Laser Shock Processing of Welded Joints for Mechanical Properties Improvement

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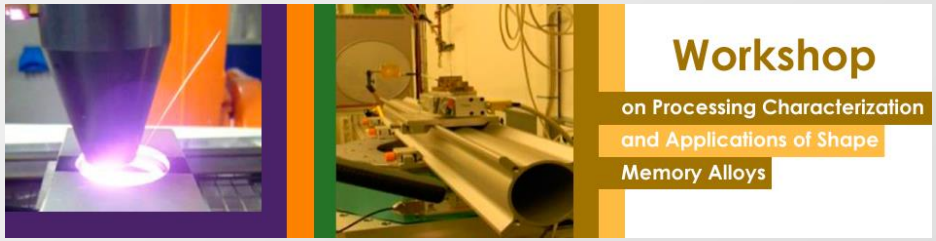

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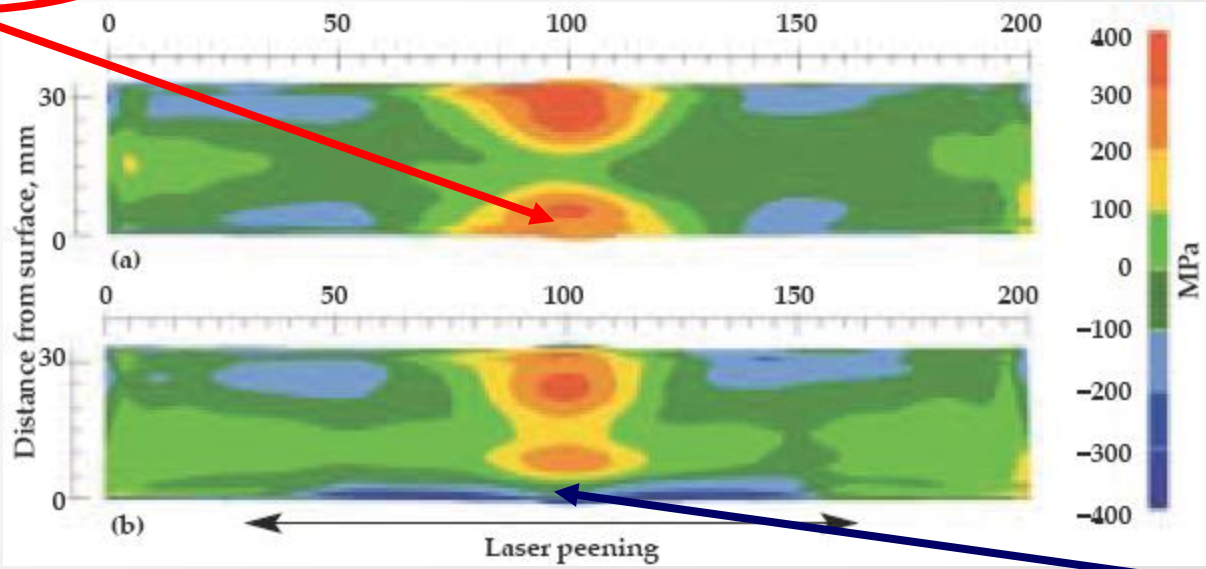
1. Introducción
2. Process Description
3. Experimental Setup & Procedure
4. Some Preliminary Results
5. Discussion & Outlook

Introduction

The Problem



The Solution

Introduction

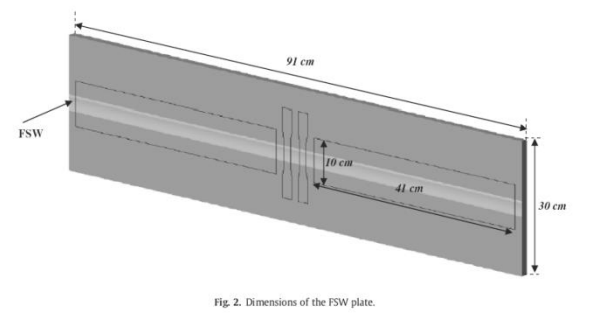


Fig. 2. Dimensions of the FSW plate.

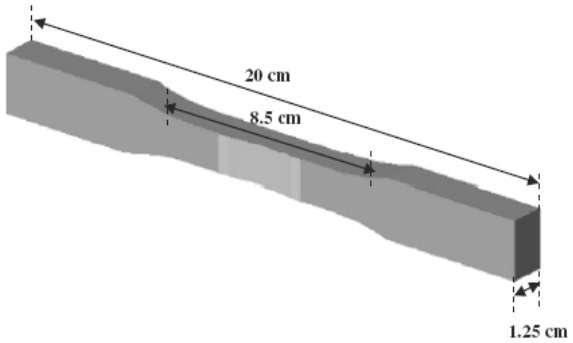
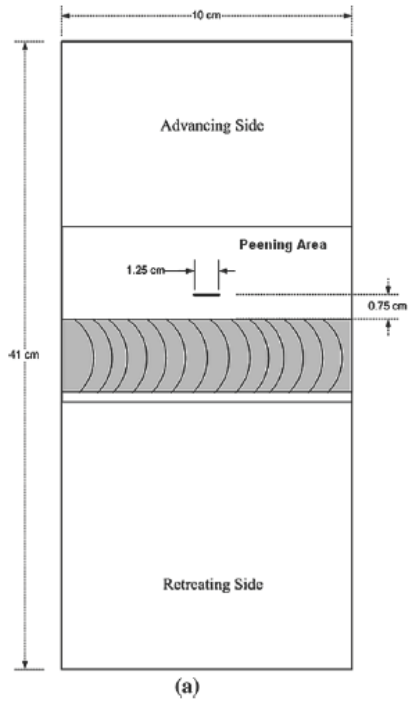


Fig. 4. Dimensions of the tensile specimen.



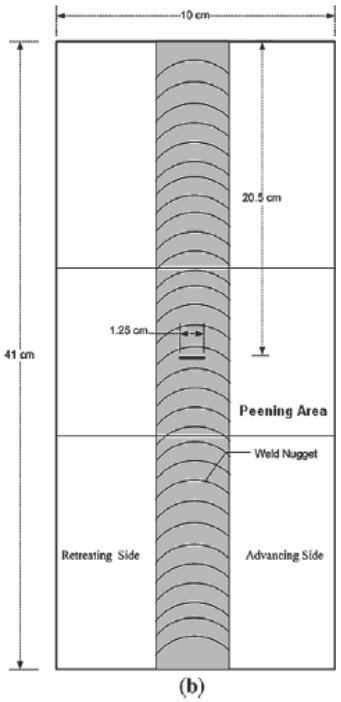


Fig. 2. Fatigue test coupons configurations: (a) Configuration I and (b) Configuration II.

O. Hatamleh et al. / International Journal of Fatigue 29 (2007) 421–434

Introduction

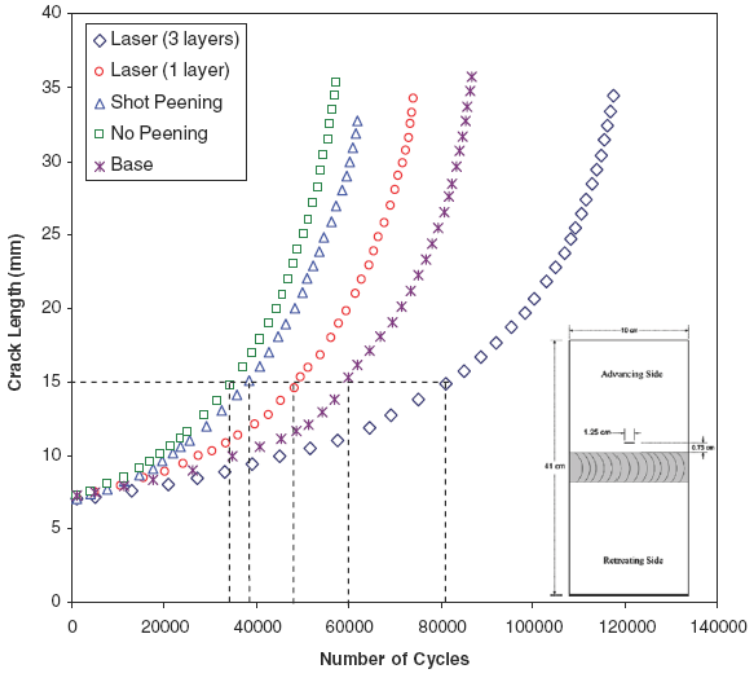


Fig. 10. Results for crack length vs. number of cycles for FSW 7075-T7351 using Configuration I (T-L) specimens.

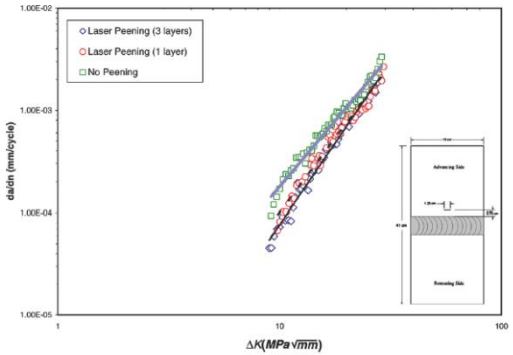


Fig. 12. Crack growth rates for Configuration I (T-L) in FSW 7075-T7351.

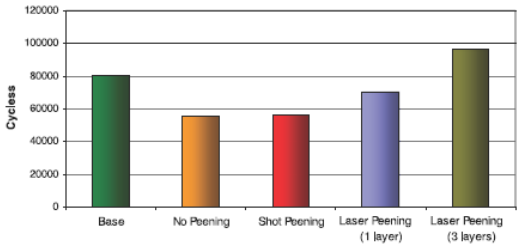


Fig. 14. Number of cycles to grow a 25 mm crack from on side of the EDM Notch for Configuration I (T-L) in FSW 7075-T7351.

O. Hatamleh et al. / International Journal of Fatigue 29 (2007) 421–434

Introduction

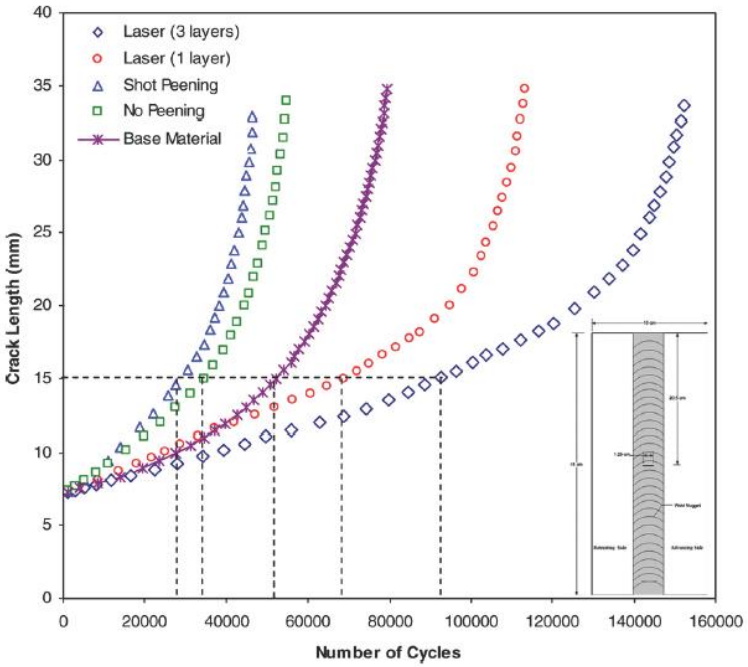


Fig. 15. Results for crack length vs. number of cycles for FSW 7075-T7351 using Configuration II (L-T) specimens.

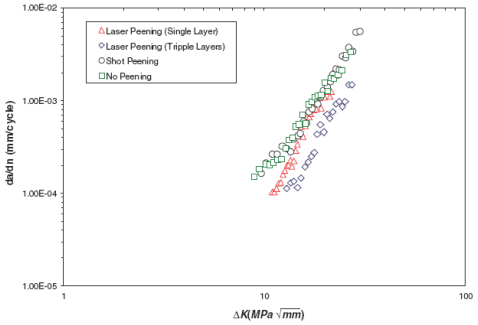


Fig. 17. Crack growth rates for Configuration II (L-T) specimens in FSW 7075-7351.

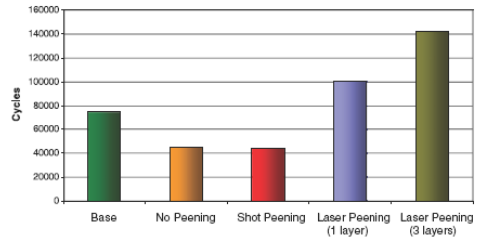
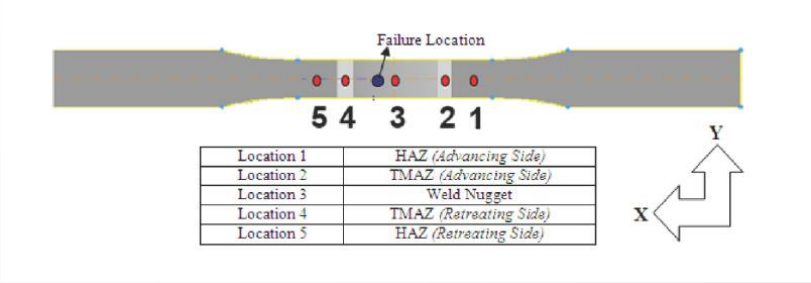


Fig. 19. Number of cycles to grow a 25 mm crack from on side of the EDM Notch for Configuration II in FSW 7075-T7351.

O. Hatamleh et al. / International Journal of Fatigue 29 (2007) 421–434

Introduction



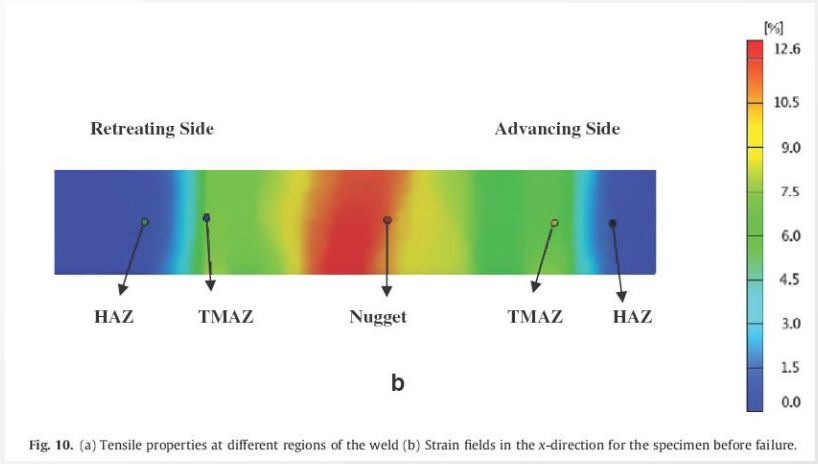


Fig. 10. (a) Tensile properties at different regions of the weld (b) Strain fields in the *x*-direction for the specimen before failure.

O. Hatamleh / International Journal of Fatigue xxx (2008) xxx–xxx

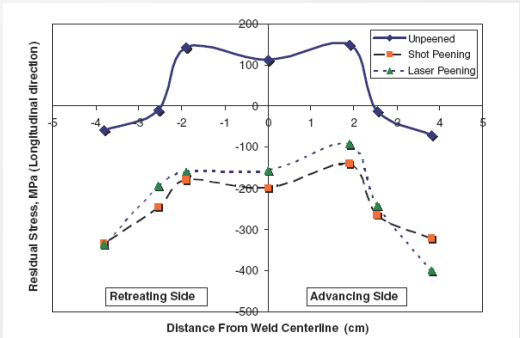


Fig. 11. Residual stresses for the various peened FSW specimens.

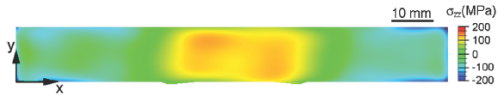


Fig. 12. Two-dimensional map of the measured residual stress for the unpeened FSW specimen.

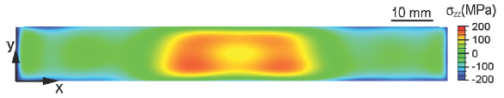


Fig. 13. Two-dimensional map of the measured residual stress for the shot peened FSW specimen.

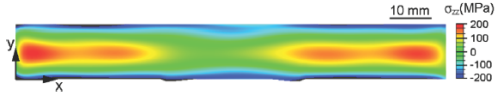
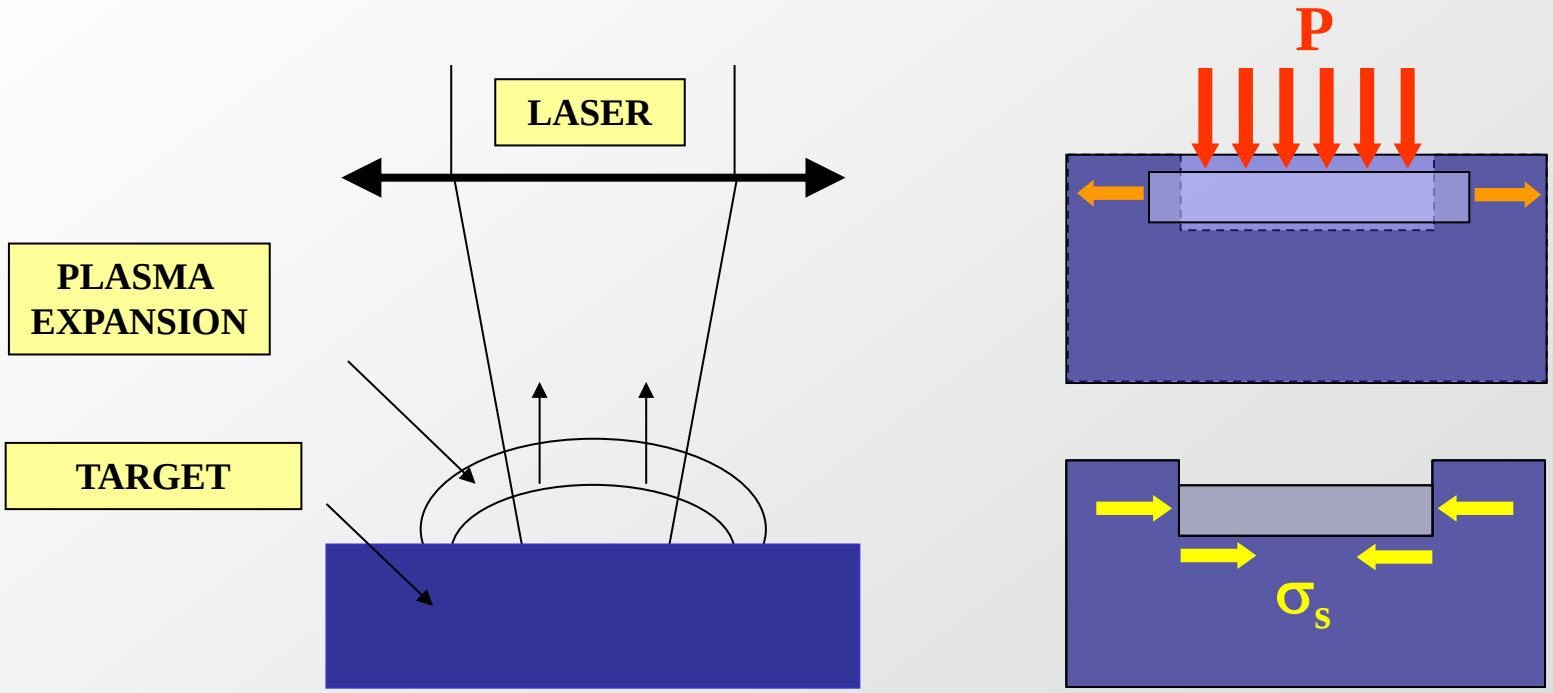


Fig. 14. Two-dimensional map of the measured residual stress for the laser peened FSW specimen.

LSP Technique for Materials Properties Improvement
Process Description



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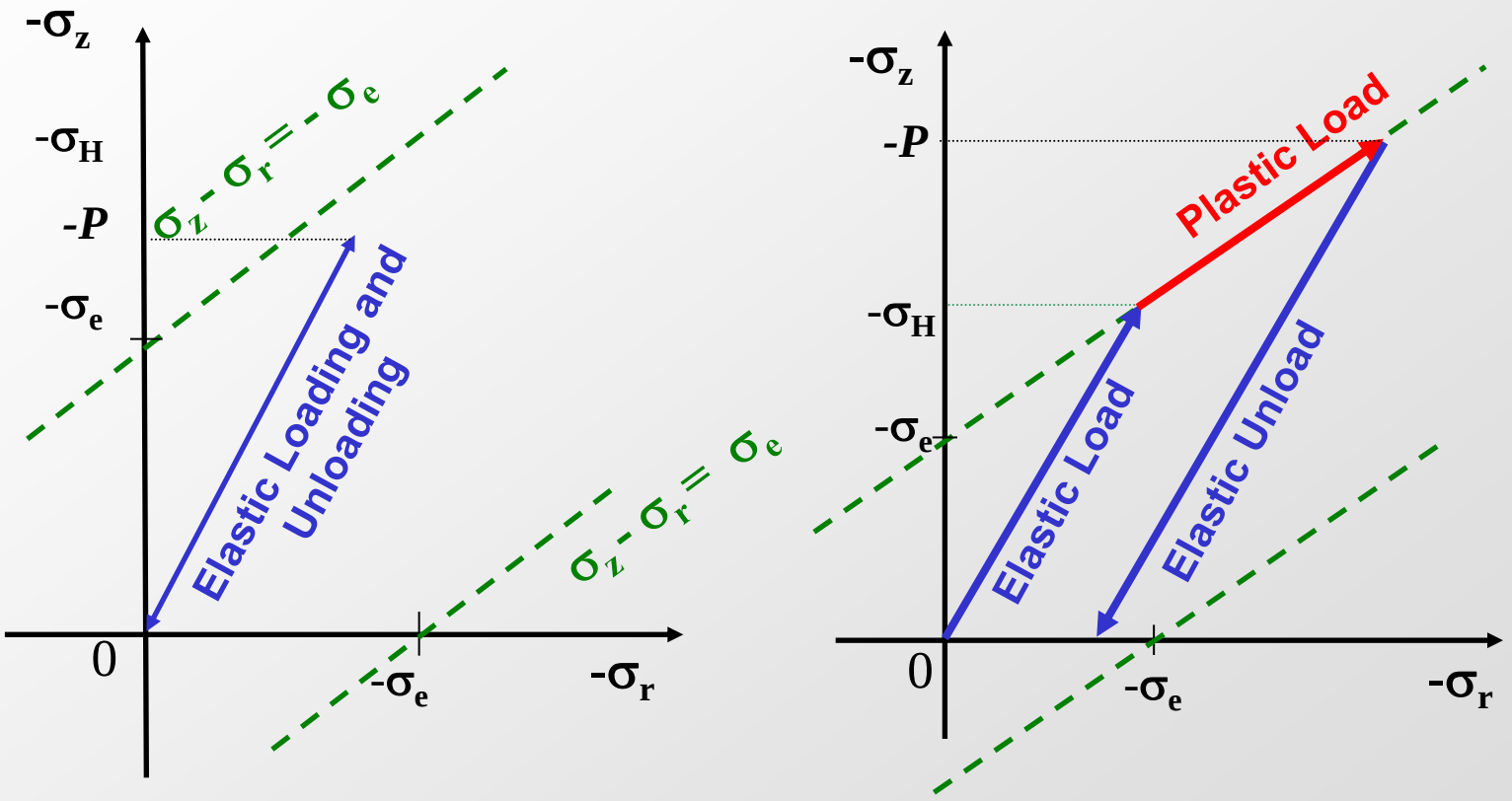
Process Description



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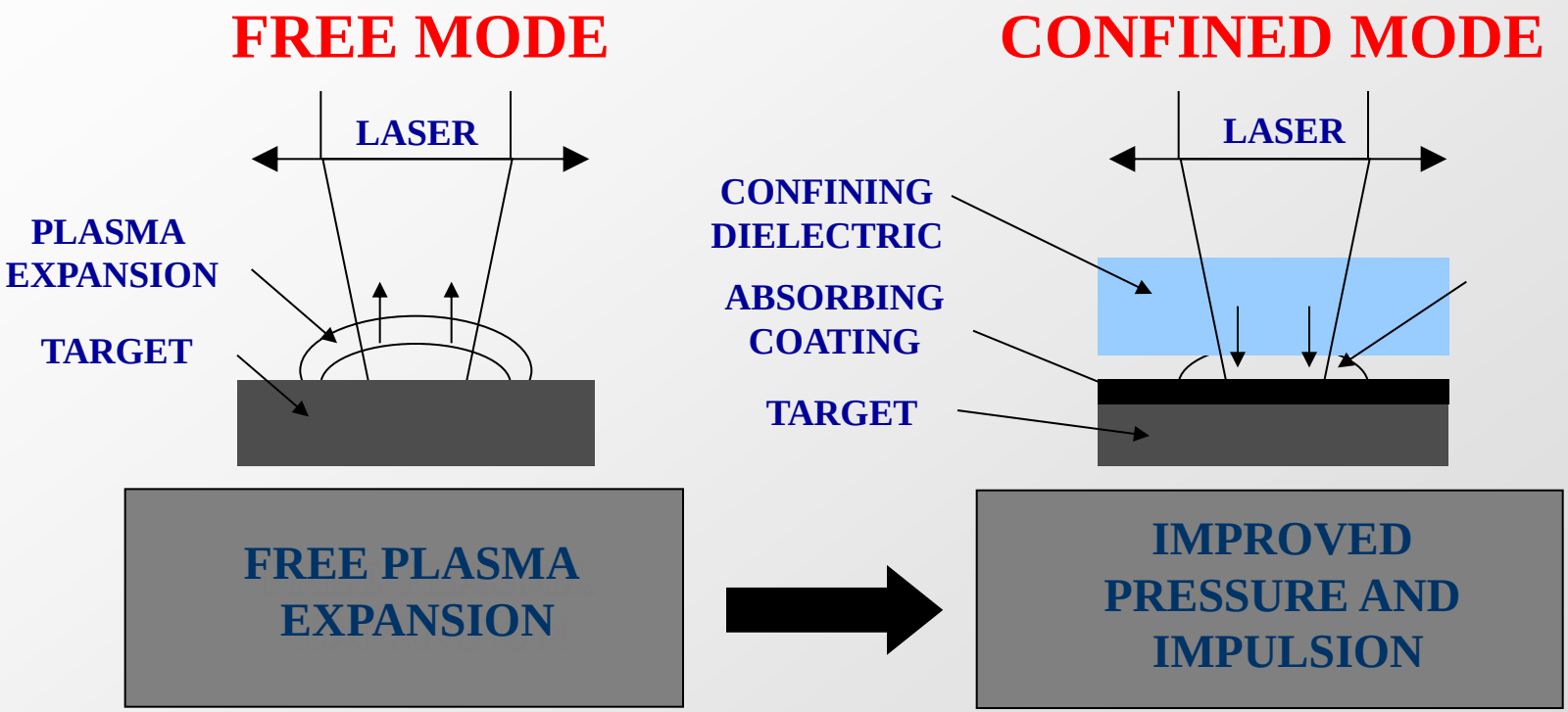
Process Description



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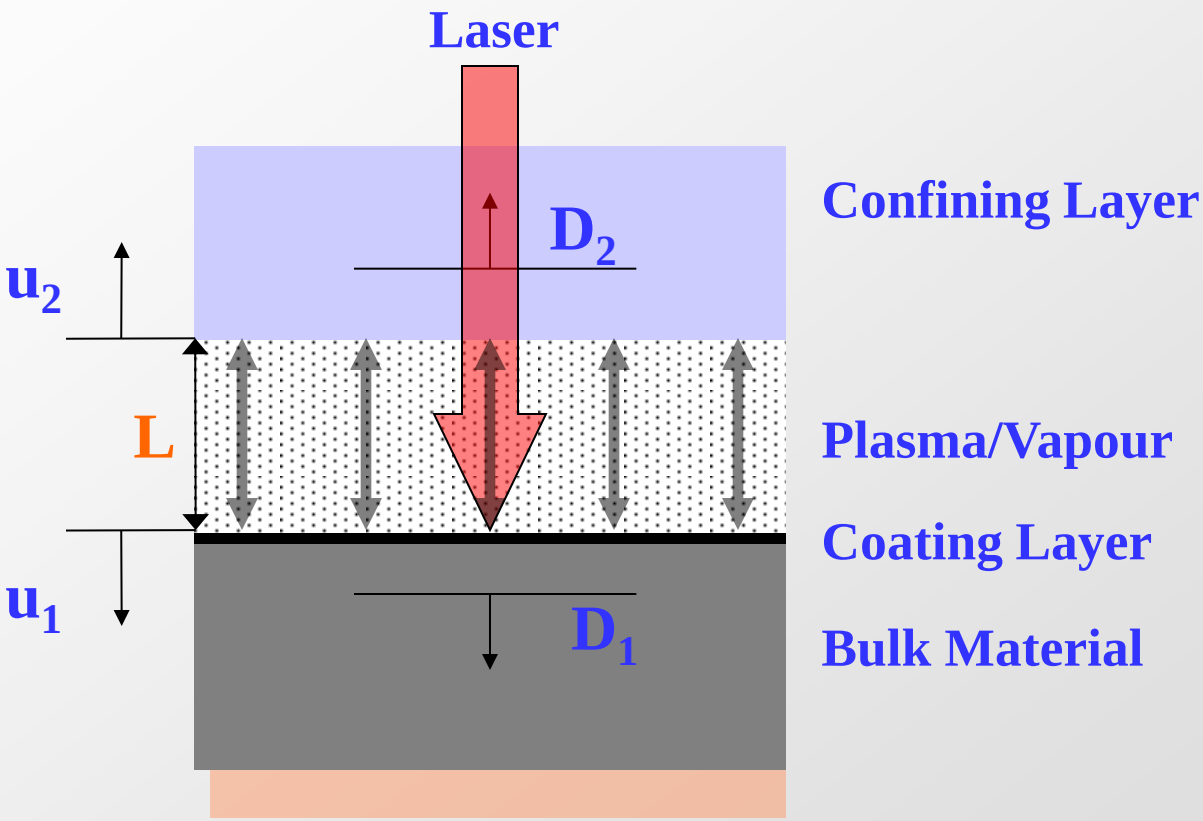

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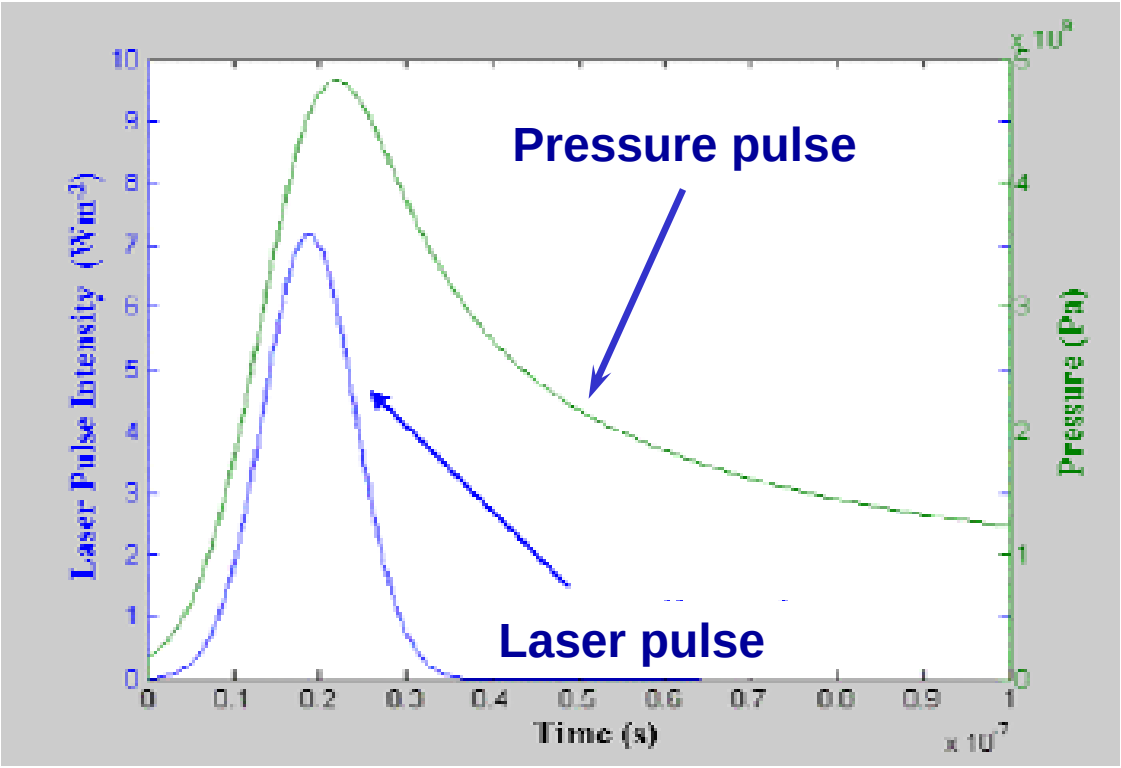
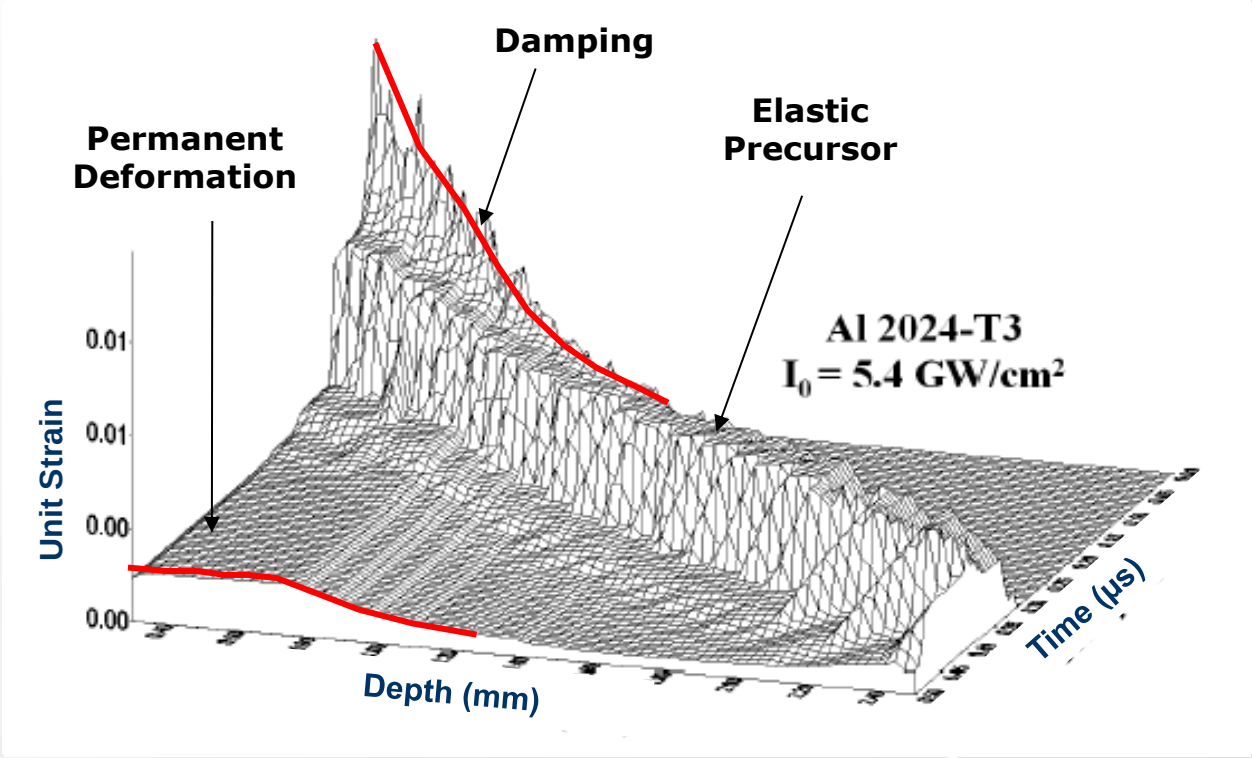
Process Description



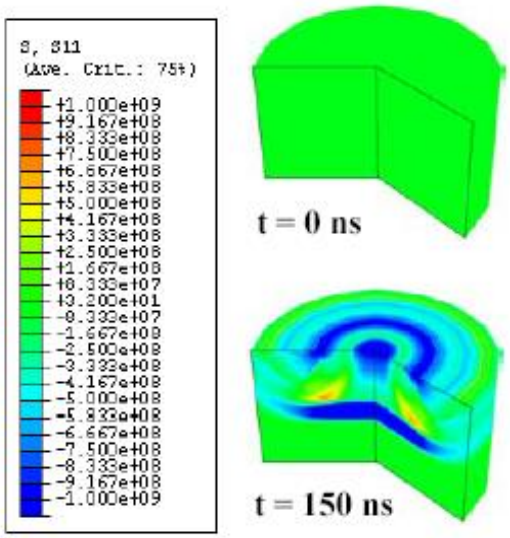
LSP Technique for Materials Properties Improvement
Process Description



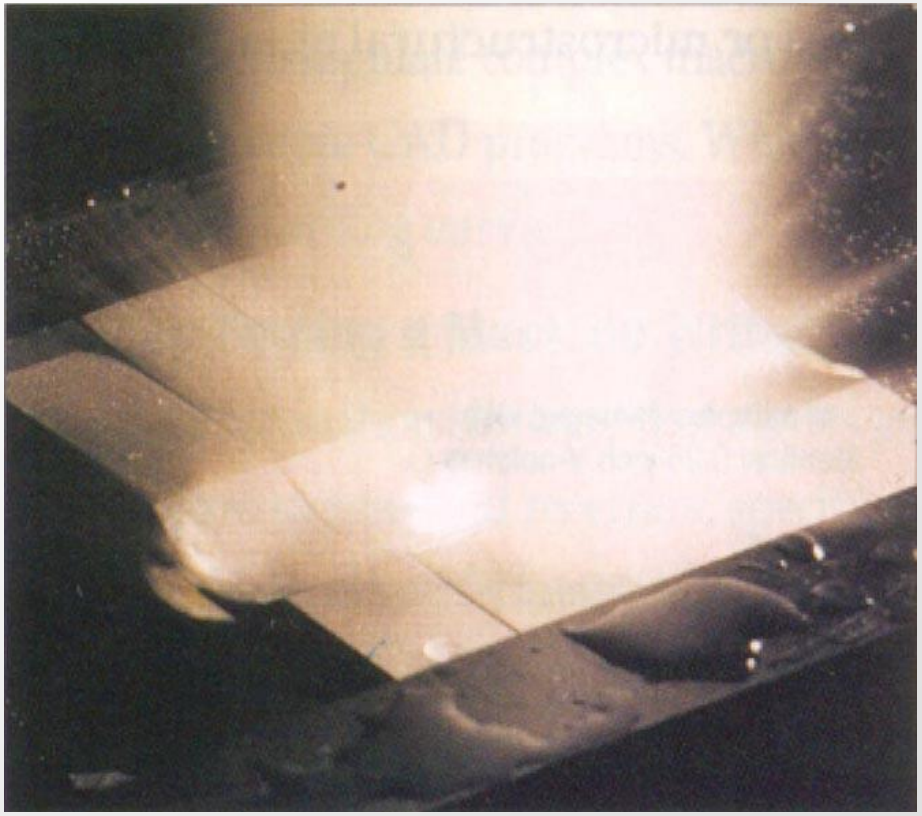
LSP Technique for Materials Properties Improvement
Process Description

Ti6Al4V

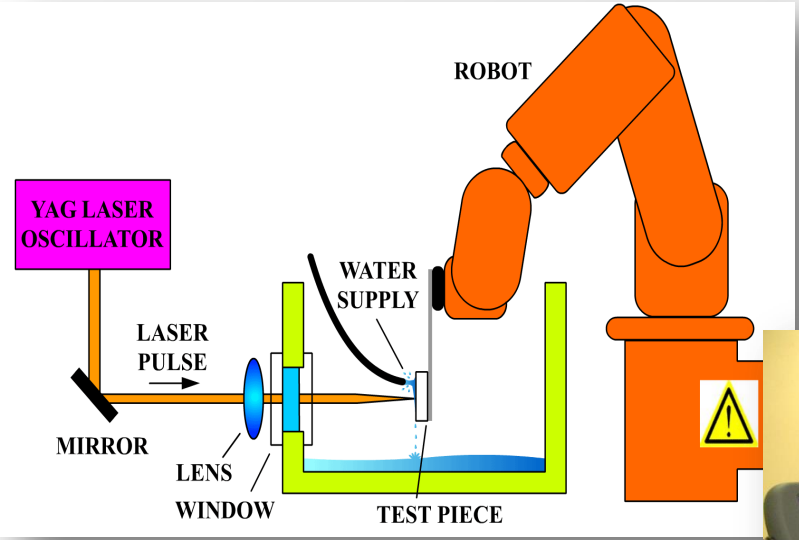
Radial stress dynamic analysis

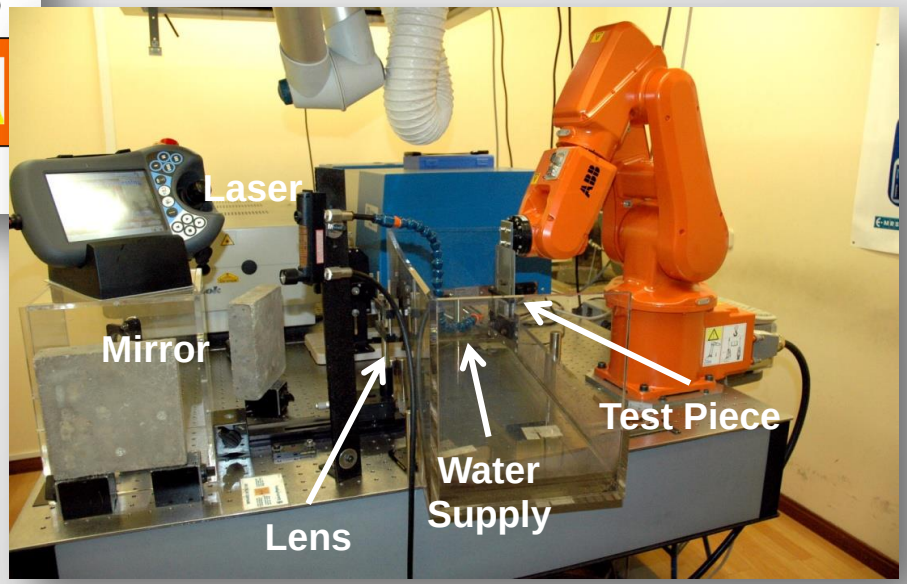


LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure



LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

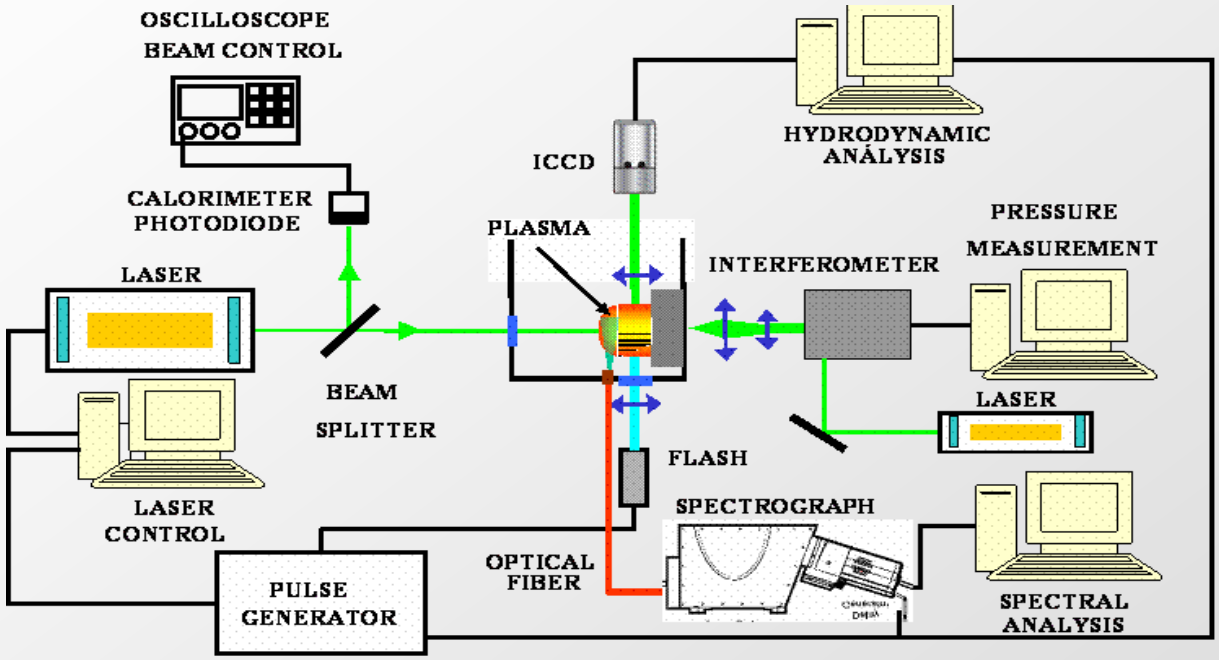




LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

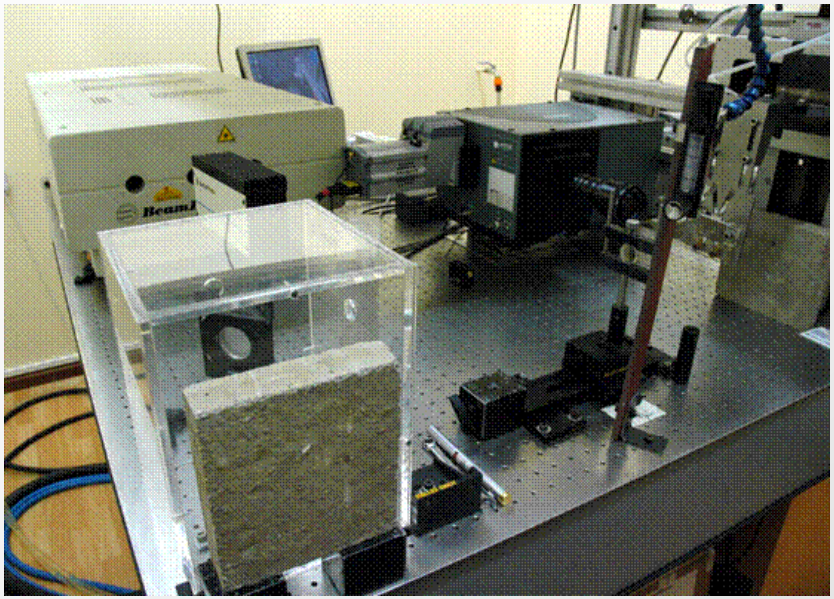
CONCEPTUAL INTERRELATED DIAGNOSTICS SYSTEM

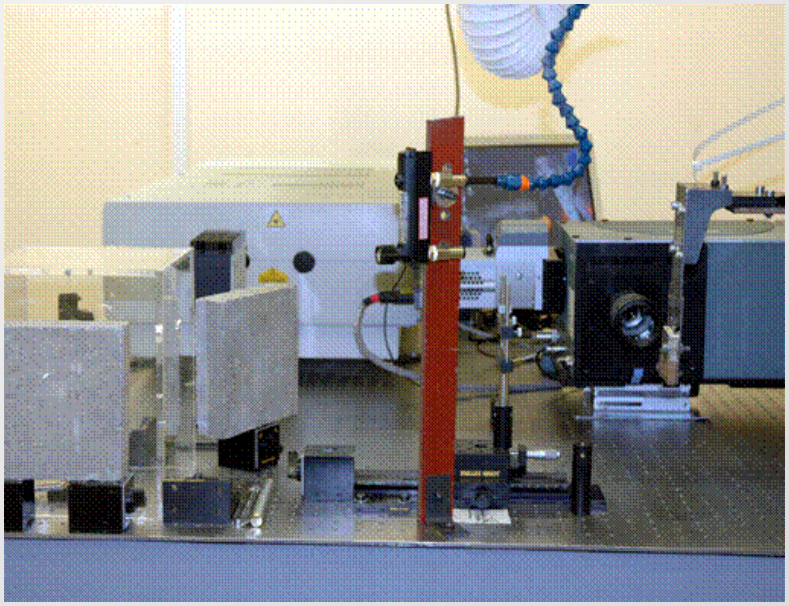


Ocaña, J.L. et al.: ".: "A review of the physics and technological issues of high intensity laser shock processing of materials as a method for mechanical properties modification". In XVI International Symposium on Gas Flow, Chemical Lasers and High-Power Lasers, Schuöcker, D., Ed. SPIE Vol. 6346, 63461P, (2006)

LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

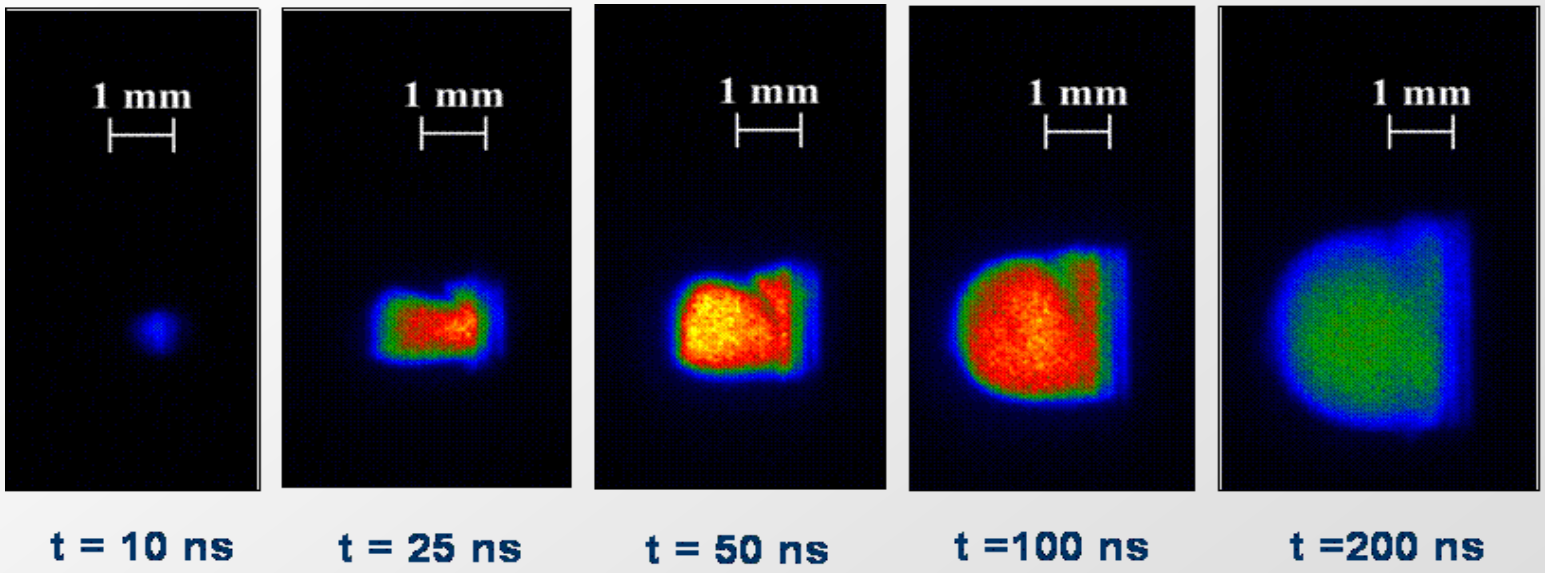
CONCEPTUAL INTERRELATED DIAGNOSTICS SYSTEM





LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

DIRECT IMAGING - HYDRODYNAMIC ANALYSIS



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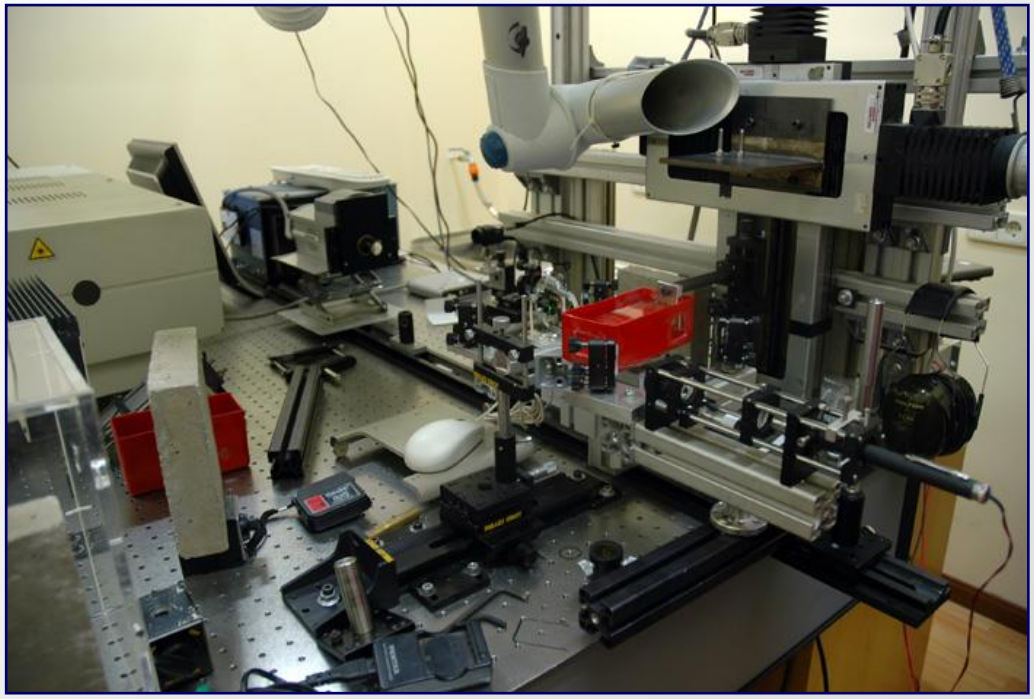
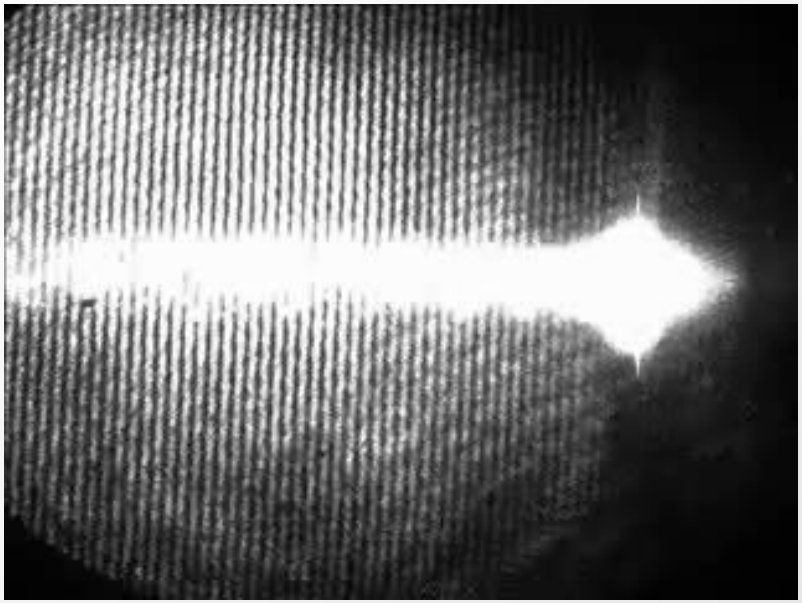
LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

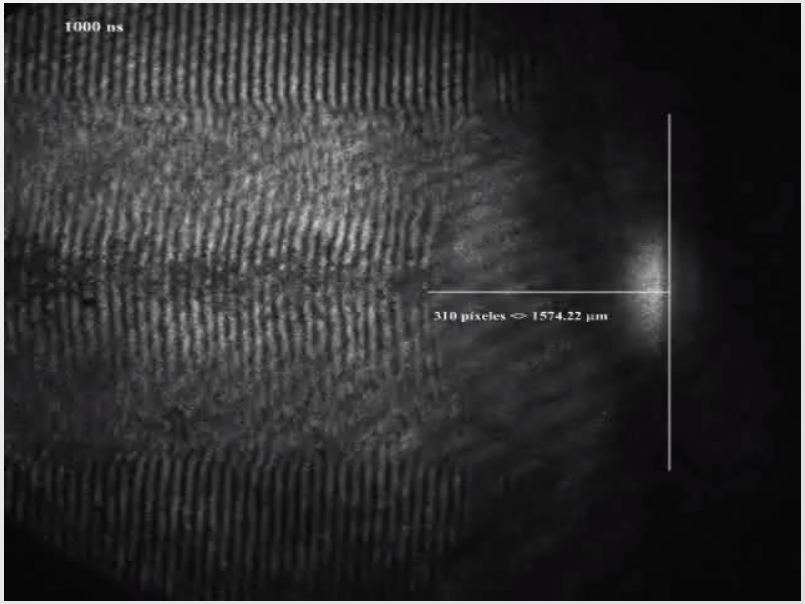
IMAGING TECHNIQUES – SCHLIEREN / INTERFEROMETRY



LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

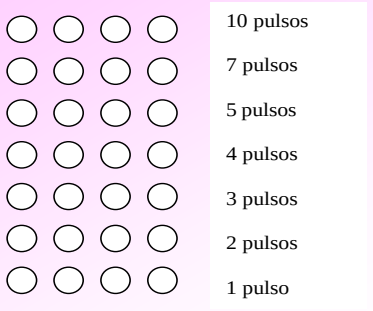
IMAGING TECHNIQUES – SCHLIEREN / INTERFEROMETRY

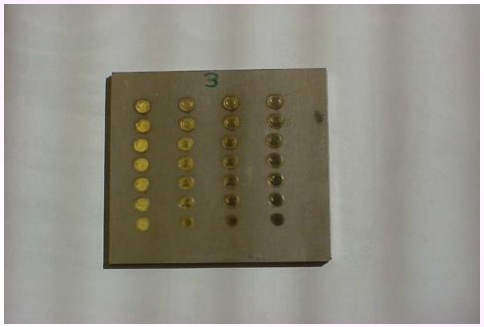


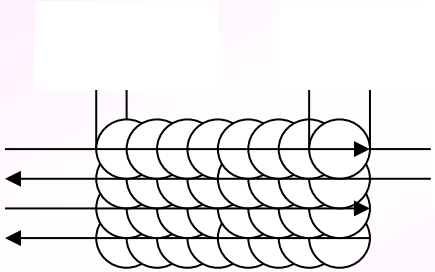


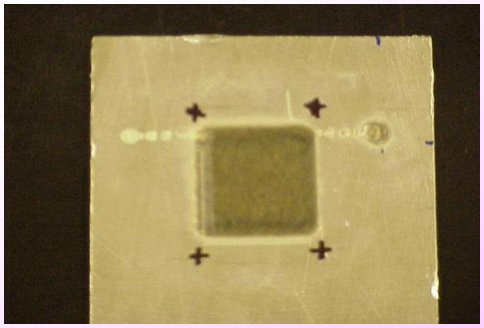
Martí-López, L. et al.: Appl. Optics, 48, 3671-3680 (2009)

LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

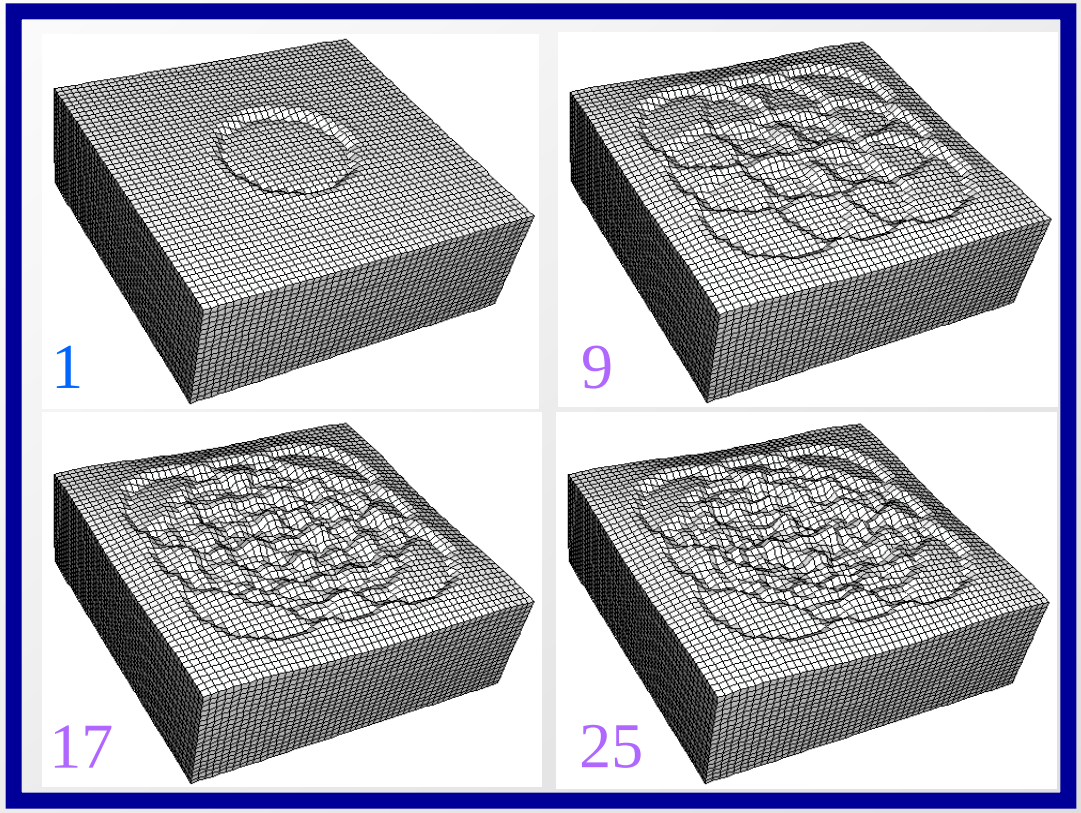








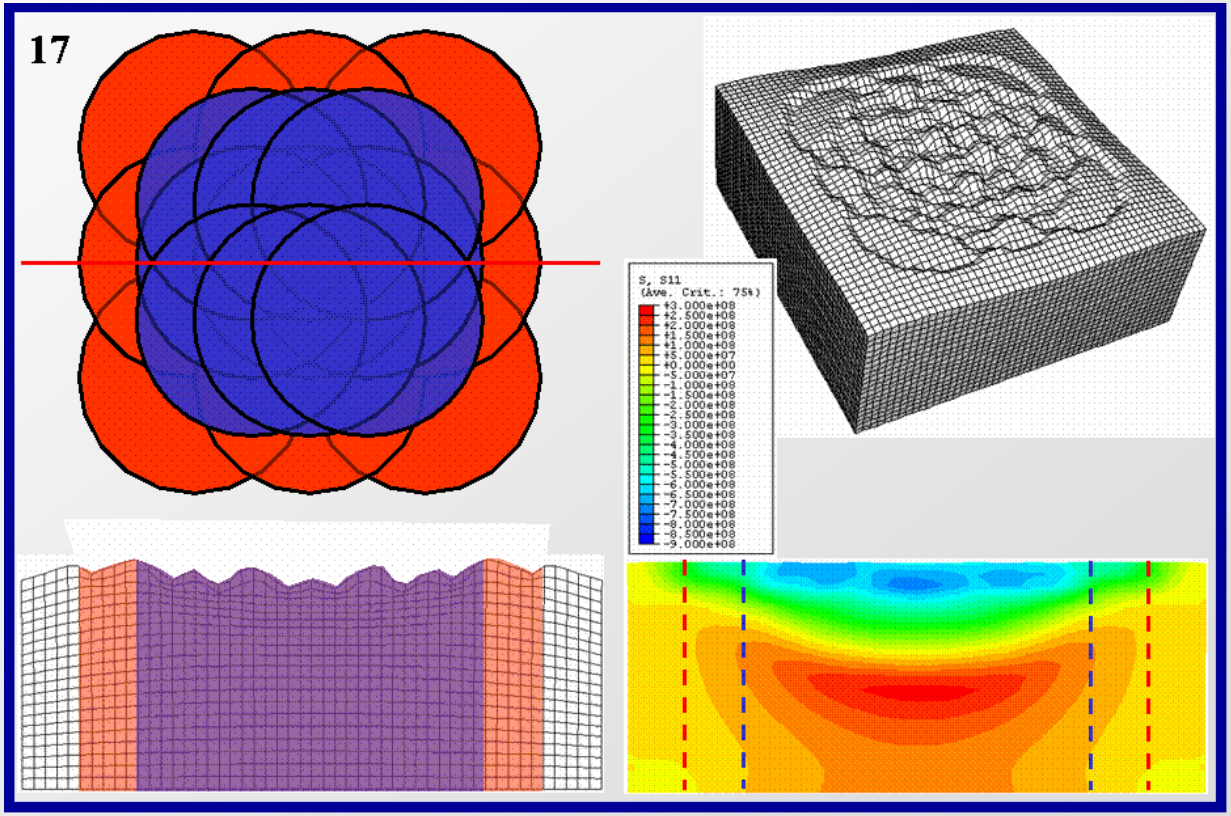
LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure



LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

Ti6Al4V

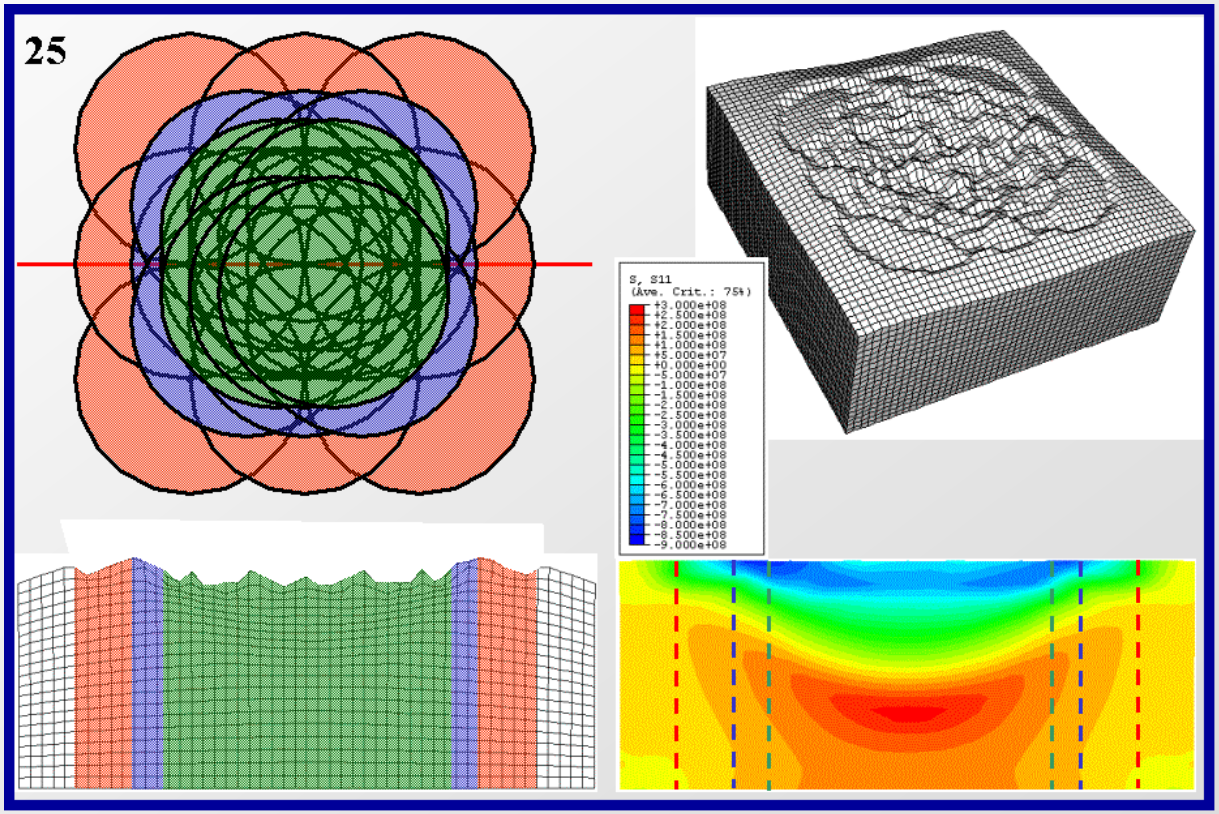
Nd:YAG (1064 nm)
P_{av}= 5,7 W/cm^2
Spot radius = 0.75 mm
FWHM = 10 ns
α= 0.15
Overlapping = 900/cm^2



LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

Ti6Al4V

Nd:YAG (1064 nm)
P_{av}= 5,7 W/cm^2
Spot radius = 0.75 mm
FWHM = 10 ns
α= 0.15
Overlapping = 900/cm^2

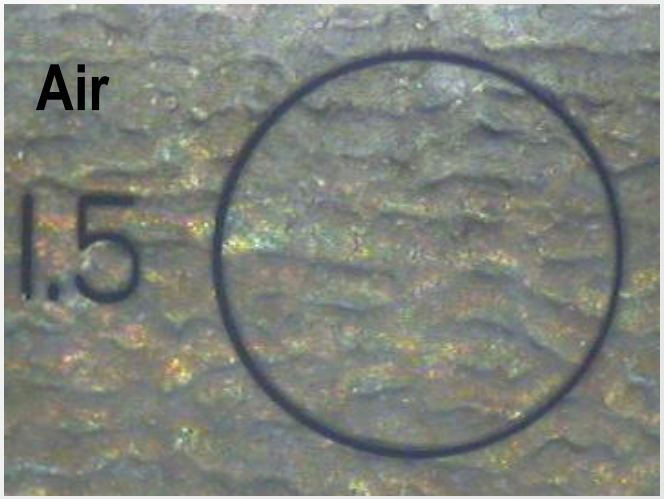


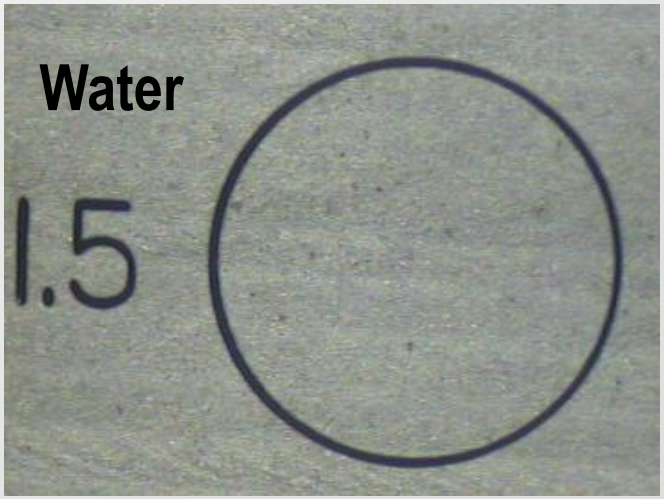
LSP Technique for Materials Properties Improvement
Experimental Setup & Procedure

Material: Al2024 T3

Pulses: ∅=1,5 mm; τ=10 ns; f=10 Hz;
E=1 J/pulse; I=1,41 GW/cm^2

Swept Area : 15x15 mm^2; 2500 pulses/cm^2

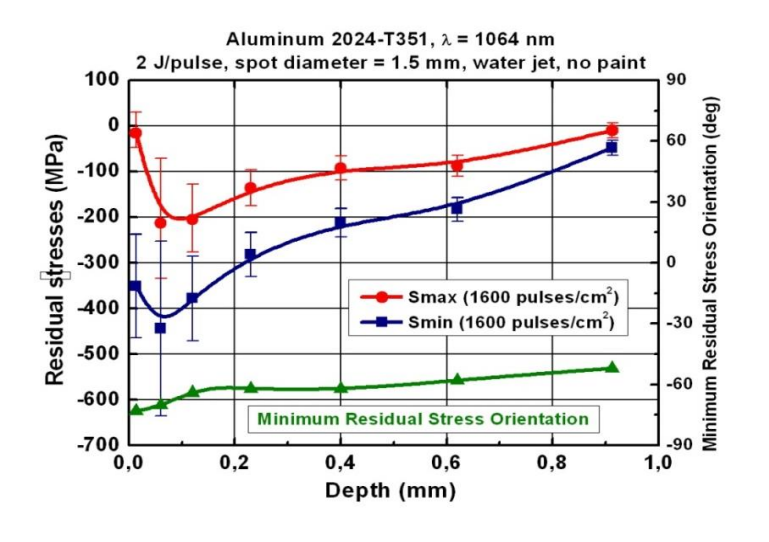




LSP Technique for Materials Properties Improvement
Some Preliminary Results

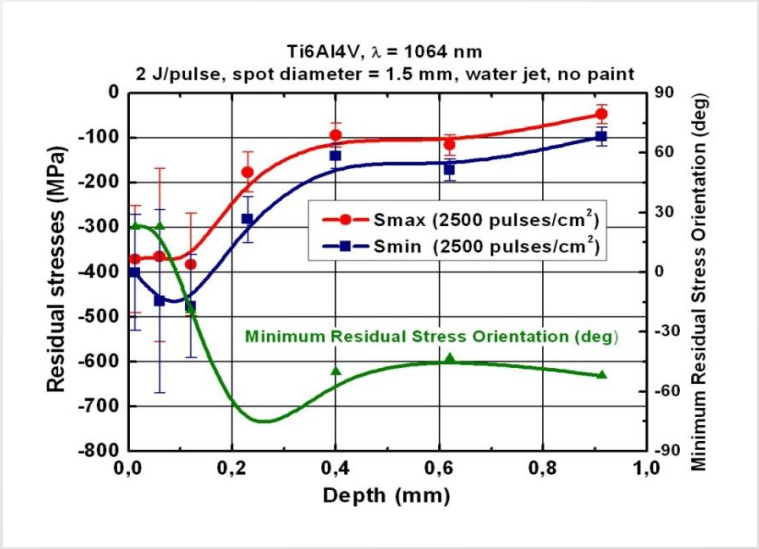
Residual Stresses (According to ASTM E837-08)

Al2024-T351



Relatively broad difference between S_{max} and S_{min} in Al2024-T351

Ti6Al4V

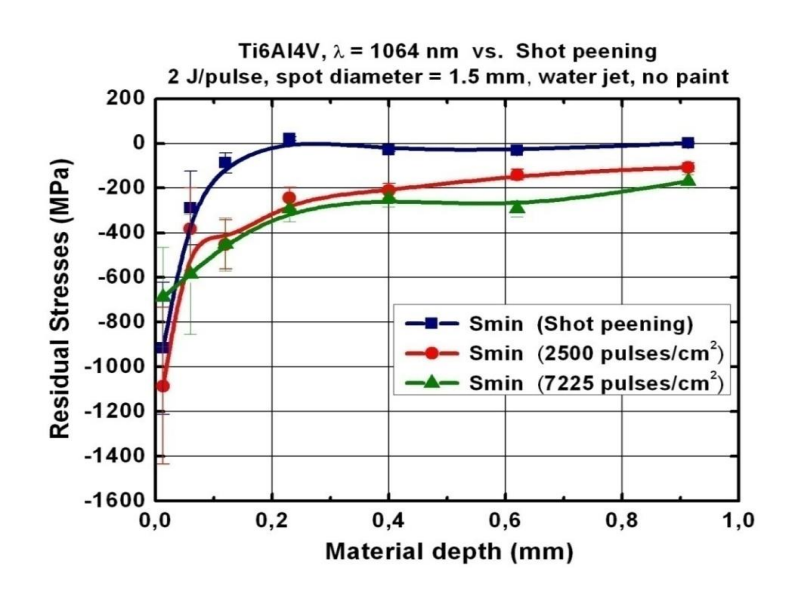


Relatively small difference between S_{max} and S_{min} in Ti6Al4V

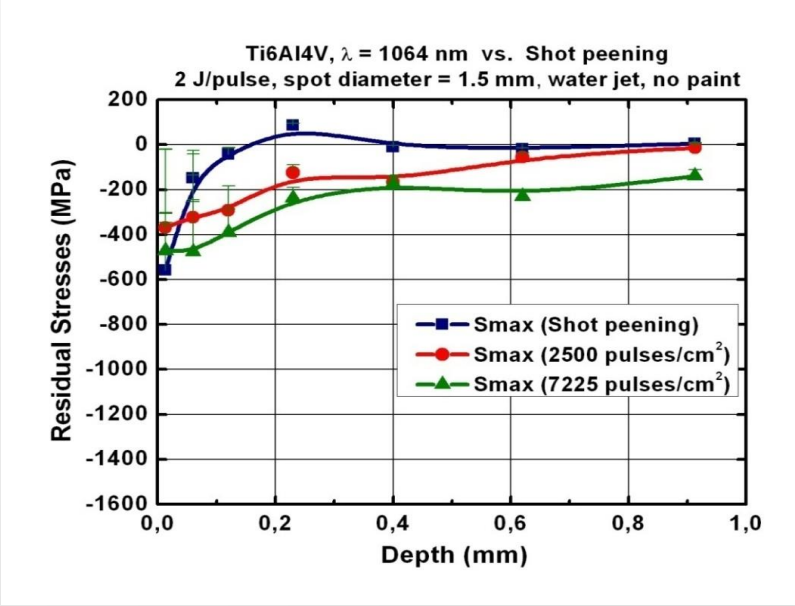
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Residual Stresses (According to ASTM E837-08)

Ti6Al4V: Comparison LSP-Shot Peening

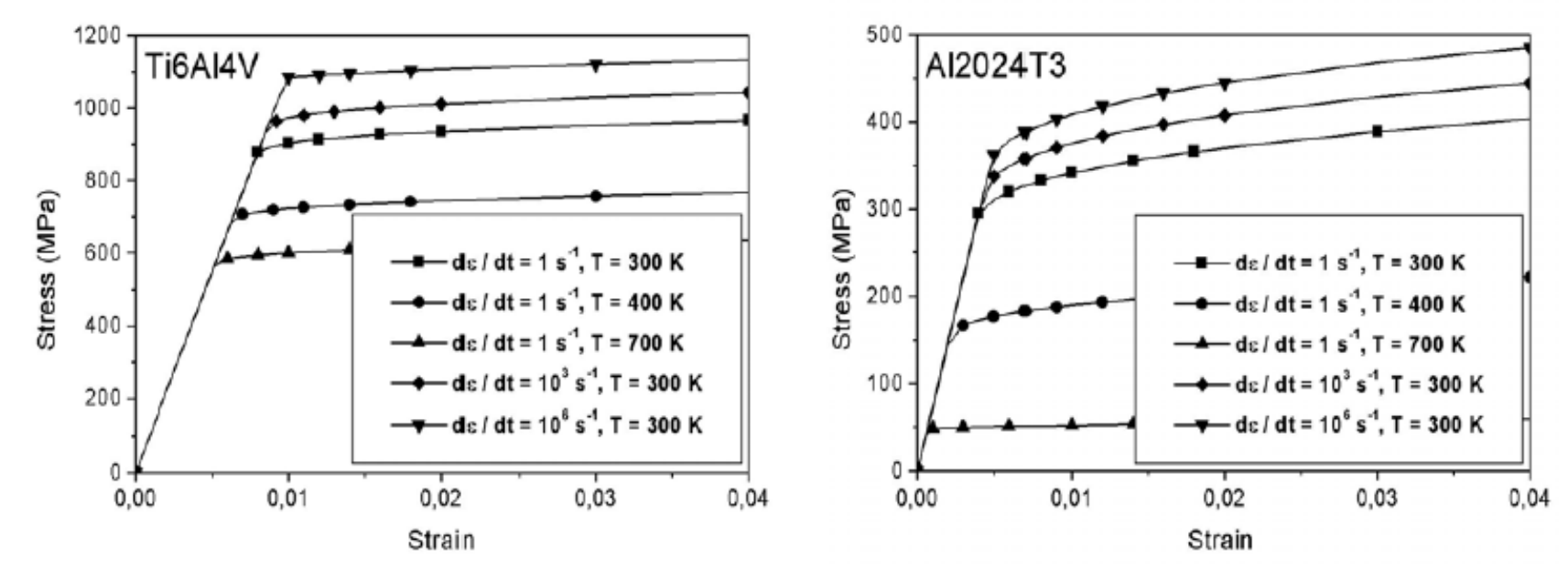


Substantial improvement in Residual Stresses Field in Ti6Al4V vs. to Shot Peening



Decisive improvement in protected depth reached in Ti6Al4V for different irradiation intensities

LSP Technique for Materials Properties Improvement
Some Preliminary Results



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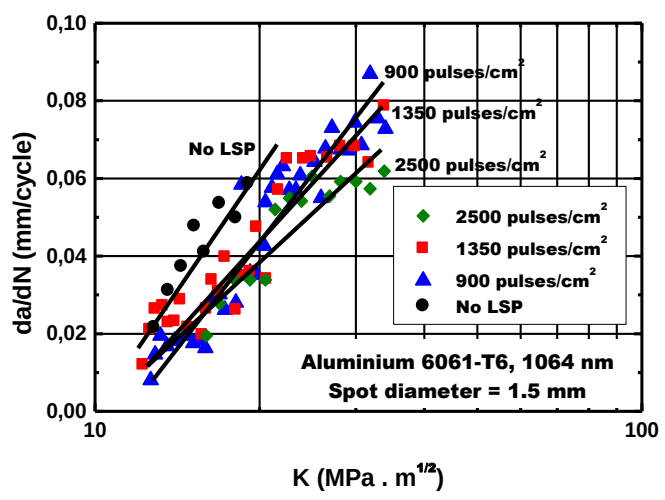
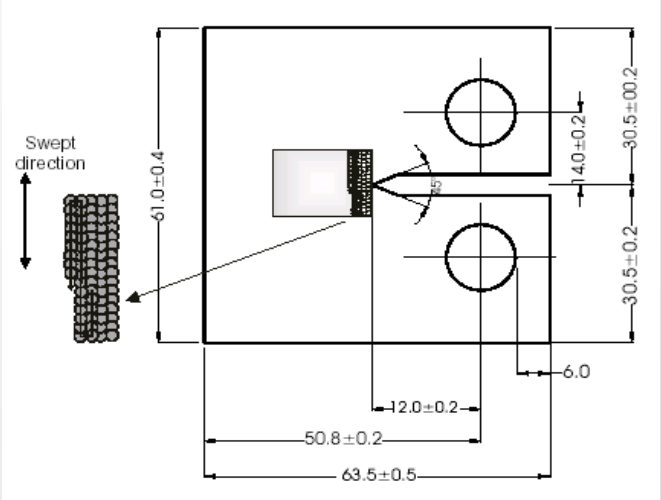
Some Preliminary Results



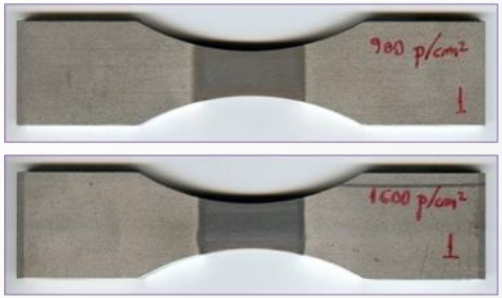


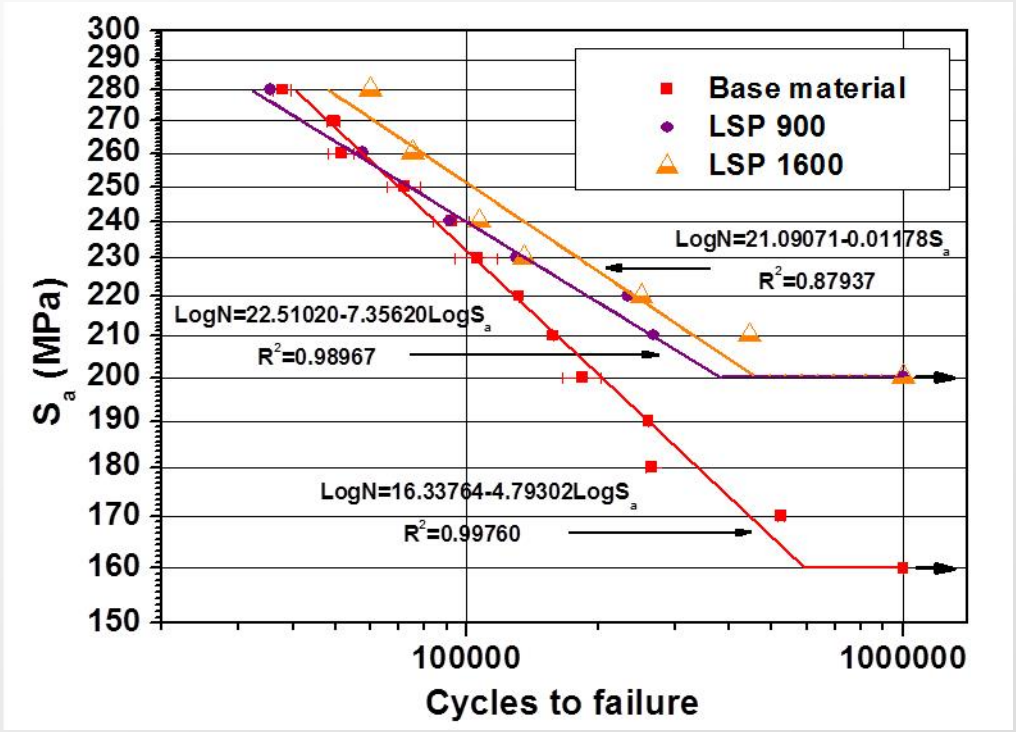
$$\frac{da}{dN} = C.K^{m}$$

Pulse density (cm^{-2})	C (mm/cycle)	M (dimensionless)
0 (No LSP treatment)	$4x10^{-13}$	7.664
900	$8x10^{-13}$	6.818
1350	$2x10^{-11}$	5.733
2500	$3x10^{-10}$	4.723

Rubio-González, C. et al.: Mat. Sci. Eng. A., 386 (2004) 291-295

LSP Technique for Materials Properties Improvement
Some Preliminary Results





Porro, J.A. et al.: 3rd ICLP. Japan 10-15 Oct. 2011

LSP Technique for Materials Properties Improvement
Some Preliminary Results

Iordachescu, M. et al.: "*Laser Shock Processing influence on local properties and overall tensile behavior of friction stir welded joints*". Surface & Coatings Technology 206 (2012) 2422–2429

LSP Technique for Materials Properties Improvement
Some Preliminary Results

4. Mechanical characterization

Digital Image Correlation System – VIC 2D

VIC software correlates location of random speckle patterns between two images.

The correlation is made between windows of pixels, typically 25 x 25 pixels, so measured values are averages over the window size

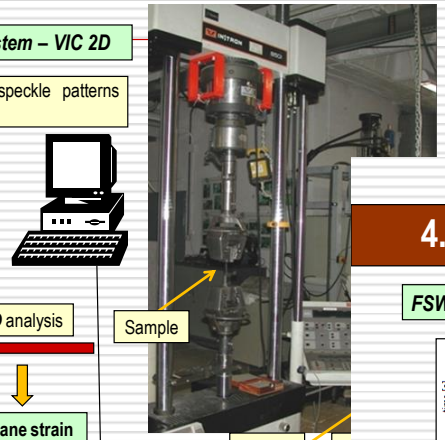
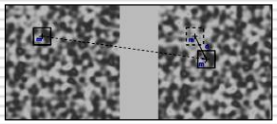


Image 0 | Deformed Image



2D analysis

Sample

Camera

speckle patterns on the sample surface

In-plane strain measurement

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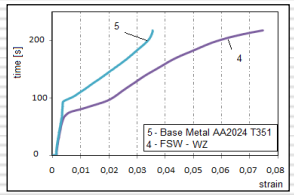
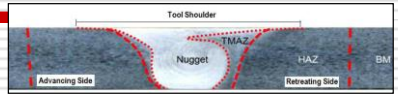
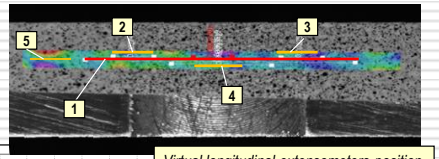
UNIVERSIDAD POLITÉCNICA DE MADRID

4. Mechanical characterization

FSW joint - Local Strain analysis

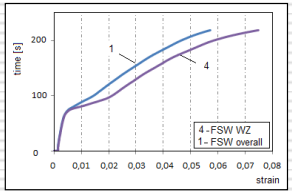


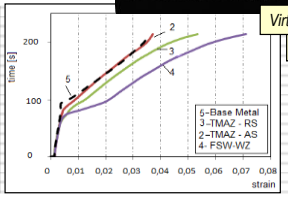




Virtual longitudinal extensometers position

1- overall ; 2 – AS; 3 - RS; 4 – WZ; 5 – BM





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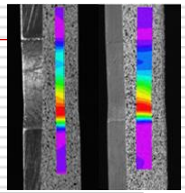
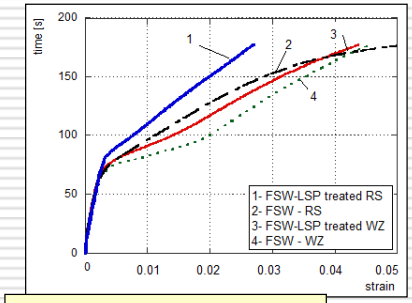
12

LSP Technique for Materials Properties Improvement
Some Preliminary Results

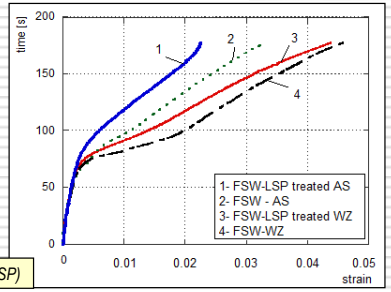
4. Mechanical characterization

FSW vs. FSW-LSP treated joint - Local Strain analysis





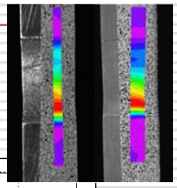
RS vs. WZ strains (FSW joint with/without LSP)

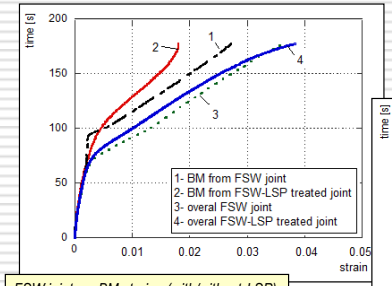


AS vs. WZ strains (FSW joint with/without LSP)

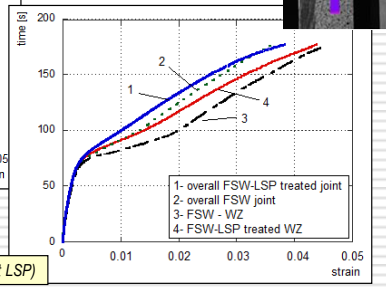
4. Mechanical characterization

FSW vs. FSW-LSP treated joint - Local Strain analysis





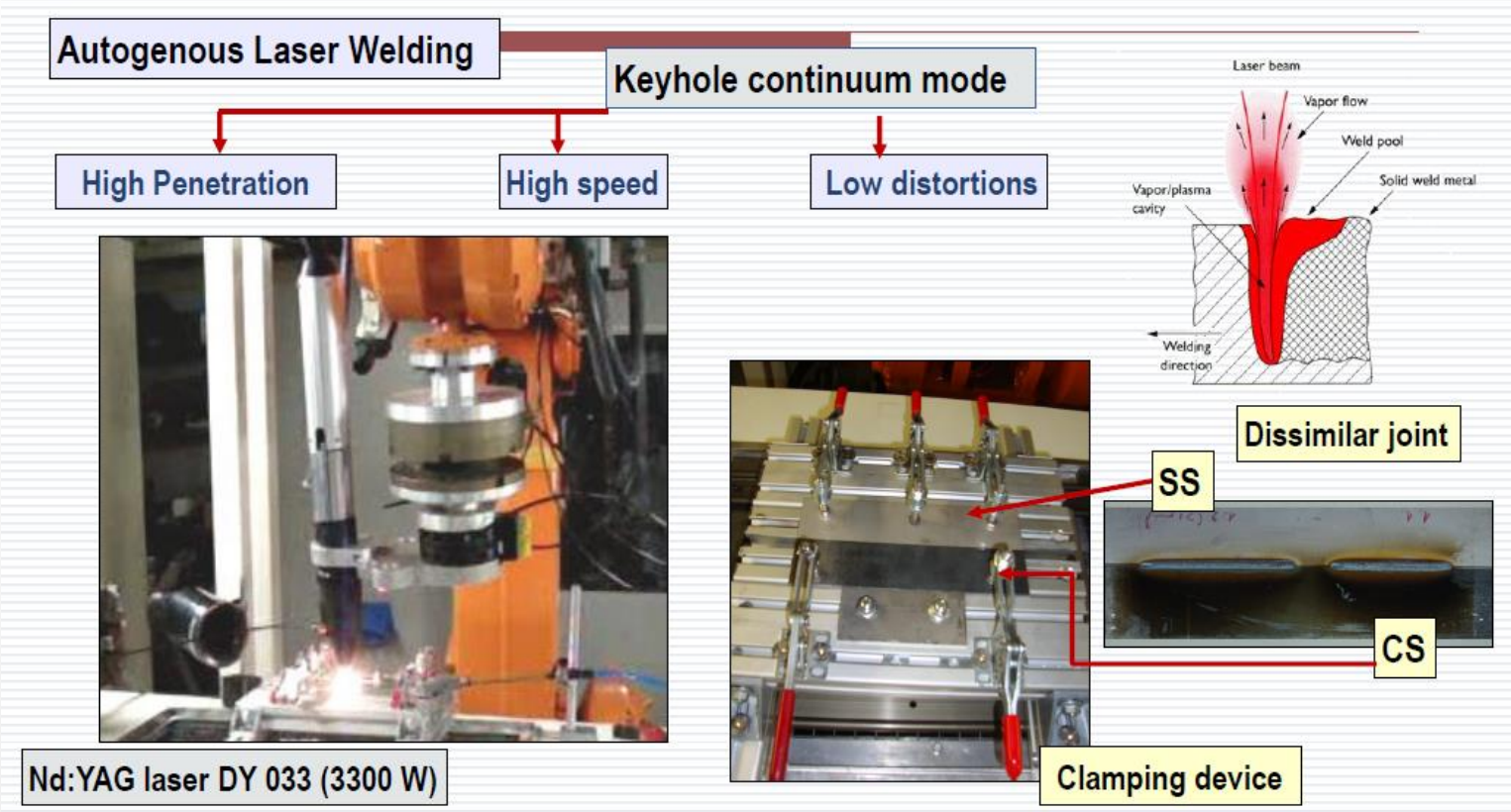
FSW joint vs. BM strains (with/without LSP)



FSW joint vs. WZ strains (with/without LSP)

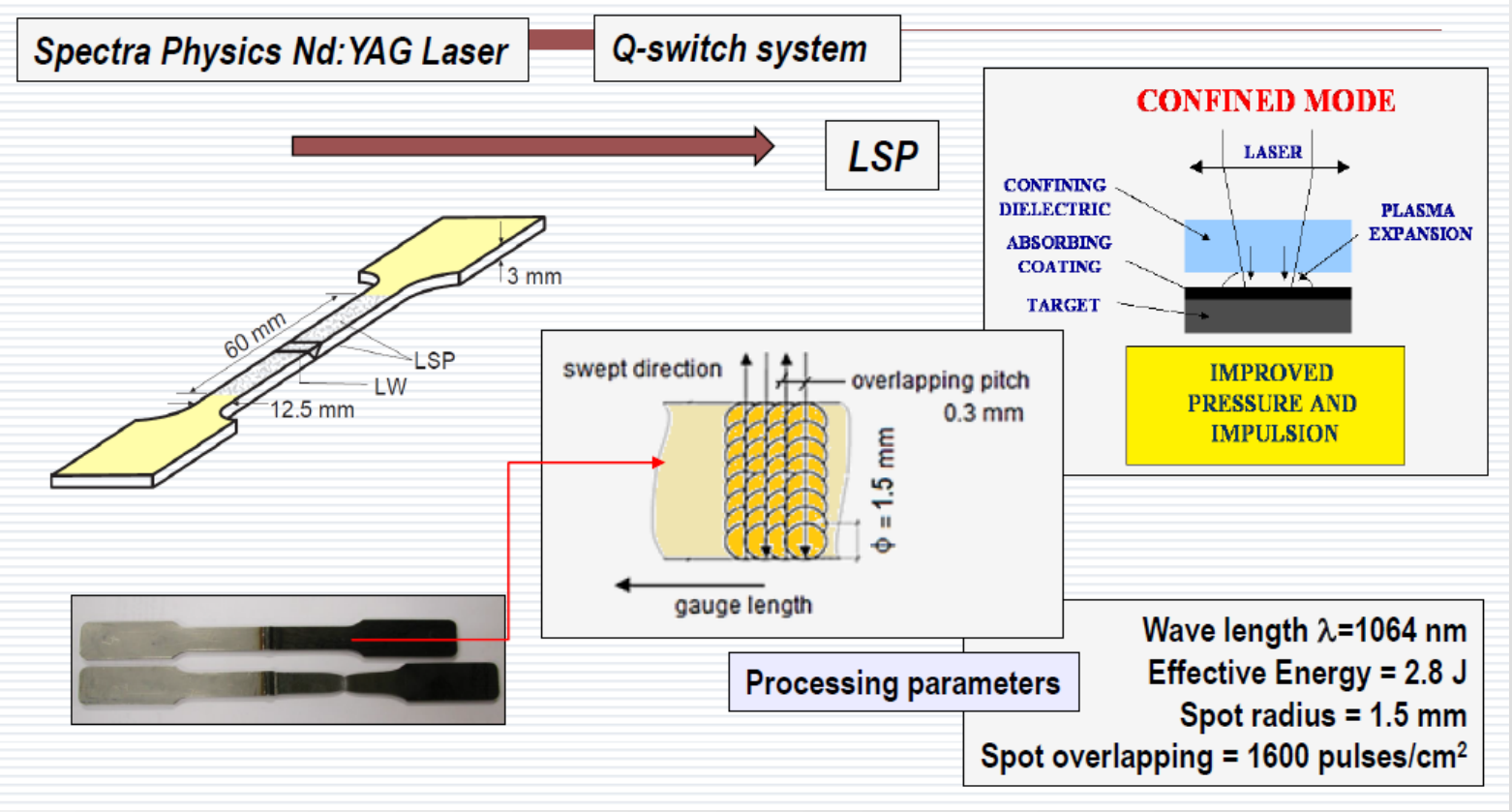
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (1/7)



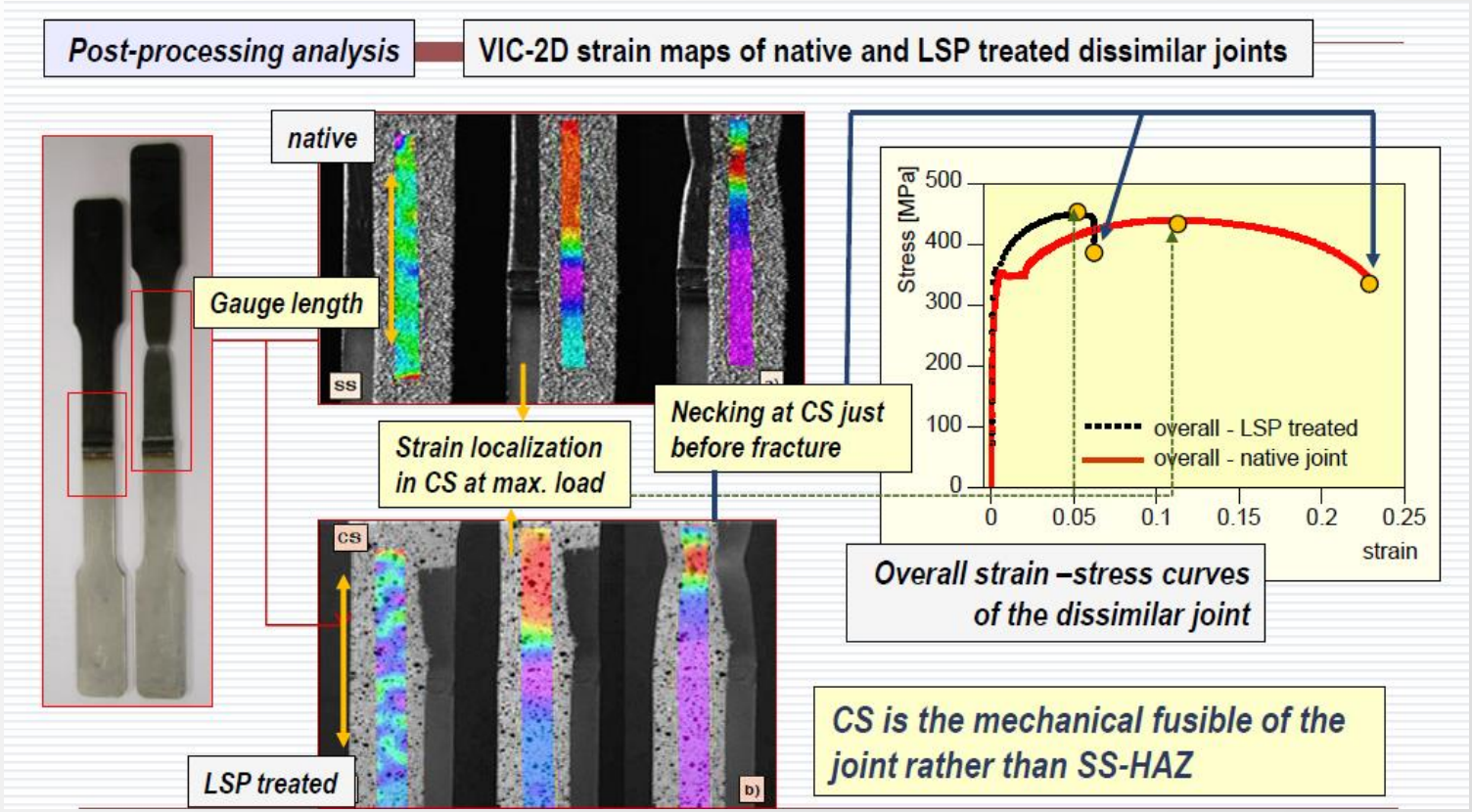
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (2/7)



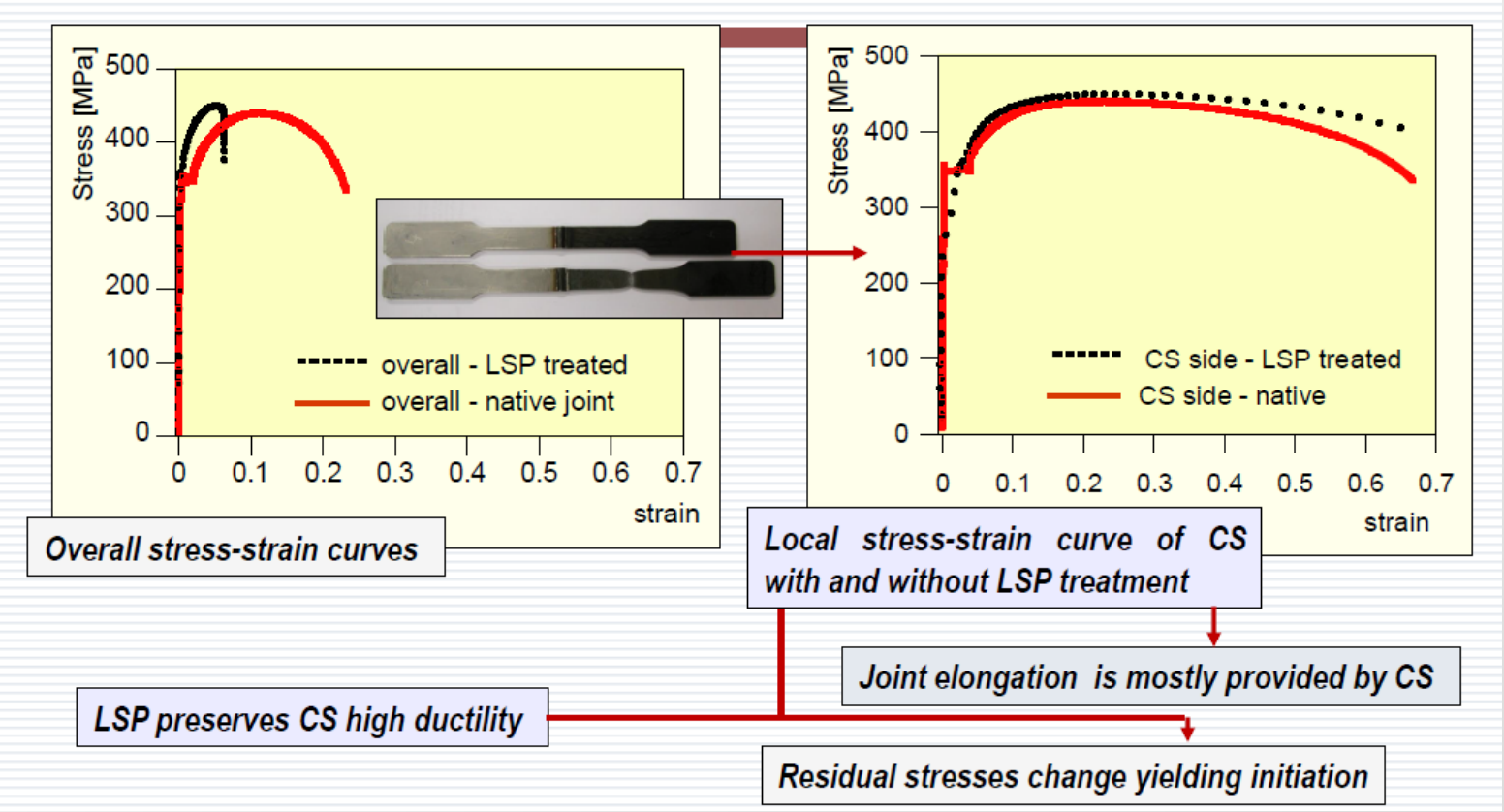
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (3/7)



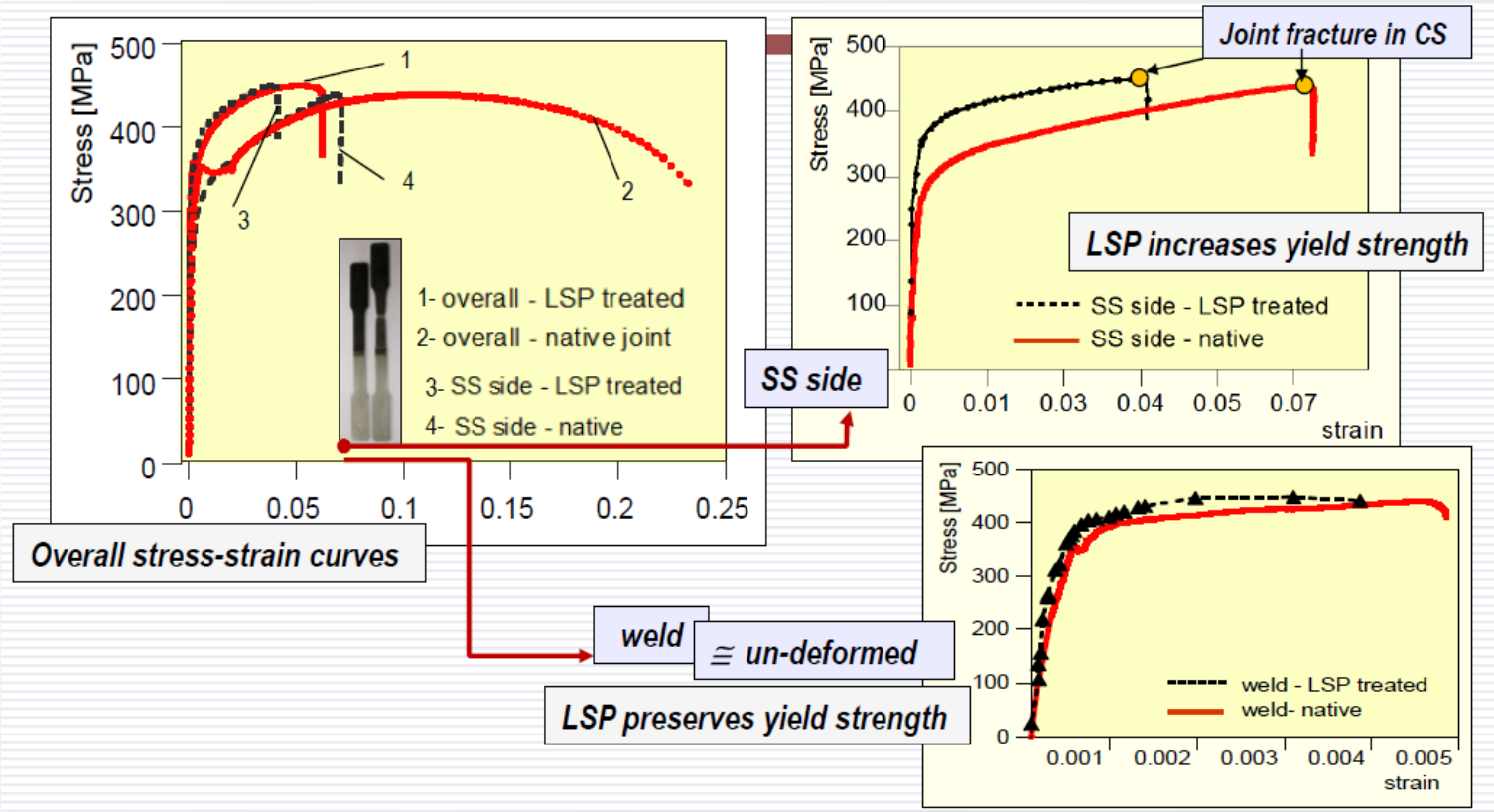
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (4/7)



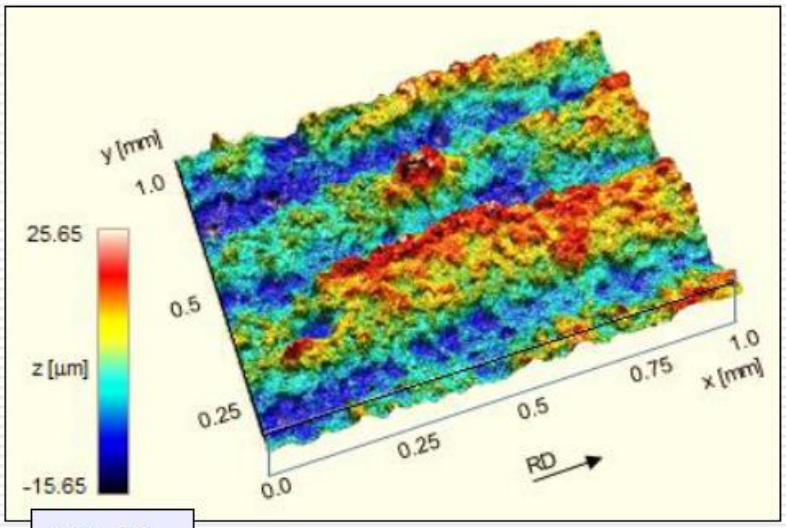
LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (5/7)

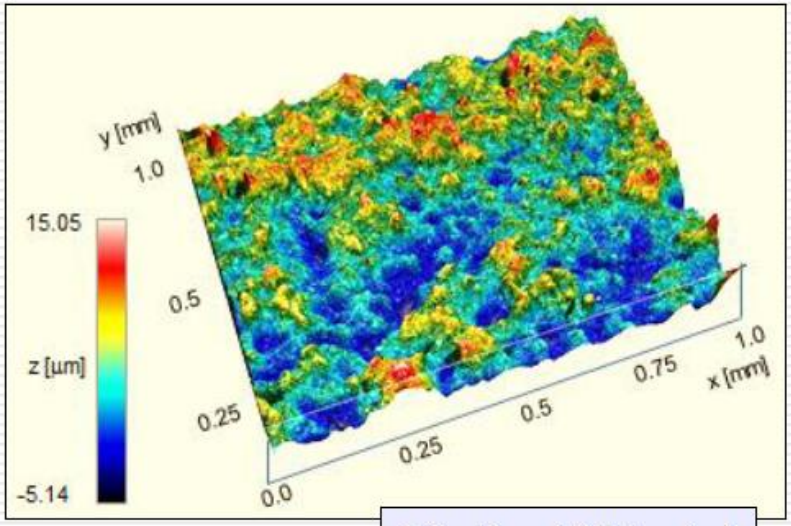


LSP Technique for Materials Properties Improvement
Some Preliminary Results

Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (6/7)



CS side



CS side – LSP treated

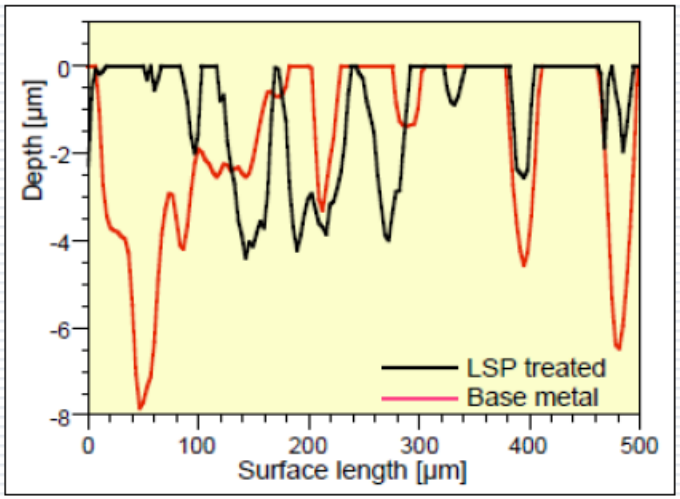
Roughness is slightly decreased by LSP

Processing parameters

Spot overlapping = 1600 pulses/cm²

LSP Technique for Materials Properties Improvement
Some Preliminary Results

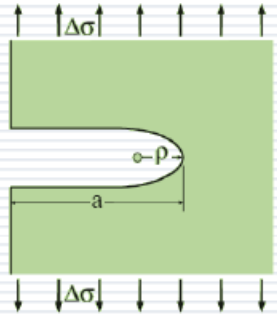
Assessment of LSP on mechanical resistance of thin dissimilar laser welded joints (7/7)



Depth of surface cavities and irregularities

Fatigue limit prediction:

Macroscopic notch models [1] can explain the fatigue strength improvement induced by LSP on the basis of roughness changes



$$\Delta\sigma_f = \frac{0.435 R_m}{\sqrt{\frac{a}{\rho} - \frac{1}{2}}}$$

[1] Barsom, J.M. and McNicol, R. C. *Effect of stress concentration on fatigue-crack initiation in HY-130 Steel, ASTM-STP 559*, ASTM, Philadelphia (USA), 1974.

$\Delta\sigma_f$ is proportional to tensile strength R_m but it decreases with the notch aspect ratio a/ρ

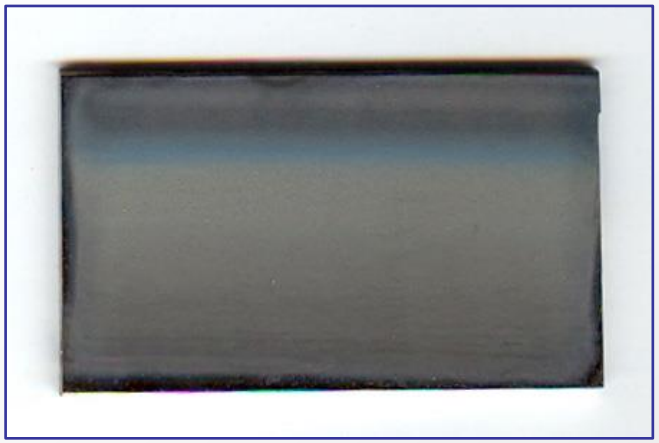
LSP decreases the aspect ratio a/ρ of roughness profile, then LSP would improve fatigue strength

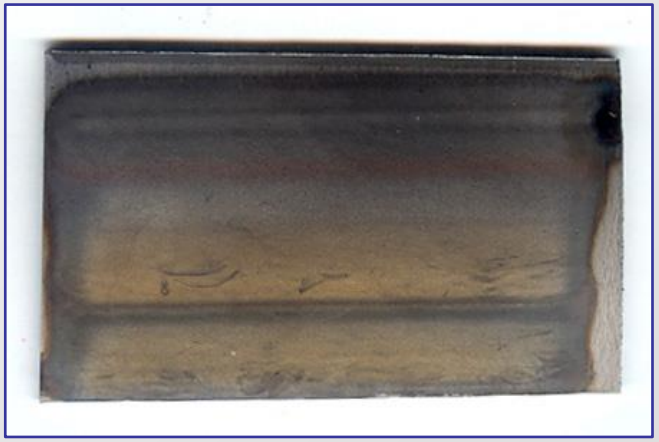
LSP Technique for Materials Properties Improvement
Discussion and Outlook

- LSP Technology is being developed and has proven successful results as competitive to classic surface and mechanical properties improvement techniques of high reliability components as, i.e. Shot Peening.
- The need for a practical capability of LSP process control in practical applications has led to the development of comprehensive theoretical/computational models for the predictive assessment of the complex phenomenology involved. The development of the appropriate experimental diagnosis facilities and the connection of numerical simulation to experimental material characterization results enable a fundamental and reliable process understanding capability in view of process industrial implementation.
- Some preliminary studies have been conducted by the authors focused to the mechanical properties improvement of different types of welded joints.
- The LSP influence has proven to be beneficial in the case of FSW joints of AA2024-T351. At joint scale, a stiffening effect is induced by LSP by hardening the superficial top and bottom layers, generating changes in the overall mechanical behaviour of the structure. The samples laser shock processed exhibited superior tensile properties as compared to the un-peened ones. The testing strain rate had no significant effect on the mechanical behaviour of the samples.
- In the case of LSP treatment of laser welded thin (< 3 mm) B&W steel sheets, significant differences in the overall mechanical resistance of treated vs. non-treated samples, mostly as a consequence of the properties improvement of the welding HAZ over those of base CS.

LSP Technique for Materials Properties Improvement
Discussion and Outlook

Recent Results on the LSP treatment of NiTi sheets. Comparison to AISI 304 SS

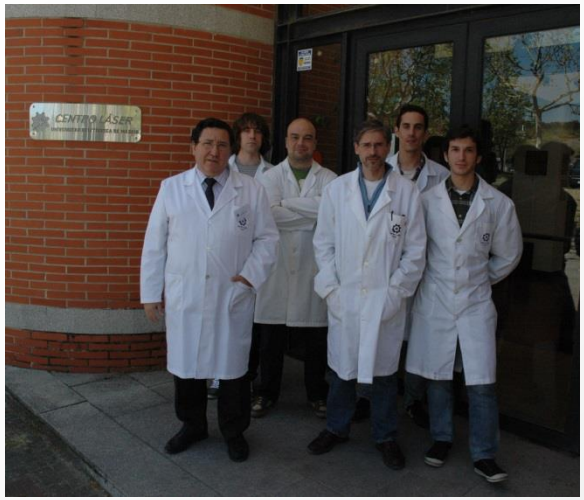


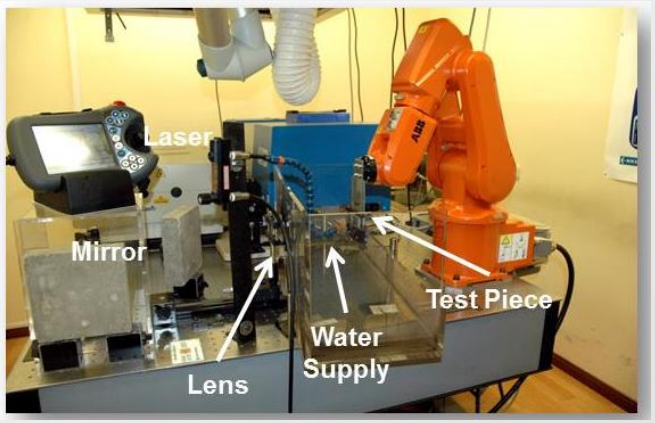


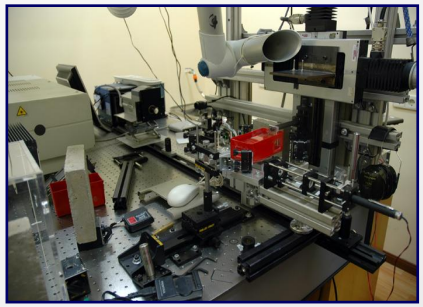
MAIN REFERENCES

1. Ocaña, J.L. et al.: "A Model for the Coupled Predictive Assessment of Plasma Expansion and Material Compression in Laser Shock Processing Applications". In: High-Power Laser Ablation II, Claude R. Phipps, Masayuki Niino, Eds., SPIE Proceedings , Vol. 3885, 252–263 (2000)
2. Ocaña, J.L. et al.: "Predictive assessment and experimental characterization of the influence of irradiation parameters on surface deformation and residual stresses in laser shock processed metallic alloys". In: High-Power Laser Ablation V, Phipps C.R., Ed.. SPIE Vol. 5548, 642-653 (2004)
3. Ocaña, J.L. et al.: Appl. Surf. Sci., 238 (2004) 242-248
4. Ocaña, J.L. et al.: Appl. Surf. Sci., 238 (2004) 501-505
5. Rubio-González, C. et al.: Mat. Sci. Eng. A., 386 (2004) 291-295
6. Ocaña, J.L. et al.: "Laser Shock Processing as a Method for Surface Properties Modification of Metallic Materials". In: Shot Peening and other Mechanical Surface Treatments, V. Shulze, A. Niku-Lari, Eds. I.I.T.T. Paris (2005), 466-471.
7. Sanchez-Santana, U., et al.: Wear, 260 (2006) 847-854
8. Rubio-González, C. et al.: Appl. Surf. Sci., 252 (2006) 6201-6205
9. Morales, M. et al.: "Numerical Simulation of Plasma Dynamics in Laser Shock Processing Experiments". In: Proceedings of LPM2008. 1-6 (2008)
10. Morales, M. et al.: Surf. & Coat. Technol., 202 (2008) 2257–2262
11. Martí-López, L. et al.: Appl. Opt. 48 (2009) 3671-3680
12. Morales, M. et al.: Appl. Surf. Sci. 255 (2009) 5181–5185
13. Ocaña, J.L. et al.: Mat. Sci. Forum, Vols. 638-642 (2010) 2446-2451
14. Morales, M. et al.: Mat. Sci. Forum, Vols. 638-642 (2010) 2682-2687
15. Morales, M. et al.: J. Optoelectr. and Adv. Mat., 12 (2010) 718-722
16. Rubio-González, C. et al.: Mat. Sci. Eng. A., 528 (2011) 914-919
17. Ocaña, J.L. et al.: Mat. Sci. Forum, Vols. 706-709 (2012) 2565-2570
18. Iordachescu, M. et al.: Surf. & Coat. Technol., 206 (2012) 2422–2429
19. Trdan, U. et al.: Surf. & Coat. Technol., 208 (2012) 109–116
20. Ocaña, J.L. et al.: AIP Conference Proceedings, 1464 (2012) 209-218

The LSP Team at CLUPM







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