Predictive Assessment of Plasma Dynamics Effects on the Shock Transformation of Metallic Alloys by Laser Shock Processing

J. L. Ocaña, M. Morales, C. Molpeceres, J. A. Porro, D. Iordachescu

ETSII-DEPI. of Applied Physics and UPN Laser Centre
Universidad Politécnica de Madrid
ETSII-UPM, C/ José Gutiérrez Abascal, 2, E-28006 Madrid, SPAIN
Tel.: (+34) 913363089, Fax: (+34) 913363000, email: jloca@etsii.upm.es

1. OUTLINE

- Introduction to Laser Shock Processing (LSP)
- Numerical Model Description
- Numerical Results
- Application to Micro-Forming
- Discussion
Laser materials processing is a broad and rapidly evolving technology area. Lasers are used for irradiating, joining, separating, micromachining and shaping of diverse materials and products.

Laser Shock Processing (LSP) is based on the application of a high power density pulsed Laser beam (I>10^8 W/cm^2; t<50 ns) on a metallic target forcing a sudden vaporization of its surface into a high temperature and density plasma that immediately develops inducing a shock wave propagating into the material.
Process Description

Laser characteristics
- pulse duration
- wavelength
- intensity

Other process parameters
- laser spot radius
- confining material
- coating layer

- nature
- thickness

Process Modelling - Targets
- formation of a vapour/plasma phase
- non-equilibrium ionization-recombination in vapour/plasma phase
- thermo-fluid-dynamic behaviour under extreme pressure
- propagation of the shock waves
- material behaviour

Process Modelling – 3-Level Approach
- Analysis of the plasma electronic population dynamics, including consideration of breakdown phenomenology in dielectric media
- Simulation of the hydrodynamic phenomenology arising from plasma expansion between the confinement layer and the base material
- Analysis of the propagation and induction of permanent structural changes by shock wave evolution in bulk material
Process Modelling

Ti6Al4V

Nd:YAG (1064 nm)
P_{av} = 5.7 W/cm^2
Spot radius = 0.75 mm
FWHM = 0 ns
\alpha = 0.15

Multiple shocks
dynamic analysis

CENTRO LASER
INELAS '86-BRAN, ROMANIA
Laser Shock Processing

HARDSHOCK-2D Semi-finite

Process Modelling

Ti6Al4V

Nd:YAG (1064 nm)
P_{av} = 5.7 W/cm^2
Spot radius = 0.75 mm
FWHM = 0 ns
\alpha = 0.15

Multiple shocks
dynamic analysis

CENTRO LASER
INELAS '86-BRAN, ROMANIA
Laser Shock Processing

HARDSHOCK-2D Semi-finite

Process Modelling

Ti6Al4V

Nd:YAG (1064 nm)
P_{av} = 5.7 W/cm^2
Spot radius = 0.75 mm
FWHM = 0 ns
\alpha = 0.15

Overlapping = 960/cm^2

CENTRO LASER
INELAS '86-BRAN, ROMANIA
Laser Shock Processing

HARDSHOCK-3D

Process Modelling

Ti6Al4V

Nd:YAG (1064 nm)
P_{av} = 5.7 W/cm^2
Spot radius = 0.75 mm
FWHM = 0 ns
\alpha = 0.15

Overlapping = 960/cm^2

CENTRO LASER
INELAS '86-BRAN, ROMANIA
Laser Shock Processing

HARDSHOCK-3D
Experimental Diagnosis

IMAGING TECHNIQUES – SHADOWGRAPHY


Experimental Diagnosis

EMISSION SPECTROSCOPY


Experimental Results

Material: Al2024 T3
Pulses: Ø=1.5 mm; τ=10 ns; f=10 Hz;
Energy: 1 J/pulse; I=1.41 GW/cm²
Swept Area: 15x15 mm²; 2500 pulses/cm²

Air: 1.5
Water: 1.5

Fig. 3 Comparative analysis of residual stresses along z-coordinate induced in Al2024-T351 by the LSP technique for three representative pulse densities.
Discussion (1/2)

- Laser Shock Processing (LSP) with high power density (>10^9 W/cm²) short pulse (<10 ns) lasers is a conceptually advanced emerging application for the improvement of surface characteristics of metallic high performance components.
- The phenomenology involved in LSP processes is, however, complicated mostly because of their characteristic laser-plasma interaction dynamics.
- The need for a practical capability of process control in practical applications has led to the development of comprehensive theoretical/computational models for the predictive assessment of the complex phenomenology involved whose practical application needs for the appropriate experimental feedback through a model-interrelated diagnosis system.

Discussion (2/2)

- From the practical point of view, the LSP technology allows the effective induction of residual stresses fields in metallic materials. Experimental results obtained with commercial Q-switched lasers prove complete feasibility at laboratory scale for the most relevant materials in heavy duty applications.
- Depending on initial material mechanical properties, the residual stresses fields can reach depths and maximum values providing an effectively enhanced behaviour of materials against fatigue crack propagation, abrasive wear, chemical corrosion and other failure conditions.
- This makes the technique specially suitable and competitive with presently used techniques for the treatment of heavy duty components in the aeronautical, nuclear and automotive industries.

Outlook: Unsolved Problems

- However:
  - Some theoretical and practical aspects are still to be made more clear, mostly in connection with the first phase of the process, high intensity laser interaction (possible beneficial role of an absorbing coating, effect and predictability of the confining layer, effect of a geometrically extended laser spot, effect of repeatedly overlapping laser pulses, possible influence of thermal effects, etc.).
  - Few commercially available lasers can reach the conditions of high energy per pulse, short pulse length and high repetition rate required for an industrial implementation of the technique.
  - According to the inherent difficulty for prediction of the shock waves evolution in treated materials, the practical implementation of LSP processes in real pieces of arbitrary geometry needs an effective predictive assessment and on-line process control capabilities.
  - ……

Acknowledgements

Work partly supported by MCYT/MEC (Spain; Projects DPI2001-3669 and DPI2005-09152-C02-01) and EADS-CASA (Spain).
The authors are indebted to Prof. M. Autric (Univ. de la Méditerranée, France) for his personal and scientific support and Dr. Y. Sano (Toshiba Corp., Japan) for very fruitful discussions on the subject of this paper.
Main References

5. CONCLUSIONS

- 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.

- A physically comprehensive calculational tool (SHOCKLAS) has been developed able to systematically study LSP processes starting from laser-plasma interaction.

- By means of full 3D thermo-mechanical treatment, a more realistic analysis is possible.

- SHOCKLAS analysis of laser micro-forming of single-end pinned targets is in good agreement with experiments.

- Experimental validation of SHOCKLAS system assures a high predictive assessment capability for LSP industrial implementation.

REFERENCES


ACKNOWLEDGEMENTS

Work partly supported by MEC (Spain; DPI2005-08152) and EADS MTM Spain

Thank you!