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Morgan Dal, Lucille Gouton. Laser surface texturing Numerical analysis of formation of low depth holes. 17th International workshop IFSW, Feb 2015, Hirshegg, Germany. cea-02489504

HAL Id: cea-02489504
https://cea.hal.science/cea-02489504

Submitted on 24 Feb 2020

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Laser surface texturing
Numerical analysis of formation of low depth holes

Morgan Dal*, Lucille Gouton

04/02/2015

Introduction

Objectives :

Texturing with pulsed fiber laser :

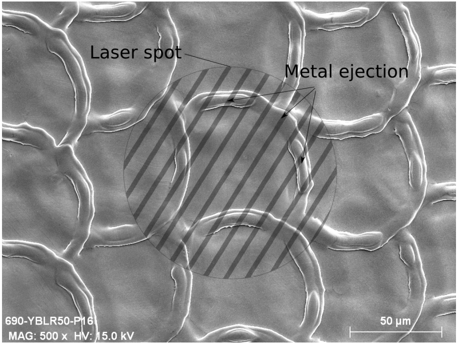


FIGURE : SEM picture of surface treated

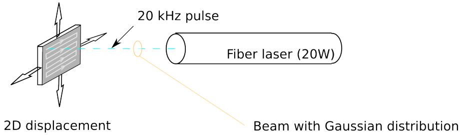
Better **understanding** of the surface deformation under laser radiation → to have a better **control**.

Outlines

Experimental setup and parameters

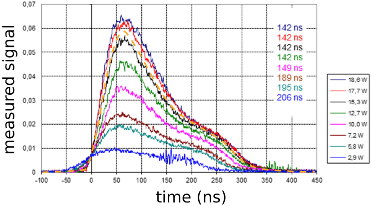
Experiment :

Laser multi-pulse treatment

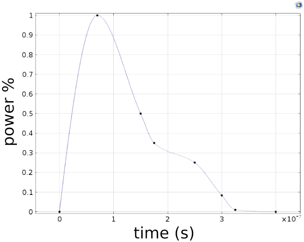


Time distribution of one pulse :

Experiment



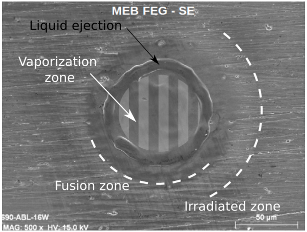
Assumption for the simulation



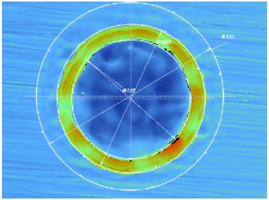
Experimental setup and parameters

Experiment :

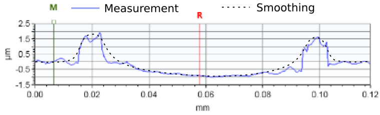
Laser one-pulse analysis



16 W mean power



Bidimentionnal topology



Diameter topology

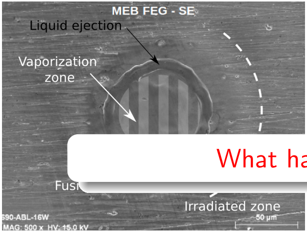
Analysis

- Disturbed shape (sensor sensitivity)
- Maximum 1.5 μm
- Minimum -1 μm

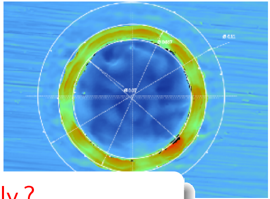
Experimental setup and parameters

Experiment :

Laser one-pulse analysis

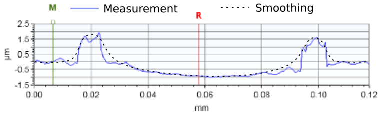


16 W mean power



ology

What happen exactly ?



Diameter topology

Analysis

- Disturbed shape (sensor sensitivity)
- Maximum 1.5 μm
- Minimum -1 μm

Numerical Simulation

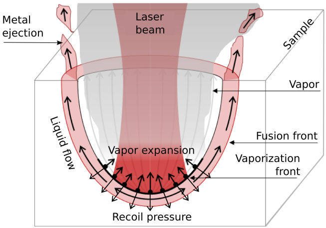
Introduction :

Why ?

- Can not measure deformation → how ?
- Can not observe → our fast cameras allow a micro second measurement
- Appropriate to understand

Knowledge

- The physical knowledge of laser welding
- The simulation of laser drilling
- Using the well known software Comsol Multiphysics®



Scheme of major phenomena [Girardot]

Numerical Simulation

The Model :

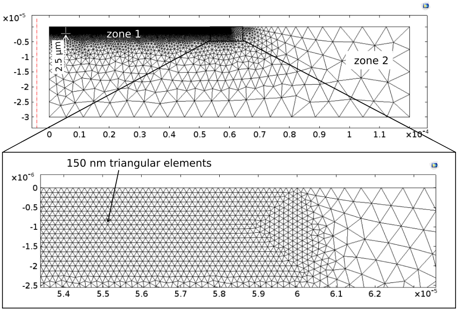
Main assumptions

1. Bi-dimensionnal study (single spot)
2. No gas (just the workpiece)
3. Heat transfer and fluid flow only

Physical assumptions

- Newtonian flow
- Thermal properties = f(T)
- No buoyancy
- No multiple reflexion
- Free boundary accounted with ALE method

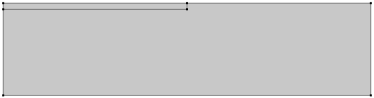
Geometry and mesh



Geometry and Mesh

Numerical Simulation

The Model :



Heat transfers

1. Heat equation

$$\rho c_p^{eq} \frac{\partial T}{\partial t} + \rho c_p \vec{V} \vec{\nabla} T = \nabla . (\lambda \vec{\nabla} T) \quad (1)$$

2. Initial condition

$$T(r, z, t = 0) = T_\infty \quad (2)$$

3. Boundary conditions
   - **at the top** :

$$-\lambda \vec{\nabla} T = \phi_{laser} - \phi_{cv} - \phi_{rad} - \phi_{evap} \quad (3)$$

   - **at the right and bottom** :

$$-\lambda \vec{\nabla} T = 0 \quad (4)$$

   - **at the left** :

$$-\lambda \vec{\nabla} T = 0 \quad (5)$$

Laser power distribution

$$\phi_{laser} = \alpha \frac{2P_{moy}}{\tau f} \frac{exp(-\frac{r^2}{2r_{laser}^2})}{2\pi r_{laser}^2}$$

Heat losses

$$\phi_{cv} = h_{cv}(T - T_\infty)$$

$$\phi_{rad} = \epsilon\sigma(T^4 - T_\infty^4)$$

Evaporation flux

$$\phi_{evap} = \dot{m} L_v$$

$$\dot{m} = \sqrt{\frac{M}{2\pi R}} \frac{p_{sat}}{\sqrt{T}} (1 - \beta_r)$$

Numerical Simulation

The Model :

Fluid flow

1. Mass and momentum conservation

$$\frac{\partial \rho}{\partial t} + \vec{\nabla}.(\rho \vec{V}) = 0 \qquad (6)$$

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho(\vec{V}.\vec{\nabla}).\vec{V} = \vec{\nabla}.\left[-p\mathbf{I} + \mu(\vec{\nabla}\vec{V} + (\vec{\nabla}\vec{V})^T)\right] + \vec{F} \qquad (7)$$

2. Initial condition

$$\vec{V}(r,z,t=0) = \vec{0} \; p(r,z,t=0) = 1.013.10^5 Pa \qquad (8)$$

3. Boundary conditions
   - **at the top** :

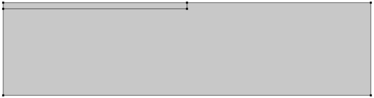
$$p - \sigma_D.\vec{n} = p_{rec} + \gamma \vec{\nabla}_s \vec{n} \qquad (9)$$

   - **at the right and bottom** :

$$\vec{V} = \vec{0} \qquad (10)$$

   - **at the left** :

$$\vec{V}.\vec{n} = 0 \qquad (11)$$



Recoil pressure

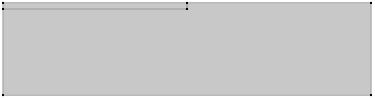
$$p_{rec} = p0 + \frac{p_{sat}}{2}(1 + \beta_r)$$

Saturation vapor pressure

$$p_{sat} = p0exp\left(\frac{ML_v}{R}(\frac{1}{T_{vap}} - \frac{1}{T})\right)$$

Numerical Simulation

The Model :



Free boundary

ALE method

1. In the bulk
   → free deformation (optimize the mesh quality)
2. at the top

$$v_n = un_r + wn_z \tag{12}$$

3. at the right and left

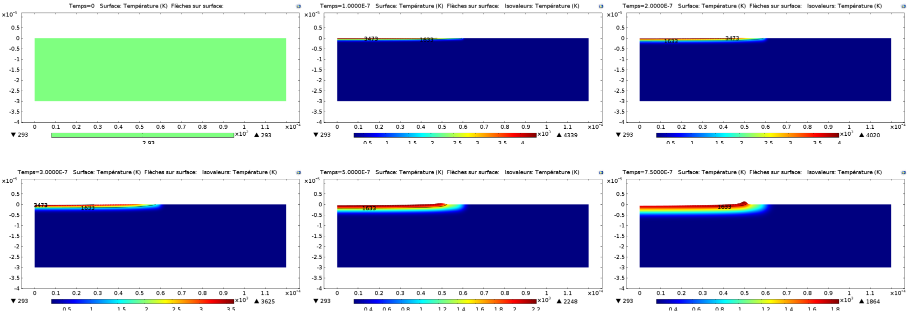
$$d_r = 0 \tag{13}$$

4. at the bottom

$$d_r = 0 \tag{14}$$

Results

The Thermal field :



Observations

- Domain sizes
- Vaporization process
- Creation of a hole shape

Questions

- Is it realistic ?
- How the ring is created ?
- What is the model parameter effect (T_{vap}) ?

Results

Experimental validation :

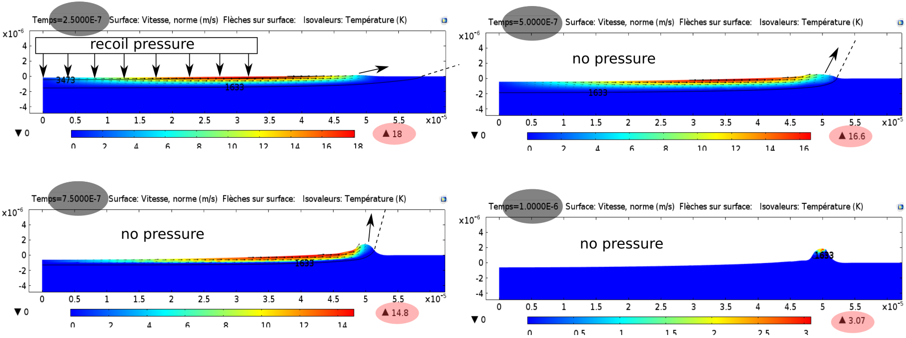
	Experiment	Simulation	
Mean power	16 W	16 W	
Depth	0.9 μm	0.6 μm	
Ring height	1.4 μm	1.8 μm	$\rightarrow$ total deformation : 2.3 μm vs 2.4 μm
Liquid diameter	110 μm	120 μm	
Ring max diameter	90 μm	103 μm	$\rightarrow$ also 10 μm to large

Potential reasons

- Laser power distribution ✗ (spatial and temporal measurement)
- Material absorption ✓
- Material thermal properties ✓
- Pressure calculation ?
- No gas shear stress ?

Analysis

Ripple formation :

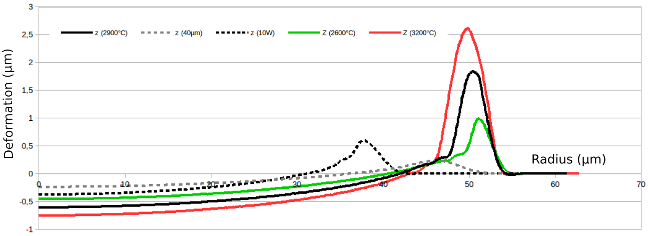


Observation :

The deformed ring is not only created by the recoil pressure (few deformation).
This particular shape is due to the inertia of the fluid coupled to the solidification.

Analysis

Vaporization temperature and power effects :



Comparison

- An increase of 10% on Tvap → increase of 40% on positive deformation
- An increase of 10% on Tvap → increase of 25% on negative deformation
- Tvap have no effect on the ring radius
- Reducing the power to 10 W → reduction of 67% on positive deformation and 37% on negative deformation
- Ring radius decreases of 26%

Conclusion and future works

Conclusion

- Quite efficient model
- Deformation due mainly to the solidification
- Increase the laser radius avoid this effect
- Difficulties with thermal properties

Future works

- Quantify the material properties
- Compute interaction between several shots

Conclusion and future works

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- Quite efficient model
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- Quantify the material properties
- Compute interaction between several shots

Thank you for your attention !