

Minimizing the distortions during the AM build-up phase by simulation based, adaptive support structure

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Laser Beam Melting (LBM) as an additive manufacturing technology has the potential for efficient lightweight production. Furthermore there is a huge potential to save material compared to subtractive methods, which leads to cost saving and a positive ecological evaluation. Nevertheless, for a successful process support structure is needed. The sort, amount, dimensions and placement of those structures are mostly based on the experience of the user. Usually there is one set of parameters for those structures applied to the whole part. Depending on how complex and filigree a part is, the amount of support structure could reach and exceed the mass of the part itself. To save material, building and postprocessing time while increasing the process stability, simulation-based adaptation of support structures can be used. In a build simulation, the distortion is analyzed and when exceeding a threshold, a new support is added and the simulation proceeds, taking the new support into account. First approaches with this method were made using pin-supports in dental applications.

Key Words – Finite Element Method, Laser Beam Melting Process, Mechanical Process Equivalent

I. INTRODUCTION

Additive manufacturing using metal powders became more important for industrial applications within the recent past [1]. However, while the LBM technology is emerging the support structures are still simple and homogeneously distributed. Those structures are required for a successful build because process induced stress leads to deformations. To minimize those deformations during the process itself, support structures have to provide a mechanical fixation. Otherwise, the deformations of the part would lead to a collision with the blade (or squeegee or roller) that adds a new powder layer. Furthermore, the support structure is needed to transport process heat out of the part to avoid overheating. Such effects lead to sintering with surrounding metal powder, which is reducing the surface quality and dimensional accuracy. However, one has to consider that these

structures are unwanted once the process is completed. Hence, reducing the amount of supports would directly reduce *wasted* material and thus material costs and build up time.

In this paper, a simulation-based approach is presented to generate an adaptive support structure. During a fast numerical build simulation, the distortion is analyzed and when a threshold is exceeded, a new support is added.

II. MATERIALS AND METHODS

The build process is simulated using the Finite Element Method (FEM). The FE mesh needed for the simulation is generated layer wise, see Kober et al. for further details [2]. For modeling the built up itself, the method of the mechanical process equivalent (MPE) is used. In this approach, the thermal shrinkage of each new layer is inserted into the simulation as a mechanical boundary condition [3]. So the process can be reduced to a static mechanical problem which saves a huge amount of calculation time. At first, a new layer of elements is activated stress-free, then the process equivalent is added as a strain. The resulting stress and strains in the part are calculated as a static state.

When generating support structures, it is in the actual process as well as in the simulation necessary to support every local minima in the part, regarding to the build-up direction. In the process, a not supported area would cause overheating and overcritical distortions. In the static, mechanical simulation there would be no overheating of cause, but large distortions will appear as well. Moreover, since no supporting gravity and powder bed is taken into account, the region might drift due to small numerical errors. In that case, the static calculation would not converge.

To avoid such problems, in the simulation every local minima will be supported at the beginning. The supports used for generating dental applications in this case are cones. They have a diameter

of 1mm at the baseplate, which is slightly decreasing in built direction. For preparing the support simulation, the FE-mesh is lifted by two millimeters to have a gap between the model and the virtual baseplate. A uniform grid of nodes represents this baseplate, which is done to avoid adding extra nodes into a running FE-simulation.

For the modeling, those supports are represented by linear beam elements. In the used FEM model, neither the nodes of linear nor volumetric elements have rotational degrees of freedom. Therefore, to gain completely defining constrains, the authors chose to represent a single pin support by a tripod of linear elements. Furthermore, to support a local minimum in the FE-Mesh, three tripods are used.

After the simulation, the support structure is exported as STL geometry. Therefore, for each tripod a cone is generated. In this step, for each local minima in mesh the actual local minima in the original STL is identified and the closest support is moved to that exact position to avoid problems during a build process.

III. RESULTS AND DISCUSSION

First results were gained using a MPE of a calibration for CoCr (Wirobond C+) [4], Fig. 1.

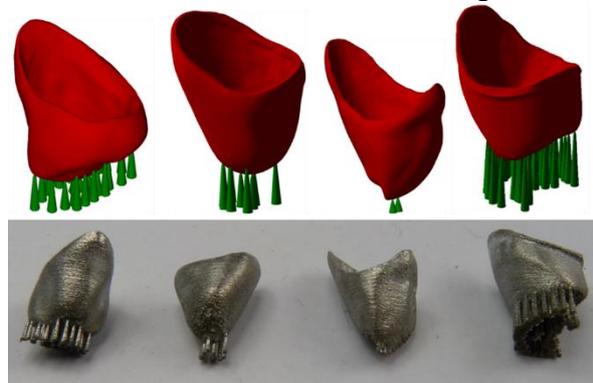


Fig. 1: Top: first calculated support structures (green) for four dental geometries (red). Bottom: the experimental results.

Those results show, that a manufacturing is possible using up to 90% less support structures compared to the state of the art (second geometry from the right). Further experiments showed that sometimes not all supports remain at the part until the end of the process. However, the failure of supports can be seen as an indicator of a not stable process. To increase the number of supports in the simulation the allowed threshold was decreased and in a second step, the MPE was increased to cause larger distortions.

In Fig. 2 one can see, that the decrease of the threshold leads, depending on the geometry, just to a slightly increase of the number of supports.

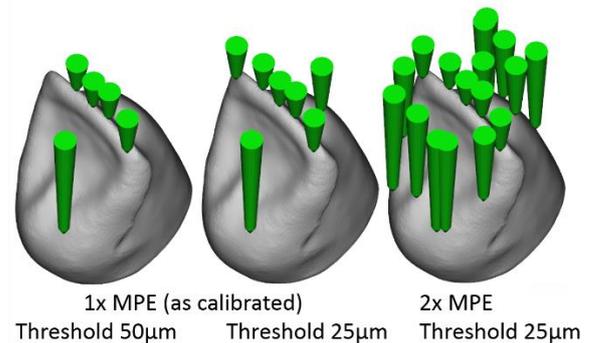


Fig. 2: Simulated supports (green) based on different input parameters.

IV. CONCLUSION

The simulation-based generation of adaptive support structures shows a great potential to decrease the support volume. Further investigations, considering thermal effects can lead to a very sophisticated and effective support structure. Especially when the developed method is combined with a *tree support approach* and lattice structures.

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