Subproject A3

Title
Massive parallelized simulation of the melt pool dynamics of laser beam micro welding with modern numerical methods.

Project management/-processing
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Task definition
The following tasks were addressed in the year under review:

- Extension of the capillary model
- Implementation of an evaporation model
- Development of an approximate model for the flow around the capillary at the vertex
- Extension of the flow solver

Procedure
In the previous year, a capillary model was presented, with which a stationary welding capillary can be determined layer by layer, and which was used in a hybrid process simulation for the calculation of temperature distributions. Based on this, model extensions were made, which include both absorption contributions from (multiple) reflections of the laser radiation and evaporation contributions in the continuum physical balance equations on the capillary surface. The calculation of the propagation of the laser radiation is realized by a ray tracing method. The evaporation contributions are derived from an evaporation model which takes into account the processes in the Knudsen layer in an ap-proximate manner. A global balance equation takes into account the correct recording of the power components absorbed by the laser radiation within a capillary layer.

To estimate typical values of surface temperature, melt film thickness and mass flow as well as mass and energy components of the evaporation, an approximate model was developed which describes the flow around the capillary vertex in a thin 2D-layer. The model deals with heat conduction and melt flow by means of integral equations and considers the processes of melting and evaporation by means of corresponding balances at the phase boundaries, whereby the above-mentioned evaporation model is also used.

Results

With the help of the capillary model developed, stationary capillaries can be calculated for a quasi-stationary state depending on the process parameters. The consideration of absorption contributions, which are caused by the reflected components of the laser radiation, lead to a significant deepening of the welding capillary. On the other hand, the consideration of melting and evaporation losses limits an overestimation of the welding depth. Thus, the aspect ratios required for microwelding in lap joints can be calculated in good agreement with experimental results from subproject A1. Furthermore, the intensity distribution of the laser radiation on the absorption surface provides information for the assessment of the stability of the capillary in the dynamic case.

The vaporization components calculated with the help of the approximate model provide a small contribution of a few percent in the energy balance for typical feed rates. With increasing feed rate this contribution increases, but remains limited to the single-digit percentage range. The main part of the absorbed energy goes into contributions for heating and melting of the solid material, followed by convective losses due to the melt flow. A corresponding tendency is shown for the evaporation mass flow, which is below one percent. The distribution of the evaporation laterally along the capillary surface leads to an acceleration of the melt in the horizontal direction and to a flow around the capillary. The mass flow of the melt flowing around the capillary far outweighs the evaporation mass flow. This observation provides a decisive insight for the three-dimensional process model with melt, in which a capillary around which the melt flows can be observed in good approximation.

The evaporation model used is based on a hydrodynamic approach in which the continuum physical balance equations are integrated via the phase boundary between melt and gas. These provide step conditions for temperature, density and pressure between liquid and gaseous phase. At first, simplifying assumptions about the state of the gas were made, since the system can generally only be solved from the gas flow if the variables are known. In the future, the flow state is to be validated by numerical calculations.

The FEM solver for the calculation of incompressible flows was implemented using a hybrid O-penMP/Open MPI parallelisation and validated on test cases. For numerical stabilization, the solution algorithm was extended based on a characteristic procedure. The solver will be integrated into the process model in the coming project year, taking into account the boundary conditions relevant for the welding process.

Summary and Conclusion

The mechanisms for the formation of the welding capillary relevant for the microwelding process were implemented in a numerically efficient process model. The flow conditions in the flow of the capillary were analysed using an ap-proximative model and indicate low evaporation rates. Evaporation as a melt driving force was included as a subproject overlapping research topic for the working group M2, because it is also a relevant phenomenon for other subprojects. The aim is to compare different approaches from the literature and to develop a methodology for the description of laser-based, melt-driven manufacturing processes.

The next working points of the subproject are:

- Extension of the capillary model by flow corrections for a more precise calculation of the distributions of the continuum-umphysical quantities on the capillary surface
- Integration of the capillary model into a hybrid process model for the calculation of three-dimensional temperature distributions
- Integration of the numerical flow solver into the capillary model to evaluate the approximate flow models
- Extension of the flow solver for the description of multicomponent melts