Laser-Material Interaction Modelling using COMSOL Multiphysics®

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Introduction:

- Surface Engineering involves adding functionality to a surface by texturing, or coating
- Laser surface texturing (LST) shows excellent repeatability, non-contact process, the ability to achieve small-size features and high-quality finishing.
- Even though LST is a mature process, its commercial applications are mainly limited to decorative rather than functional texturing.

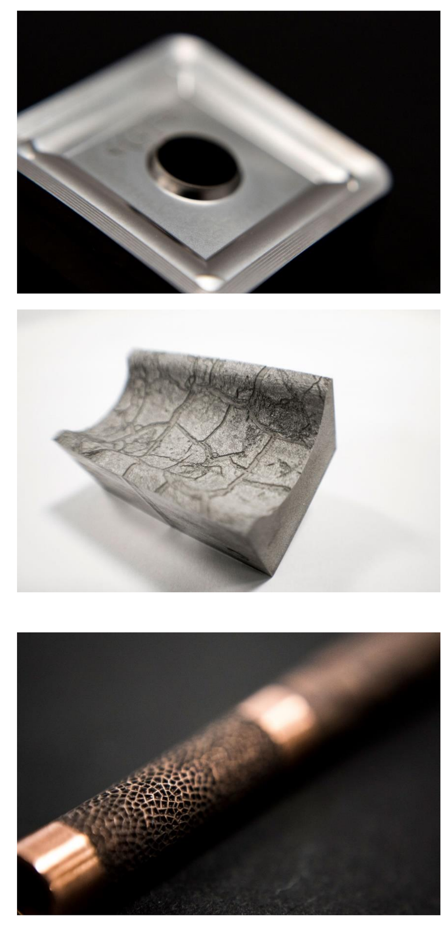

Figure 1. LSTed samples
www.sharkproject.eu

SHARK

→ Developing laser surface texturing from the current trial-and-error, lab-scale concept to a highly predictable, data driven industrial approach.

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More info on www.sharkproject.eu

SIMTEC

→ Build an application using COMSOL Multiphysics® to predict the topography produced given the set of laser parameters and the material properties.

Laser ablation modelling using COMSOL Multiphysics®:

- Laser parameters
- Material properties
- Operating conditions

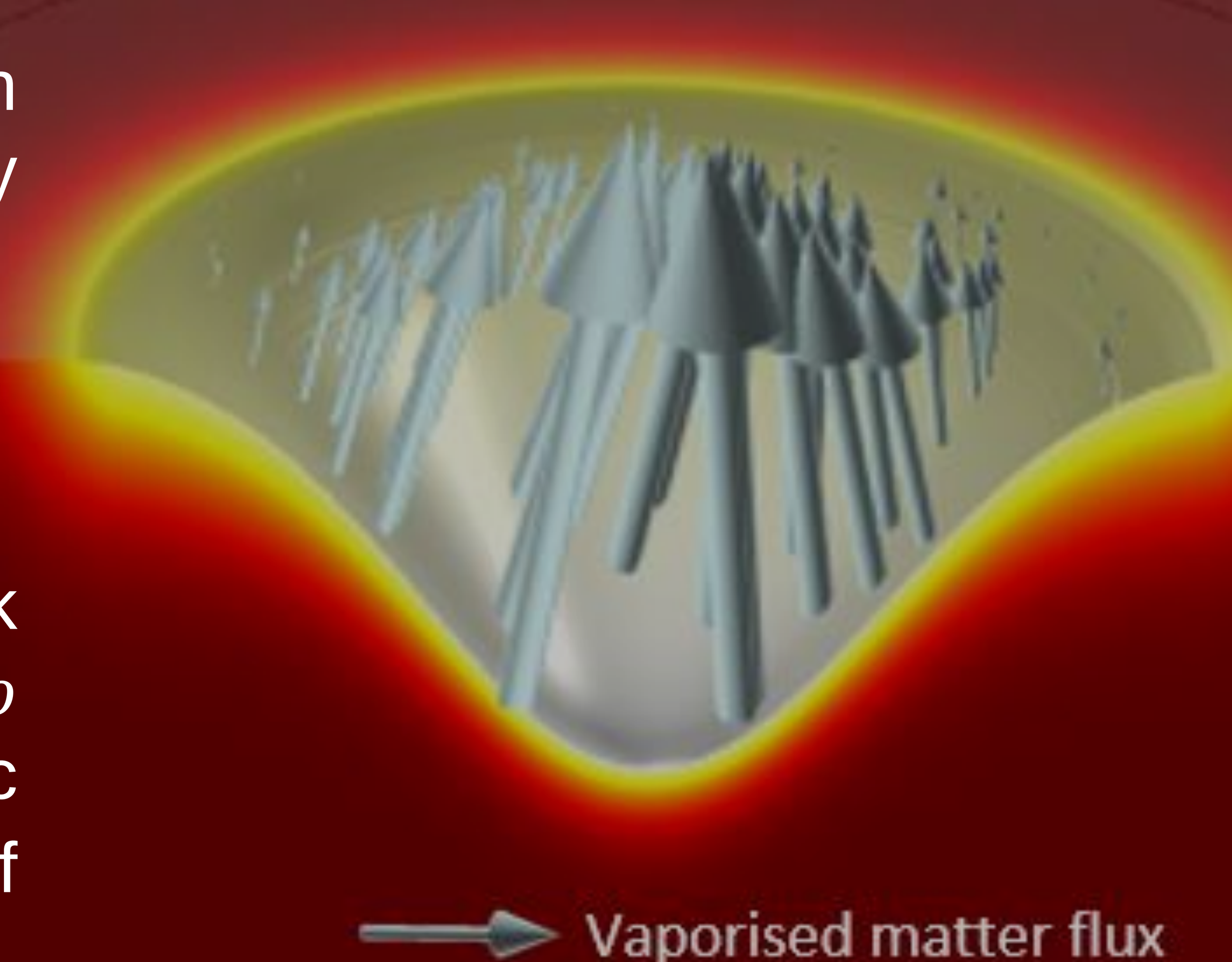
→ Crater topography
- Width
- Depth

Thermal model

The temperature is solved in the heat transfer module by solving the Energy equation:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = 0$$

Where T is the temperature, k the thermal conductivity and ρ the density and C_p the specific heat at constant pressure of the material.



Laser ablation modelling

- Numerical convective heat flux

$$Flux_{vap} = h \cdot (T - T_{vap})$$

Where h is a numerical parameter and T_{vap} is the vaporization temperature.

- Vaporization modelling using deformed geometry with the mesh velocity set at the liquid/gas interface :

$$v_{mesh} \cdot \boldsymbol{n} = \frac{Flux_{vap}}{\rho L_v}$$

Where $\boldsymbol{n}$ is the surface normal vector and L_v is the latent heat of vaporization.

Figure 2. 2D axisymmetric model of laser-material interaction

Results: The thermal predictions are satisfactory, as a good agreement is found between the peak-to-peak distance and the fusion line. The matter ablation modelling predicts relatively well the depth of the crater; however, the peaks and the volume of ablated material are not captured properly by this model (Fig. 3). Therefore a thermo-hydraulic model is developed, taking into account the recoil pressure, surface tension and Marangoni effects. Preliminary results with this model, show good agreement both in crater depth and peak height (Fig. 4).

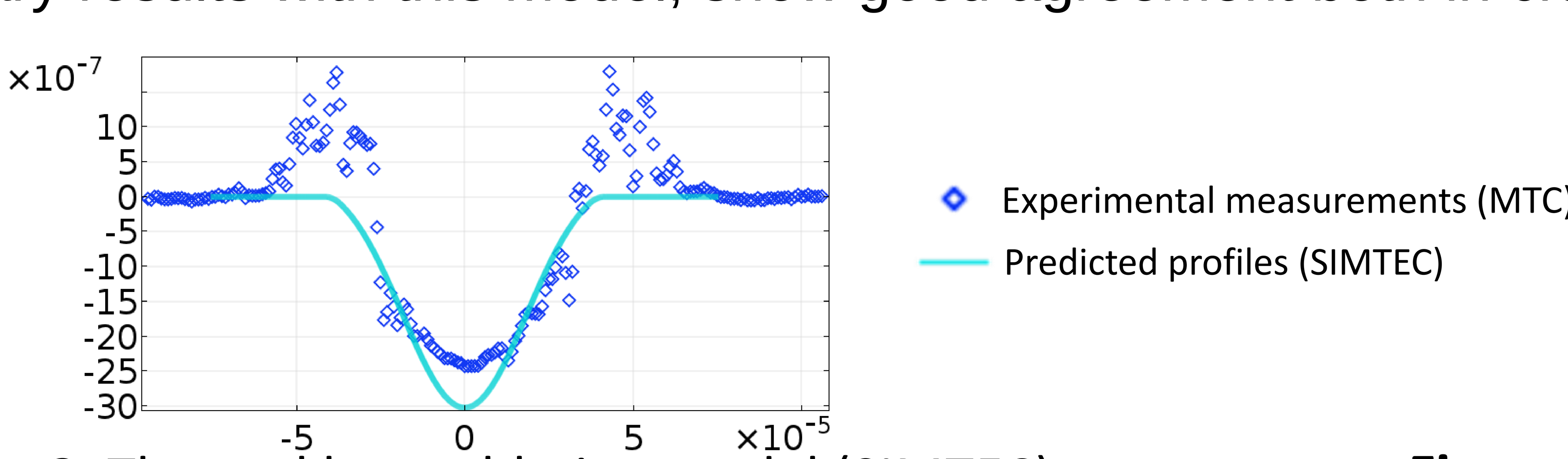


Figure 3. Thermal laser ablation model (SIMTEC) profile comparison with experimental data (MTC)

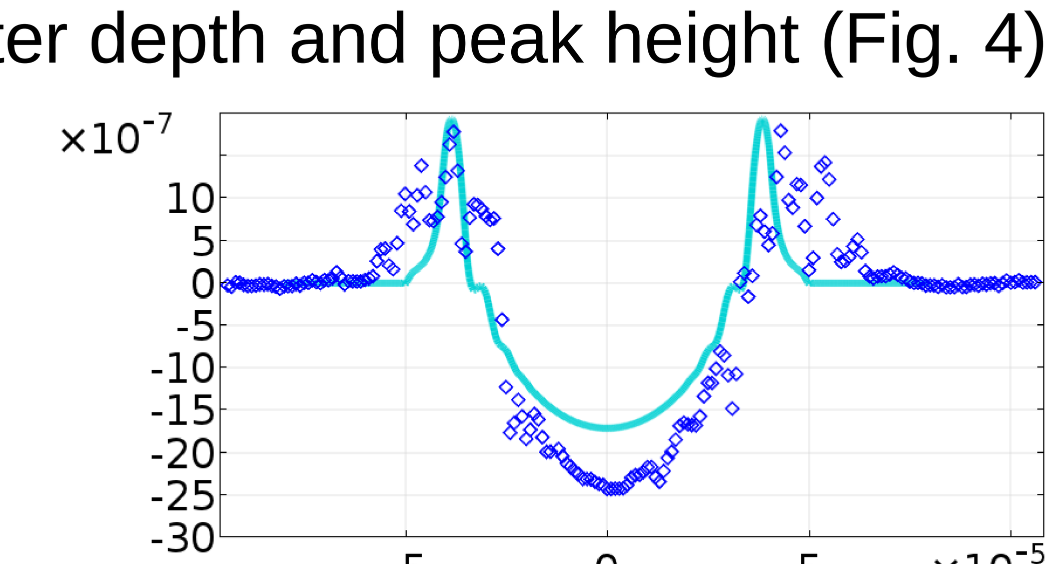


Figure 4. Thermo-hydraulic preliminary model (SIMTEC) profile comparison with experimental data (MTC)

Conclusions: As the surface functionality is deduced from the predicted topography, it is necessary to predict precisely the shape of the crater. Two numerical approaches have been developed and confronted with experimental data. The thermo-hydraulic model appears to be necessary to predict the whole crater shape.