Laser Shock Peening of Bulk Metallic Glasses – Part 1

Center for Laser Applications
UT Space Institute
Tullahoma, TN 37388-9700
http://www.utsi.edu

Midterm Presentation **MSE516: Mechanical Metallurgy**

Deepak Rajput

Email: drajput@utsi.edu / **Web:** http://drajput.com

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Outline

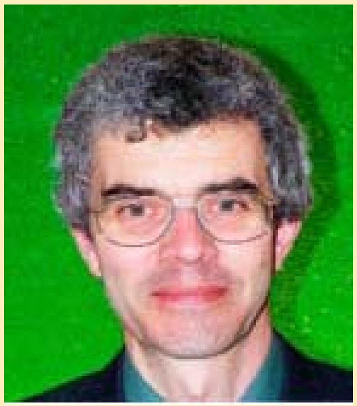
- Importance of surface and its relation to failures
- Surface improvement techniques
- Laser Shock Peening
    - history, process, layout, examples, etc.
- Experiment planned
- References

Team Members

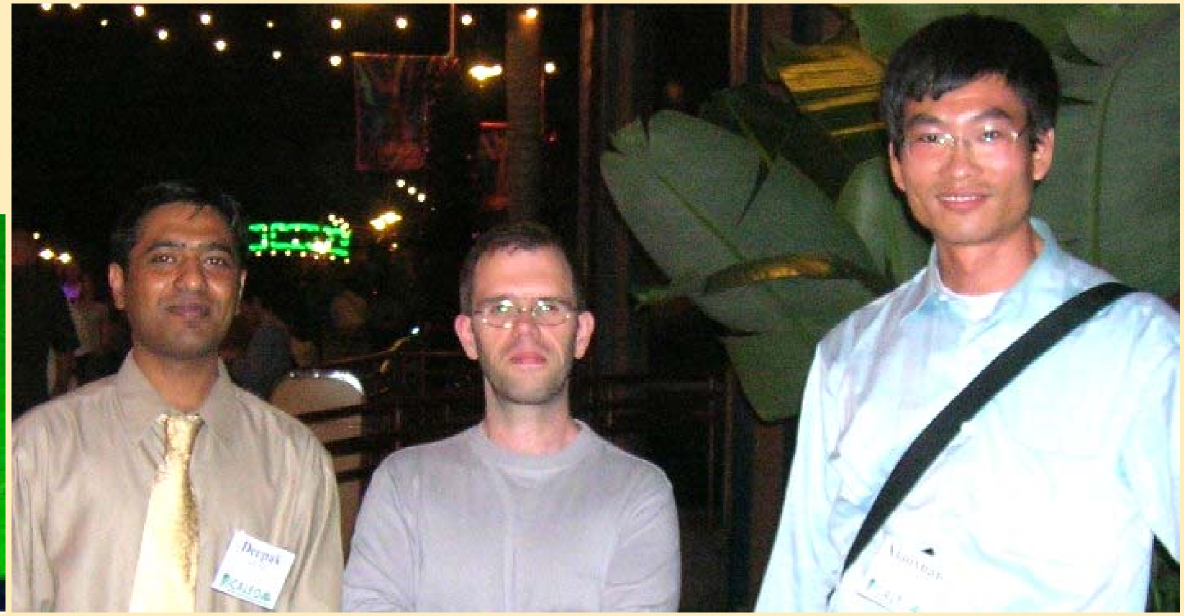
Center for Laser Applications

THE UNIVERSITY of TENNESSEE
Space Institute

Kate Lansford



Alexander Terekhov



Deepak Rajput Dr. Lino Costa Dr. Xiaoxuan Li

Dr. Hofmeister
Director, CLA
UT Space Institute

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Failure: Why & How?

- Nearly all the fatigue and stress corrosion failures originate at the surface of the component. (long term failures)

- Surface of a material (or material near the surface) has unique properties. Surface grains deform plastically at lower stress level than those interior grains that are surrounded by neighboring grains because they are subject to less constraint.

(a) dislocations terminating at a clean surface will move under a lower stress than those internal dislocations which are anchored at both the ends.

(b) minute surface irregularities act as dislocation sources.

Due to these reasons mechanical failures mostly occur/initiate on the surface. Hence, surface plays a vital role in the service of a component.

Failure: Why & How?

Cont..

- In most modes of long-term failure, the denominator is tensile stress.
- Tensile stresses attempt to stretch or pull the surface apart and may eventually lead to crack initiation.
- Because crack growth is slowed significantly in a compressive layer, increasing the depth of this layer increases crack resistance.

Prevention Idea: Generate compressive stresses on the surface.

Peening

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Peening: Generation of Compressive Stresses

Mechanical working of materials:

- Hammer ⇒ **Although obsolete, it is still used today in the hand manufacture of high quality cutting blades**
- Shots
- Laser

380 mm ball-peen hammer

Peening: Generation of Compressive Stresses Cont.

- Shot peening is a cold working process in which small spherical media called ***shot*** bombard the surface of a part.
- During the shot peening process, each piece of shot that strikes the material acts as a tiny peening hammer, imparting to the surface a small indentation or dimple.
- To create the dimple, the surface of the material must yield in tension.
- Below the surface, the material tries to restore its original shape, thereby producing below the dimple, a hemisphere of cold-worked material highly stressed in compression.
- The overlapping dimples from shot peening create a uniform layer of compressive stress at metal surfaces.

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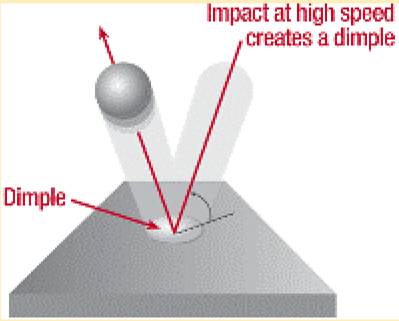
Peening: Generation of Compressive Stresses Cont.

- Shot peening provides considerable increases in part life because cracks do not initiate or propagate in a compressively stressed zone.

- Compressive stresses are beneficial in increasing resistance to fatigue failures, corrosion fatigue, stress corrosion cracking, hydrogen assisted cracking, fretting, galling and erosion caused by cavitation.

- The maximum compressive residual stress produced just below the surface of a part by shot peening is at least as great as one-half the yield strength of the material being shot peened.



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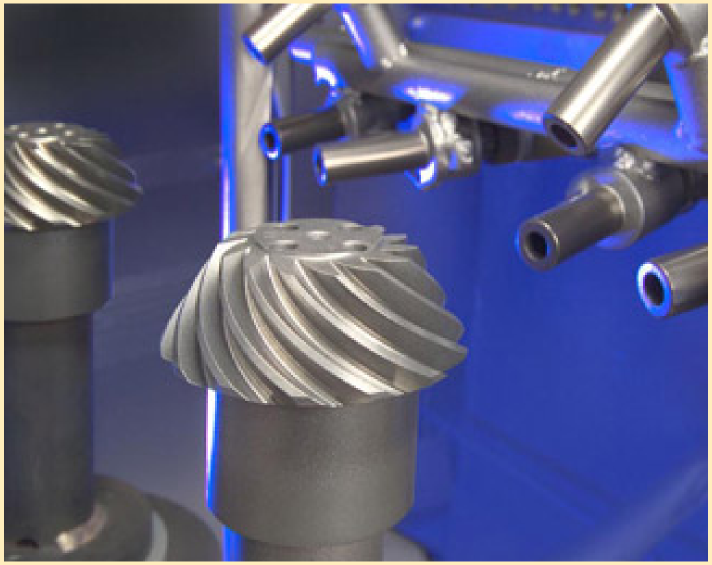
Peening: Generation of Compressive Stresses Cont.



Shot peened gear
Metal Imrovement Company
Paramus, New Jersey

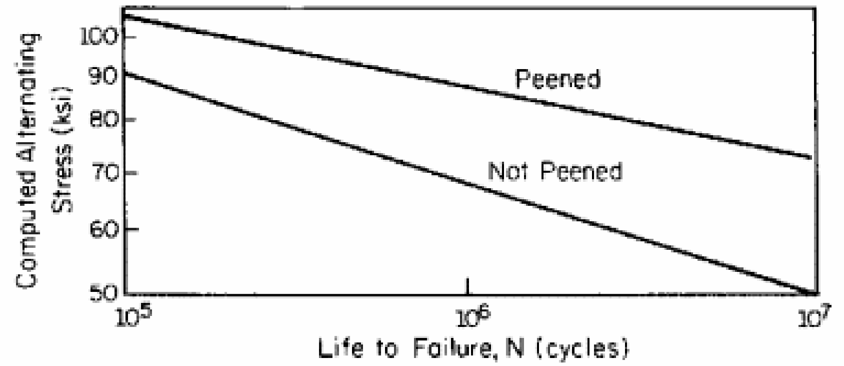


Figure 1.23 *S–N* curve of carburized gears in peened and unpeened conditions. (From Ref. 12.)

J.A. Bannantine, J.J. Comer and J.L. Handrock. Fundamentals of Metal Fatigue Analysis. Prentice-Hall, 1990.

Problem: Leaves surface dimpling

Peening: Generation of Compressive Stresses Cont.

Laser Peening or Laser Shock Peening (LSP):

"A process that induces residual compressive stresses on the surface of a component due to **shock waves** produced by plasma"

"**Four times deeper** than that obtainable from a conventional Shot Peening process"

Prototype Laser Peening machines were developed in the **1970s**.

Laser Shock Peening

Historical background:

William I. Linlor
Hughes Research Laboratories
Malibu, California

Linlor, W.I. (1962) "Plasma Produced by Laser Bursts" *Bull. Am. Phys. Soc.* **7**, 440

Ready, J.F., (1963) "Development of Plume of Material Vaporized by Giant Pulse Laser", *Appl. Phys. Letters* **3** (1), pp 11-13

giant pulse investigation, carbon plume speed in air

Linlor, W.I. (1963) "Ion Energies Produced by Laser Giant Pulse", *Appl. Phys. Letters* **3** (11), pp 210-211

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Laser Shock Peening

Process:

❖ Specimen is coated with a black paint which is opaque to laser beam.

❖ It acts as sacrificial material and is converted to high pressure plasma as it absorbs energy from a high intensity laser (1-10 GW/cm^2) for very short time durations (<50 ns).

❖ Generally, specimen is submerged in a transparent media like water or glass plate so that the rapidly expanding plasma cannot escape and the resulting shock wave is transmitted into the specimen subsurface.

❖ Shockwaves thus produced can be much larger than the dynamic yield strength of the material (>1 GPa) and cause plastic deformation to the surface and compressive residual stresses (~1 mm).

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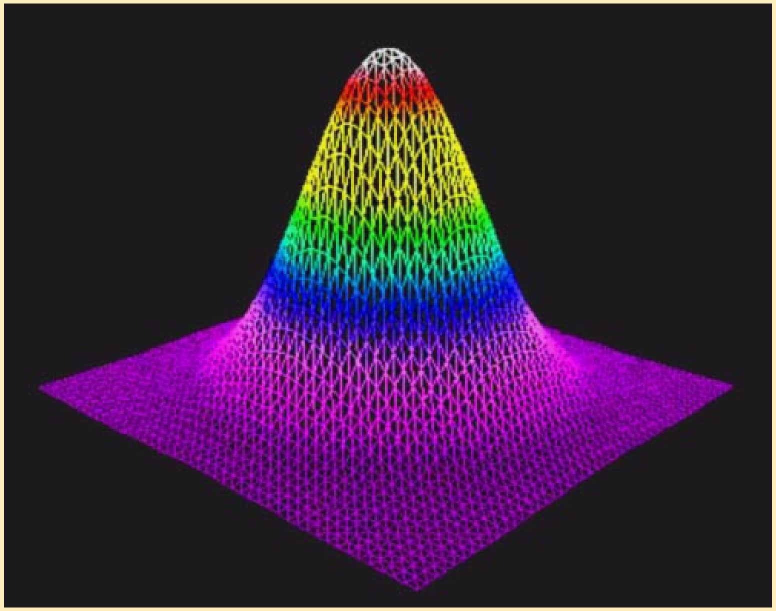
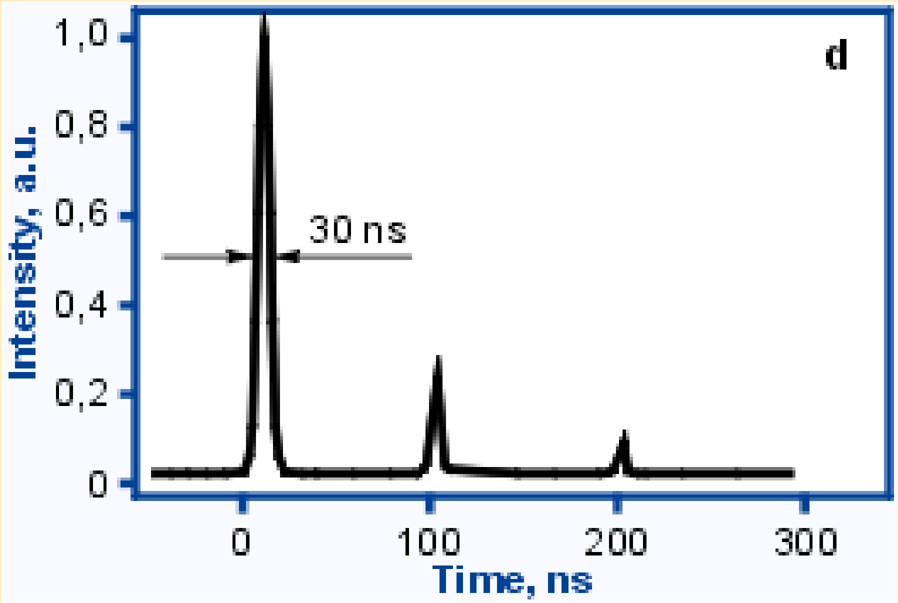
Laser Shock Peening

Laser used is always a Pulsed Laser

- Ability to deliver very high fluence (J/cm^2) at shorter time scales (<50 ns)
- High repetition rates



Spatial resolution



Temporal resolution

Gaussian Laser Beam Profile

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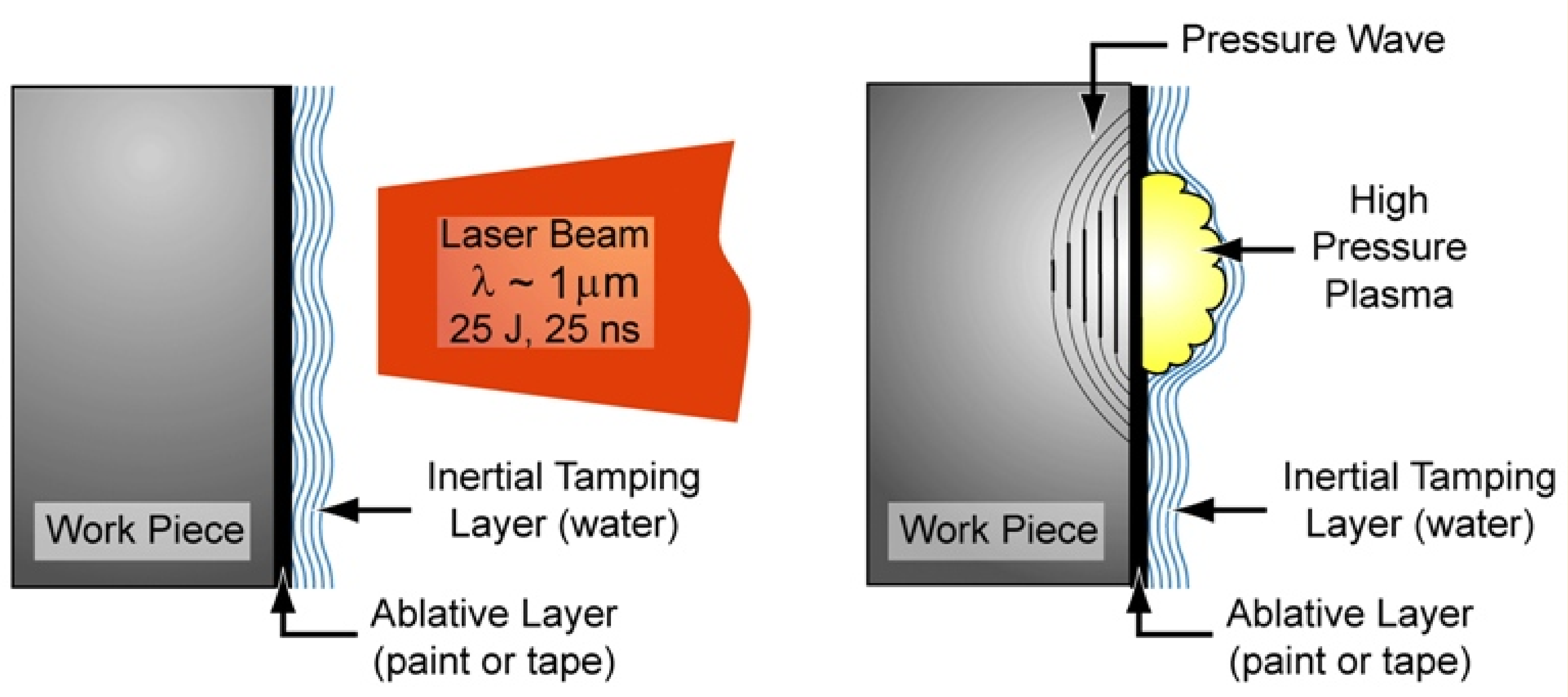
Laser Shock Peening

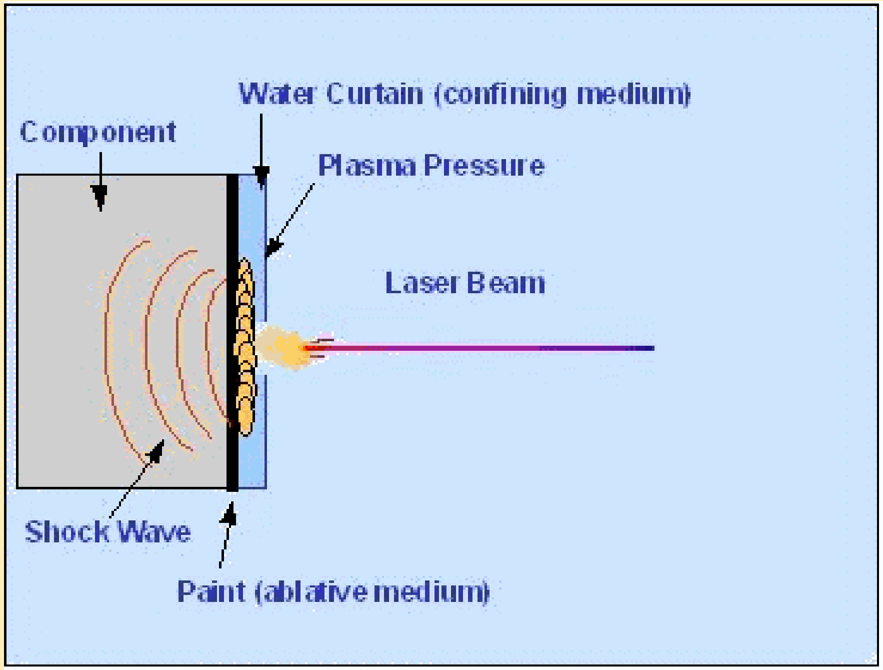
Process layout



Taken from Metal Improvement Company website
(http://www.metalimprovement.com/laser_peening.php)

Laser Shock Peening

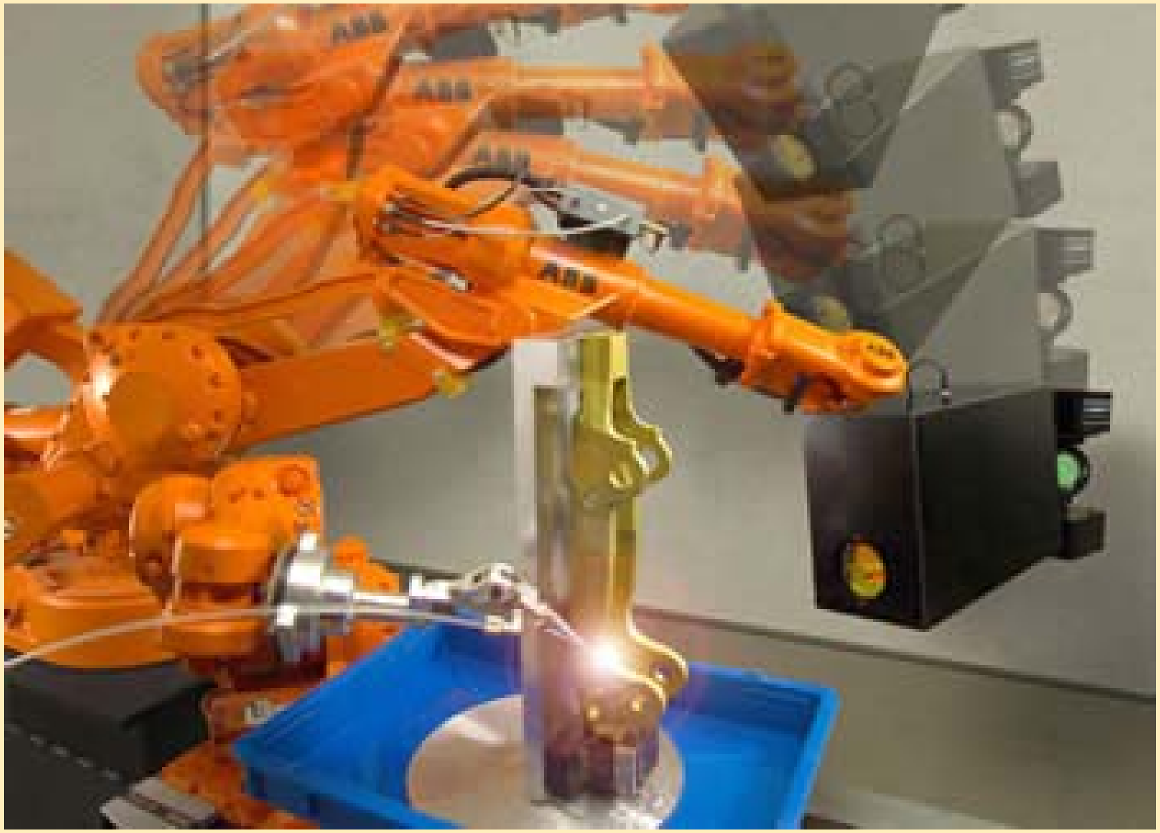
Research @ Purdue University



Dr. Yung C. Shin (Professor)
Laser-Assisted Materials Processing Laboratory (LAMPL)
School of Mechanical Engineering
Purdue University, West Lafayette, Indiana

Laser Shock Peening

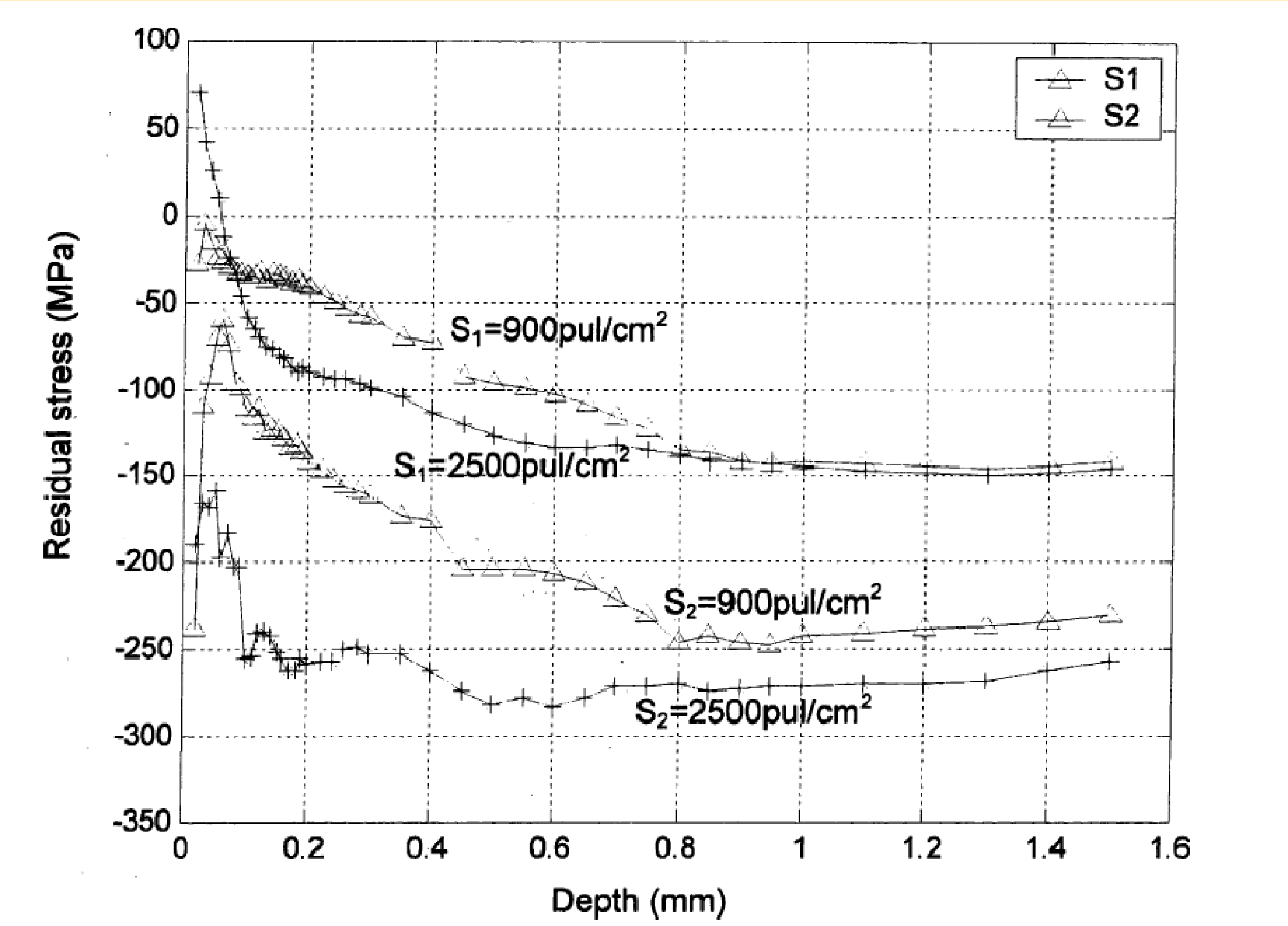
Example: Robot controlled LSP



Taken from Metal Improvement Company website
(http://www.metalimprovement.com/laser_peening.php)

Laser Shock Peening

Laser Shock Peening of 6061-T6 Aluminum Alloy



Rubio-Gonzalez C. et al. (2004), "Effect of Laser Shock Processing on Fatigue Crack Growth and Fracture Toughness of 6061-T6 Aluminum Alloy", *Mat. Sci. Eng. – A,* 386: 291-295

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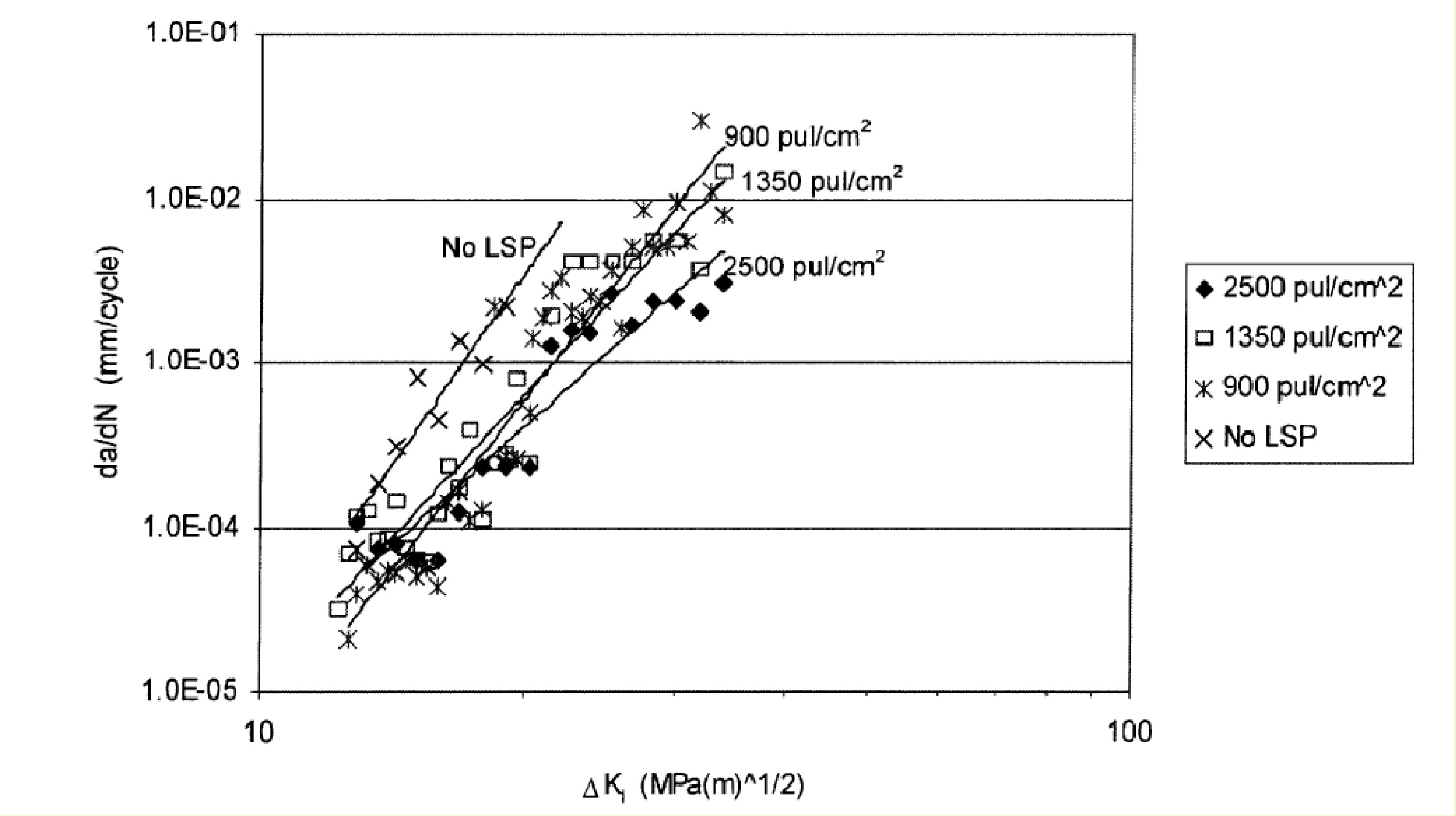
Laser Shock Peening

Laser Shock Peening of 6061-T6 Aluminum Alloy

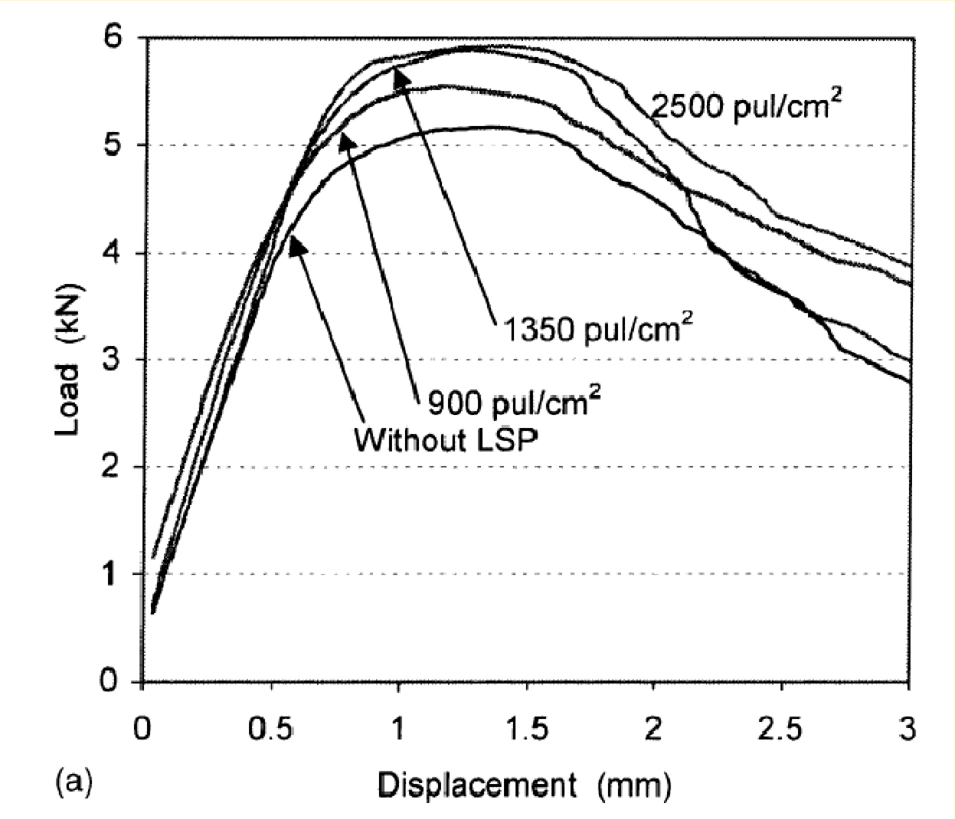


Fatigue crack growth rates with and without LSP under different pulse densities

Rubio-Gonzalez C. et al. (2004), “Effect of Laser Shock Processing on Fatigue Crack Growth and Fracture Toughness of 6061-T6 Aluminum Alloy”, Mat. Sci. Eng. – A 386: 291-295

Laser Shock Peening

Laser Shock Peening of 6061-T6 Aluminum Alloy



Load-displacement curves to determine fracture toughness

Rubio-Gonzalez C. et al. (2004), "Effect of Laser Shock Processing on Fatigue Crack Growth and Fracture Toughness of 6061-T6 Aluminum Alloy", Mat. Sci. Eng. – A 386: 291-295

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Laser Shock Peening

An increase in fatigue strength is accompanied by:

- the creation of large magnitudes of compressive residual stresses and
- the increased hardness

which develop in the subsurface!

The transient shock waves can also induce:

- microstructure changes near the surface
- cause high density of dislocations to be formed

⇨ Microstructure changes + Dislocation entanglement = Improved mechanical properties

Problem at hand: BMG

Poor tensile ductility of Bulk Metallic Glasses

- **Work- softening**
- **Shear localization**

Idea = Control of Residual Stress

<u>Genesis:</u> Zhang Y., Wang W.H., and Greer A.L, (2006) “Making Metallic Glasses Plastic by Control of Residual Stress”, *Nature Materials*, Vol 5, pp 857-860

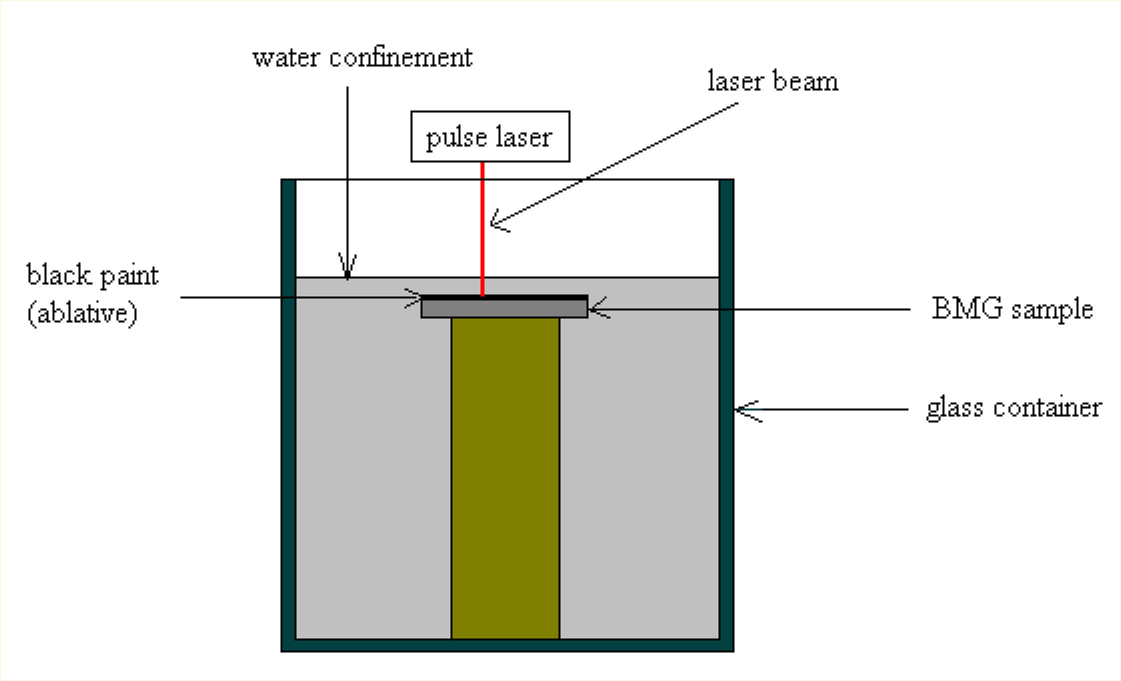
BMG studied : Vitreloy 1
Process used: Shot Peening

Planned Experiment

Laser Shock Peening of Cu-based Bulk Metallic Glasses

Suggested Laser: Excimer laser (λ = 337 nm)

Planned Layout:



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- Wang H., Xijun S., and Li X. (2003). "Laser Shock Processing of an Austenitic Stainless Steel and a Nickel-base Superalloy", *J. Mater. Sci. Technol.*, 19(5): 402-404
- Zhang Y., Wang W.H., and Greer A.L, (2006) "Making Metallic Glasses Plastic by Control of Residual Stress", *Nature Materials*, Vol 5, pp 857-860
- Rubio-Gonzalez C. et al. (2004), "Effect of Laser Shock Processing on Fatigue Crack Growth and Fracture Toughness of 6061-T6 Aluminum Alloy", *Mat. Sci. Eng. – A,* 386: 291-295

Questions ?

Thank You

for your patience

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