MATHEMATICAL MODELLING OF LASER JOINING PROCESSES

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ABSTRACT

The aim of this work is essentially the mathematical modelling of the ceramic heating process by laser radiation. For these simulations the Finite-Element-Code COMSOL is used. The transient control of the laser beam is modelled by the implementation of additional dynamic equations in the code. The used heat transfer module of COMSOL offers two possibilities of modelling the interaction between laser beam and material. The first one is that the laser beam is regarded as an incoming thermal flow at the surface, at the other way basically the modelling of the laser beam as a local volume heat source is on focus. The results of the simulations, that have been achieved, show a good agreement between model and experiment, being an important part of further research works.

The **AIM** of the work, presented here, is to describe the laser joining process for ceramic materials. Particulary the interaction of laser radiation with *non-transparent* and *semi-transparent* ceramics is on focus (in consideration of: scattering, reflection, absorption, …).

non-transparent

Figure 1: Laser joining process of non-transparent ceramic (SiC)

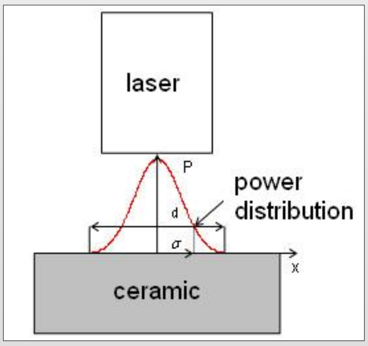


Figure 2: Schematical desription of the laser power distribution

semi-transparent

Figure 3: Laser joining process of semi-transparent ceramic (Al_2O_3)

Thermodynamical BASICS:

Fourier's differential equation

$$\delta_{ts} * \rho(T) * Cp(T) * \frac{\partial T}{\partial t} = div(-k(T)*grad(T)) + Q$$

Radiation: Surface-to-ambient

$$-n*q = q_0 + h*(T_F - T_W) + \varepsilon * \sigma * (T^4_{Umgeb} - T^4)$$

Gaussian distribution of laser power

$$q = \frac{P0}{2*\pi*\sigma^2} * \exp\left(-0.5\left(\left(\frac{x-x_0}{\sigma}\right)^2 + \left(\frac{y-y_0}{\sigma}\right)^2 + \left(\frac{z-z_0}{\sigma}\right)^2\right)\right)$$

Laser motion

$$x_0 = x_{00} + a*\cos(\omega*t) \qquad y_0 = y_{00} + b*\sin(\omega*t)$$

On a plane suface: elliptical

$$x_0 = r_Z*\cos(\omega*t) \qquad y_0 = r_Z*\sin(\omega*t) \qquad z_0 = const.$$

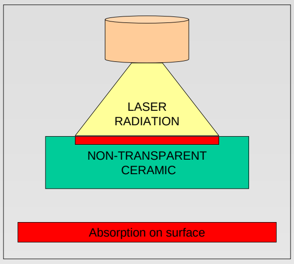
On a curved suface: cylindrical

Exponential weakening of radiation

$$q_{abs}(\Delta d) = q_0 * \exp(-k_\lambda * \Delta d)$$

Non-transparent ceramics

- laser radiation is absorbed on surface (penetration depth ca. 1 µm)
- energy transportation mainly due to thermal conductivity (SiC: ca. 100 W/(mK))
- no transmission, reflection depends on surface condition



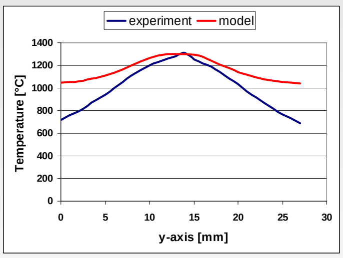


Figure 4: Temperature distribution on y-axis

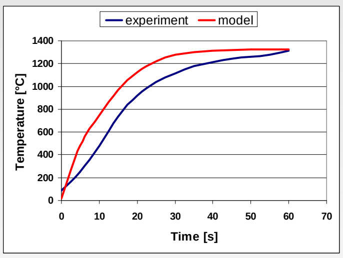


Figure 5: Heating rate of the sample

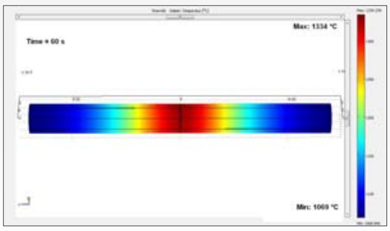


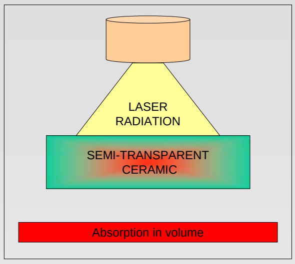
Figure 6: Calculated temperature field of SiSiC-sample

Description of experiment / model:

- rods SiSiC (l=28 mm, d=5.5 mm)
- laser beam power P_0 = 340 W
- laser motion on curved surface (cylindrical)
- time of joining process t = 60 s
- incoming laser radiation modeled as heat source [W/m³]
- no scattering in sample

Semi-transparent ceramics

- laser radiation is absorbed in volume (laser radiation passes sample f(λ))
- energy transportation mainly due to laser radiation
- Thermal conductivity (Al_2O_3: ca. 36 W/(mK))
- high percentage of transmission, reflection depends on material properties



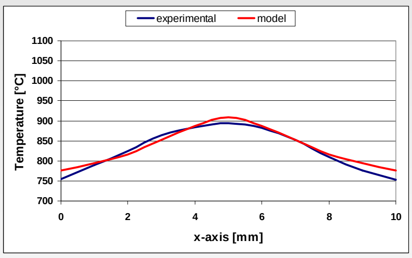


Figure 7: Temperature distribution on x-axis

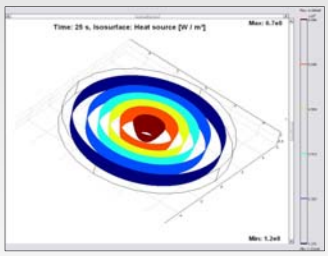


Figure 8: Weakening of heat source in volume

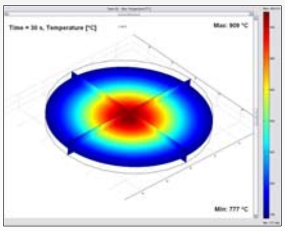


Figure 9: Calculated temperature field

Description of experiment / model:

- disc Al_2O_3 (h = 1 mm, d = 10 mm)
- laser beam power P_0 = 1.100 W
- time of process t = 30 s
- scattering in sample not considered
- absorbed laser radiation for heating:

experiment: 1.29 % → 14.2 W in ceramic
model: 1.30 % → 14.3 W in ceramic

CONCLUSIONS AND OUTLOOK

In order to gain conclusions about the obtained quality of the models of the laser joining process, the calculations are compared with experimental data. The results of the simulations, that have been achieved, show a good agreement between model and experiment.
The development of a light scattering model is on focus for research work in order to gain the final aim: Modelling the complete laser joining process for ceramic materials (non-transparent and semi-transparent).

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