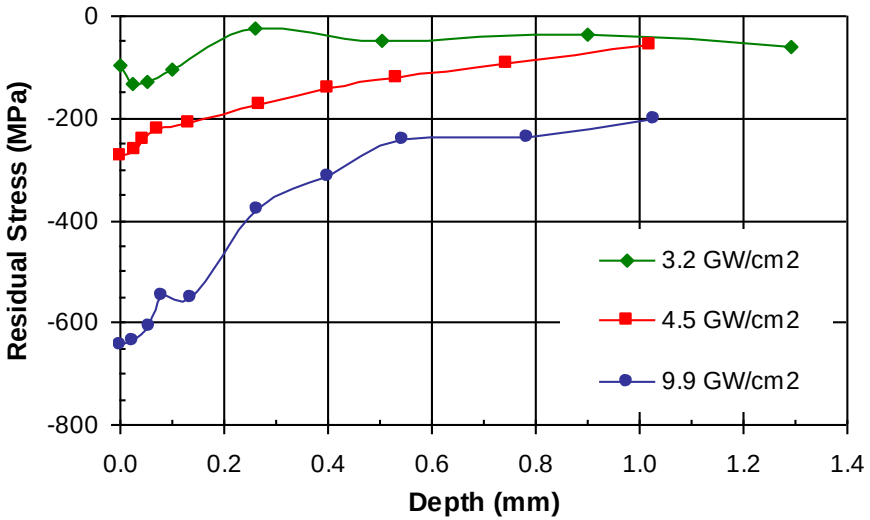
Depth increases by an order of magnitude or more.

Advantages Over Shot Peening

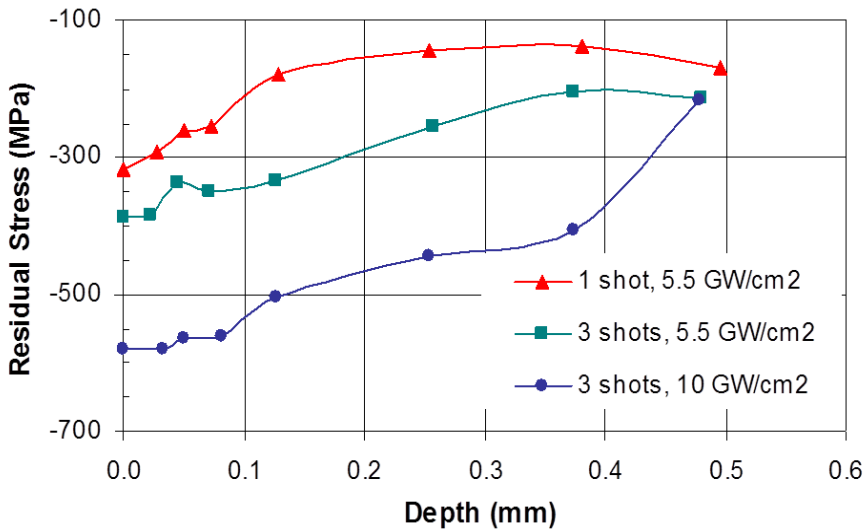
- Deeper compressive residual stresses
  - Up to **5 mm** in depth compared to 0.2 mm for shot peening
- Induces minimal cold work
  - LSP parts retain benefits at high temperatures
- Highly controlled process
  - Masking is unnecessary for protecting sensitive areas
- Produces greater curvatures than shot peening
  - Applicable to forming complex structures
- Produces significantly less surface disturbance compared to shot peening

Part thickness effect on Residual Stress Profiles

Parts of same metal but different thicknesses will react differently to the same laser peening conditions.



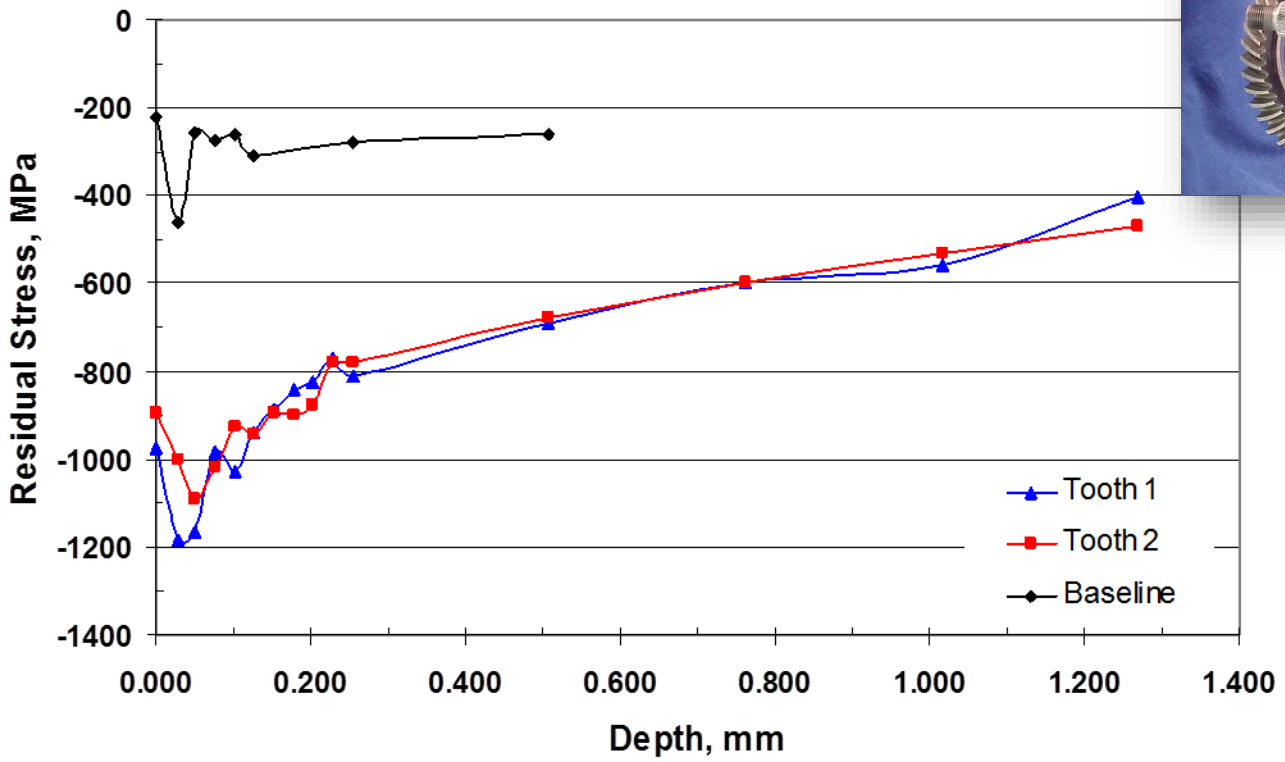
Thick (12 mm), single-sided laser peening
Ti-6Al-4V at increasing irradiance, single impact



Thin (1 mm), double-sided laser peening
Ti-6Al-4V for three different laser peening conditions

Residual Stress Profiles - components

Ring Gear



Laser peened in the tooth roots, drive side average of two teeth

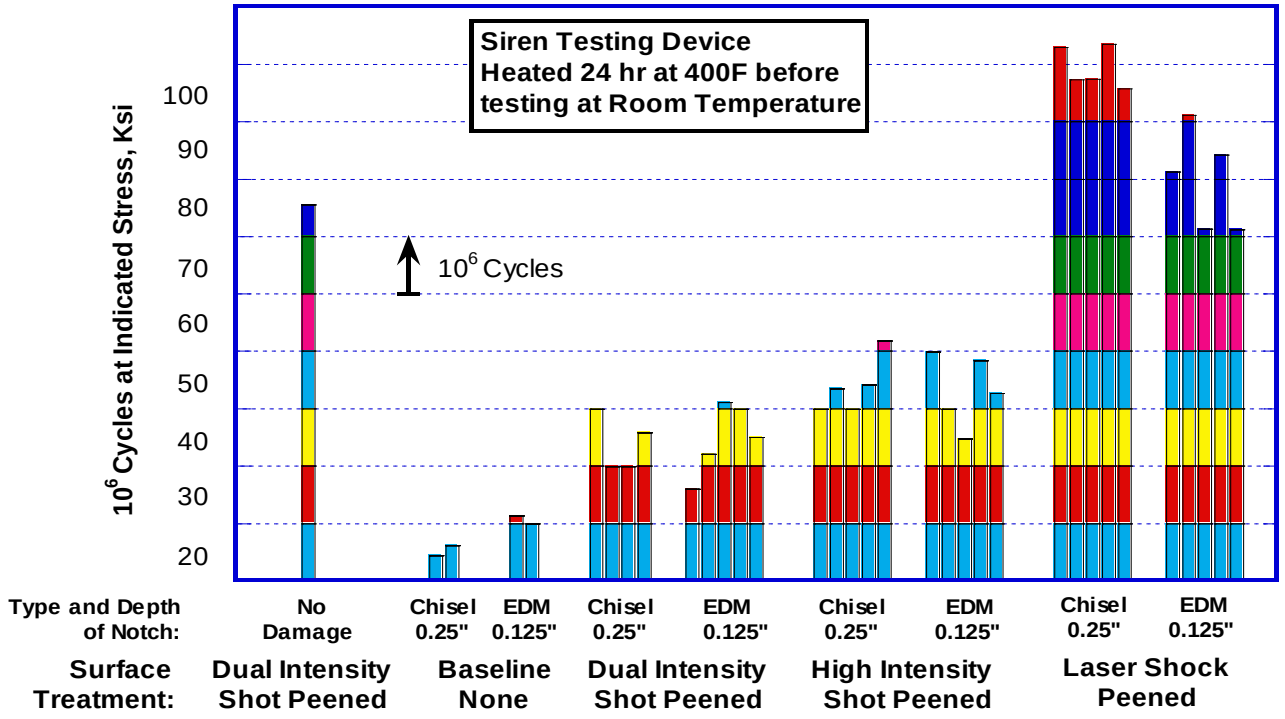
Metal Improvement

- Resistance to FOD (Foreign Object Damage)
- Improved fatigue strength
- Increased fatigue life
- Resistance to crack initiation and propagation
- Resistance to fretting fatigue
- Reduction in stress corrosion cracking

https://www.lsptechnologies.com/metal-failure-types.php

Resistance to Simulated FOD

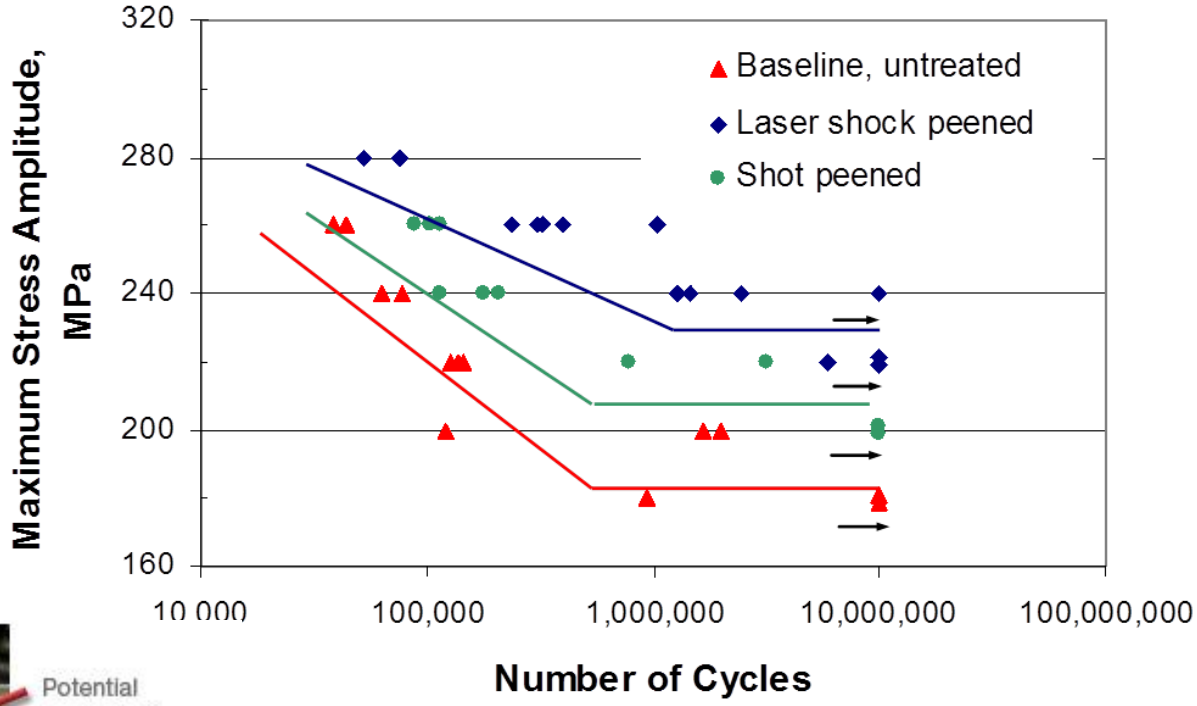
F101 1st Stage Fan Blades



After See, Thompson and Sampson, Air Force Research Laboratory, USAF

Improvement of Fatigue Properties

7050-T7351 Aluminum
4 GW/cm^2
3-point bending,
R=0.1,
Notched: K_t=1.68



After P. Peyre, et al.

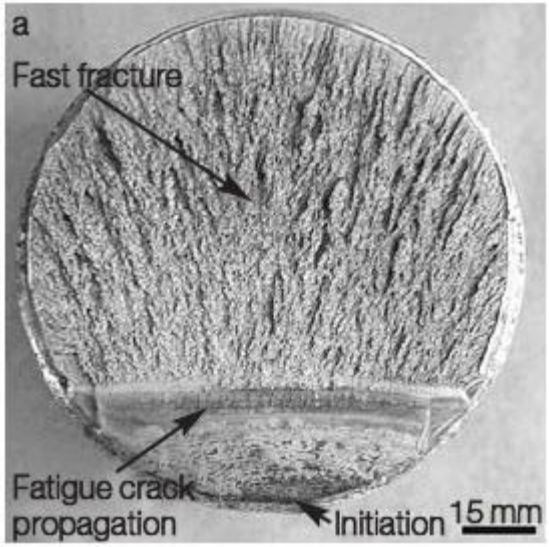
Potential location of cracks forming during high performance applications

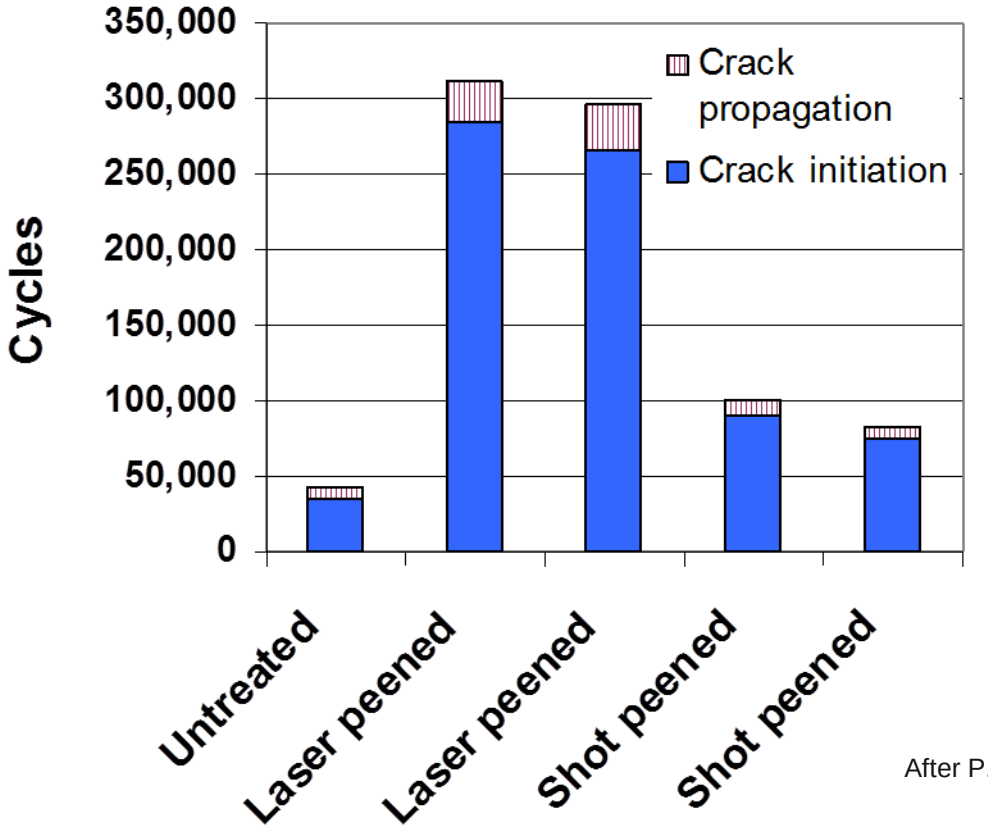
https://www.olympus-ims.com/es/applications/fatigue-crack-detection-marine-propellors/

Resistance to Crack Initiation and Propagation

7050-T7351 Aluminum

s_{max} = 37.7 ksi,
YS 54 to 59 ksi
3-point bending,
R=0.1
Notched: K_t=1.68

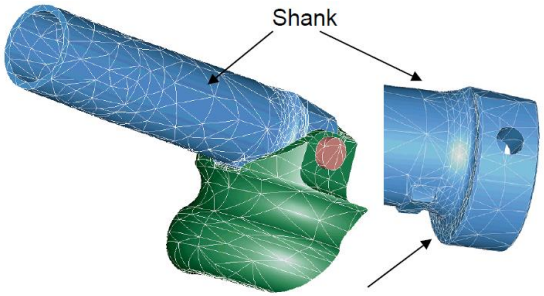




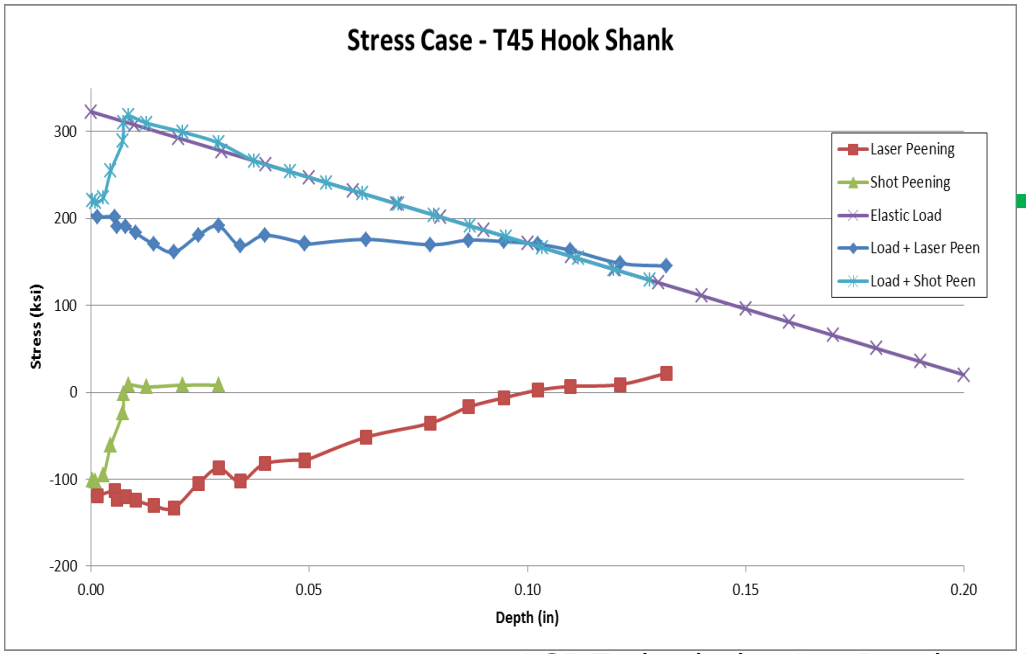
After P. Peyre, et al.

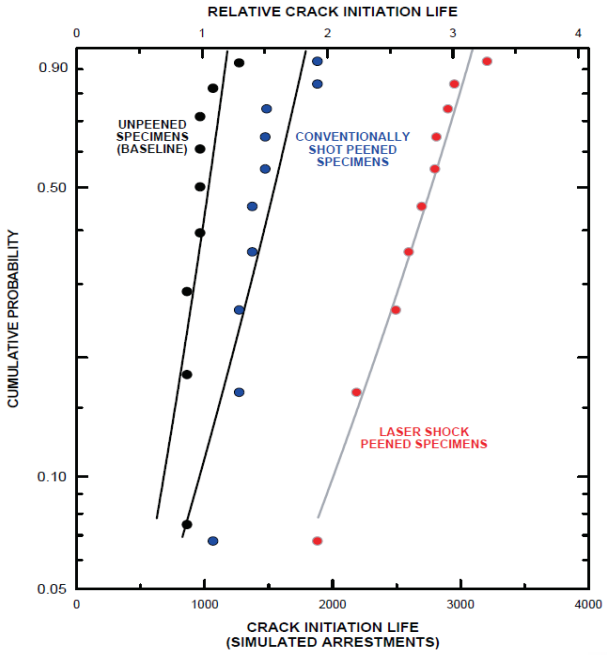
https://www.totalmateria.com/page.aspx?ID=CheckArticle&LN=EN&site=KTS&NM=299

Resistance to Crack Initiation (T-45 Goshawk Arresting Hook)

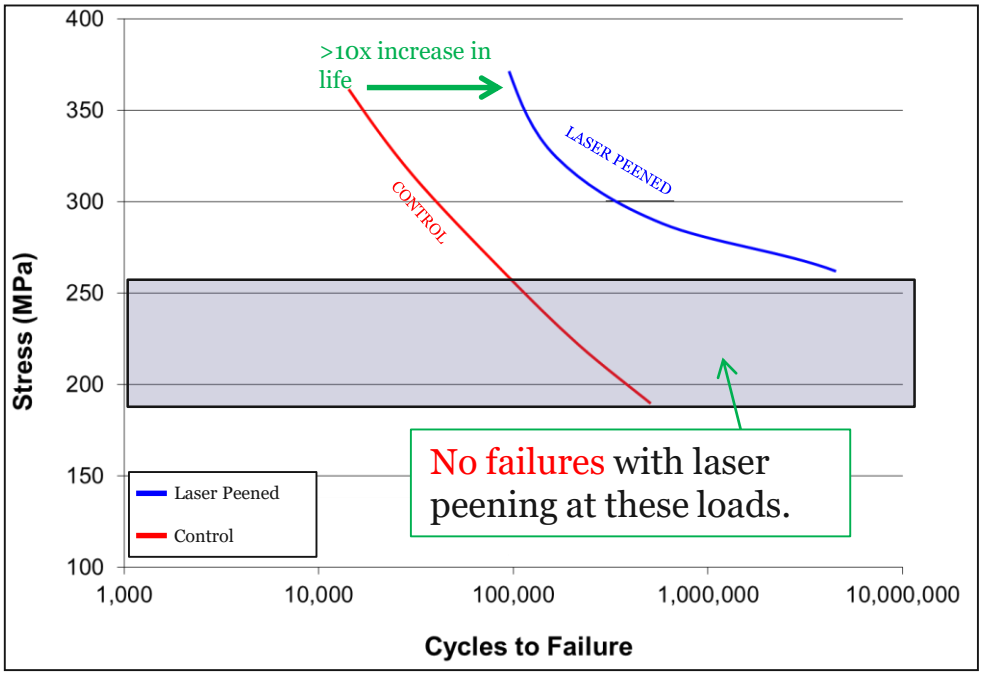


REF: Leap, Fatigue life improvement of arrestment hook shank by laser peening

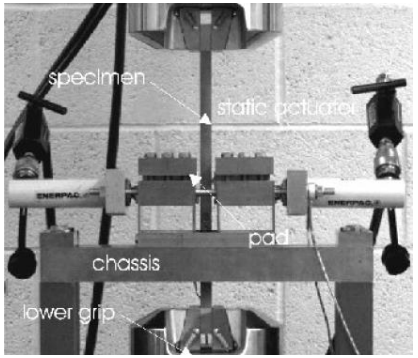


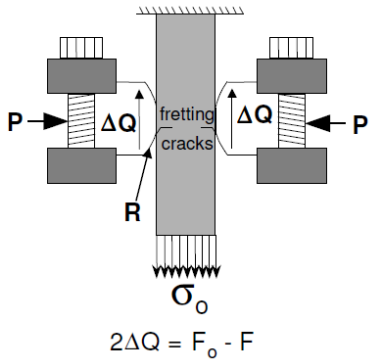


Fretting Fatigue Resistance



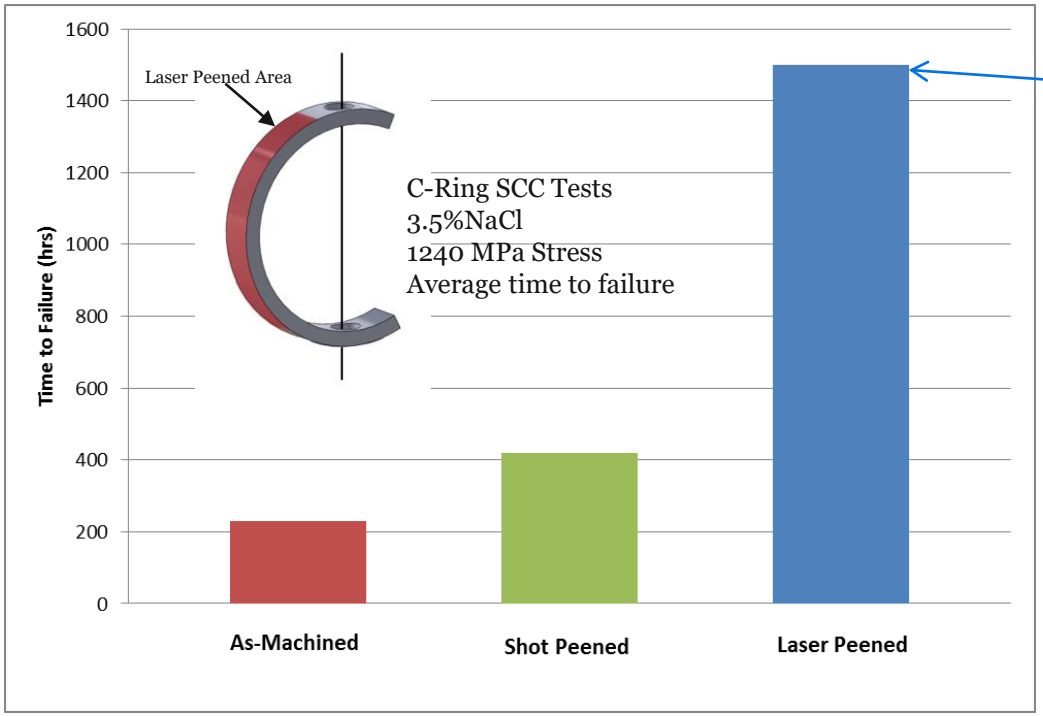
Ti-6Al-4V : very susceptible to fretting, high notch sensitivity





REF: FRETTING R=0.0, LSP OF HIDDEN SURFACES

Stress Corrosion Cracking (SCC) Immunity



Tests stopped after 1500h of no failures with laser peening

High strength steel (54 HRC), extremely susceptible to SCC

REF: PISTOCHINI, EFFECT OF LASER PEENING IN 300M STEEL

http://www.esa.int/spaceinimages/Images/2014/12/Tank_failure_due_to_stress_corrosion_cracking

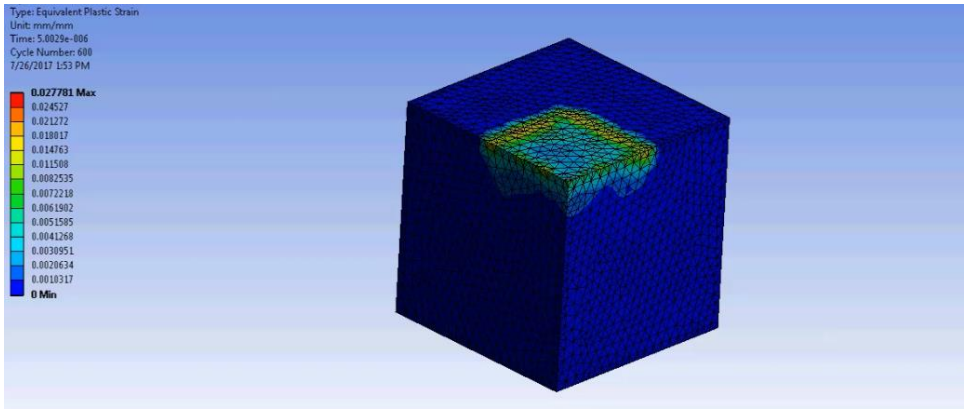
LSP Application Development

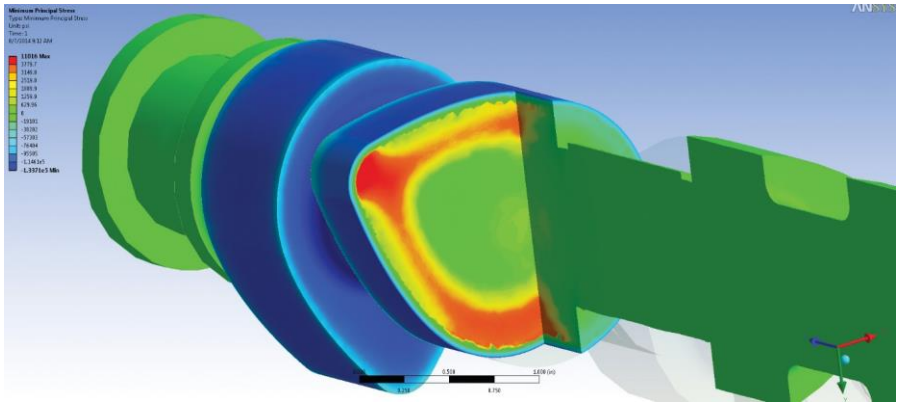
How we develop a solution for parts

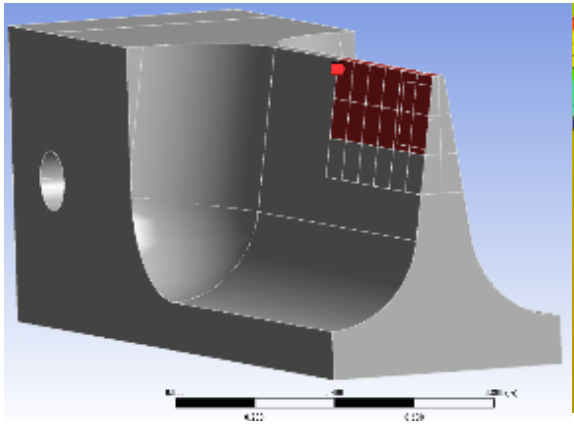
- Modeling industrial shapes
- Fine-tuning parameters
- Benefits for parts
- Return on investment

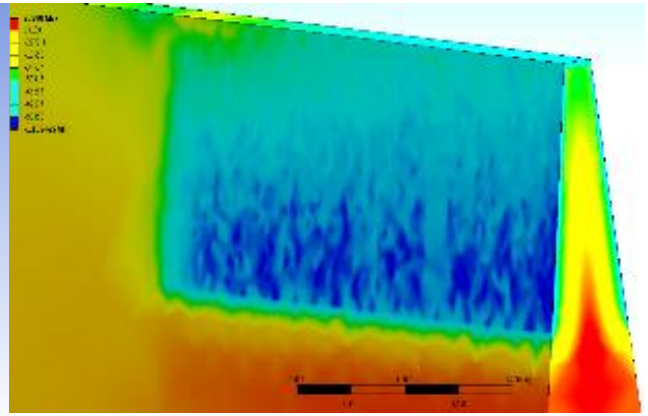
Modeling industrial shapes

- LSP Technologies have the capability to model your components and design laser peening recipes tailored to improve the performance of your parts.



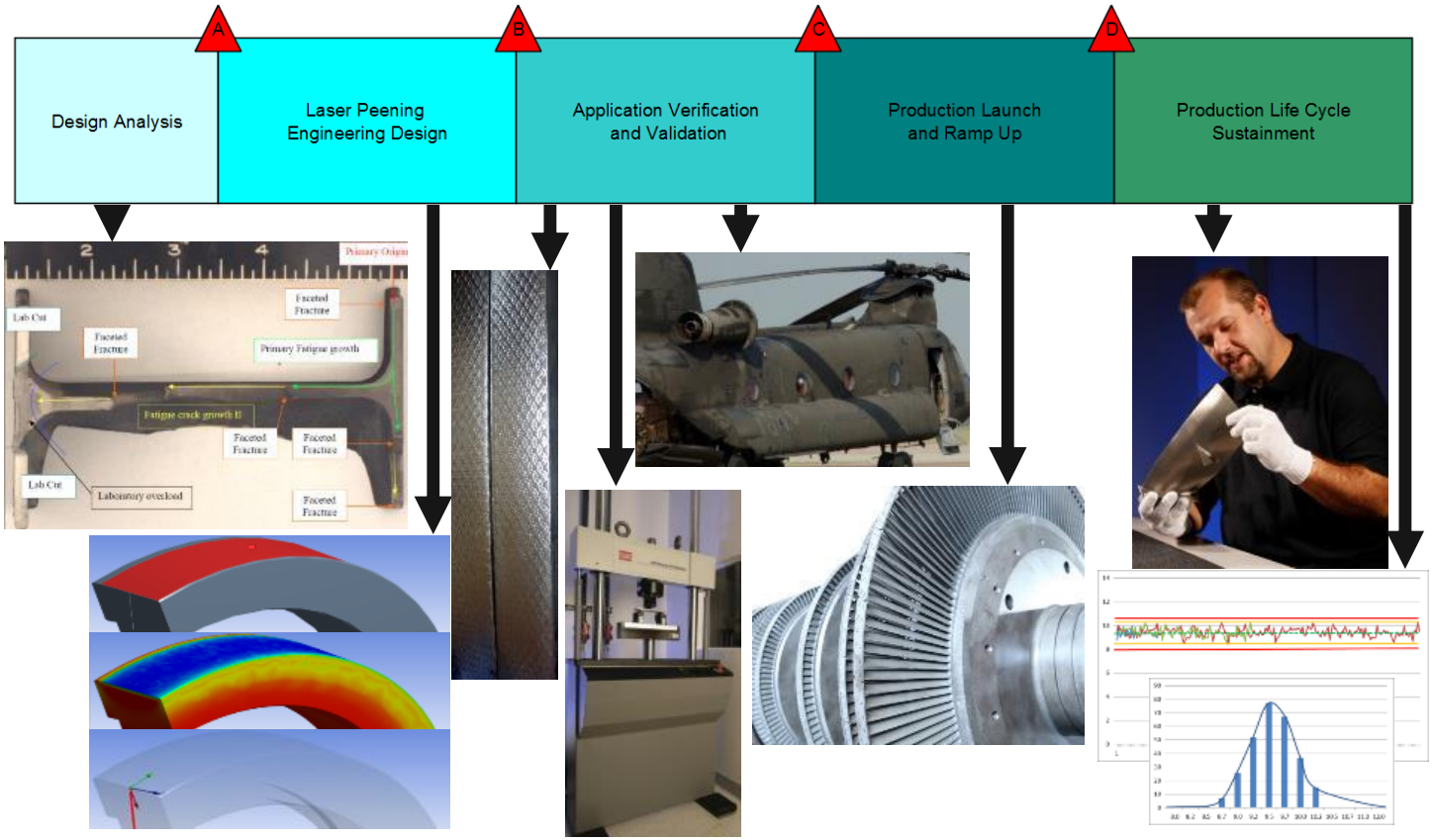






The Laser Peening Process

Development Program Structure



Laser Peening Benefits

Primary (In-service component improvement):

- Fatigue crack prevention (initiation and propagation)
- Stress corrosion cracking prevention
- Increase damage tolerance (FOD)
- Fretting fatigue prevention

Secondary (Future component design):

- Use less expensive alloys and obtain same performance as premium alloys
- Enable higher performance designs
  - Increase flexibility
  - Increase efficiency
  - Lighter materials

Surface Enhancement – Return on Investment

Why add cost to a part?

How much does surface enhancement cost?
Often less than 1% of the part cost

How long is service life extended?
Often between 2-5x the original part life

Surface enhancement reduces:

- Total lifecycle cost
- Replacement parts
- Maintenance cost
- Inspection cost
- Downtime
- Risk to system
- Risk to personnel

Surface enhancement increases:

- Part life
- System safety
- System readiness
- System reliability
- Repair effectiveness

Quality Commitment

LSP Technologies, Inc. is dedicated to meeting all of our customers' requirements with high-quality laser services and equipment. We are committed to complying with the requirements of our quality management system and continually improving its effectiveness.

- AS9100 Certified since 2004
- Compliant with General Electric's quality system
- Compliant with Pratt & Whitney's quality system
- Committed to Continuous Improvement

QUESTIONS?

To learn more about laser peening and LSP Technologies, please visit our website:

http://www.lsptechnologies.com

We can also be reached via phone and e-mail for any questions you have regarding the process and potential applications. Contact:

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