SIMULATION OF THE SHRINKAGE BEHAVIOR IN FUSED DEPOSITION MODELING

The Fused Depositioning Modeling (FDM) process is one of the most common additive manufacturing processes. Due to the cooling of the material after the deposition of the thermoplastic strand, shrinkage occurs. The degree of the occurring shrinkage depends on certain process parameters as well as on the geometric properties of the components. As the influences of these process parameters and geometric properties are not yet sufficiently known, this project investigates the effects on the shrinkage by the use of simulations of the ongoing processes inside the FDM machine.

PROJECT OVERVIEW

DURATION

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Objectives

As with other additive manufacturing processes the components built with Fused Deposition Modeling (FDM) are generated layer by layer. Therfore a thermoplastic filament is conveyed into the FDM head. Here it is plastified inside a heated nozzle and deposited onto the building platform or an existing structure. The heat of the newly deposited strand is responsible for a successfull welding of this strand to the prior deposited material.

As the temperature inside the building chamber is lower than the nozzle temperature and therefore the temperature of the strand exiting the nozzle, the material cools down. In the course of this cooling the strand shrinks. As the component to be manufactured is built up strand by strand and layer by layer, the shrinkage of the strands is not steady. Rather the overall shrinkage of the part depends not only on the shringake of a single strand but is influenced by the surrounding strands. Therefore the shrinkage is influenced by process parameters that vary the position of the strands relative to each other, as well by the geometric properties of the component to be manufactured. This is related to the already solid strands obstructing the shrinking of the newly deposited strands as well as the influence of different temperature levels due to changing cross sections of the component to be manufactured.

In the course of this project the decisive influencing factors and their effects on the shrinkage shall be determined. With the help of simulations the shrinkage behavior is to be modelled. Subsequent to the validation of the simulations a local scaling of the component to be manufactured is intended to avoid a discrepancy concerning the CAD model and the resulting component manufactured with the FDM process.

Procedure

The investigations are carried out with a Stratasys Fortus 400mc FDM machine processing the material ABS M30. In the course of the investigations two further materials will be taken in account. These are Ultem 9085 and FDM Nylon 12.

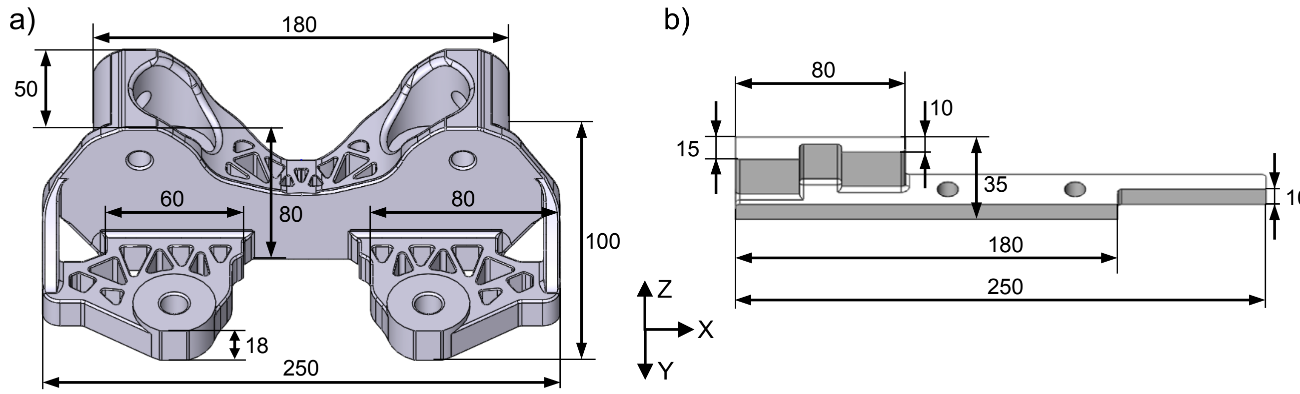

FIGURE 1 Visualisation of the demonstrators used to validate the determined local scaling factors.

To begin with the investigation of the shrinkage behavior, at first an elementary cell shall be determined. The aim of this procedure is to achieve a division of any component to be manufactured into the smallest volumes possible. During the finding of this elementary cell it is mandatory to pay attention to a reasonable size of the elementary cell. If the volume of the cell is chosen too small, the simulation of the shrinkage occurring in the cell cannot be validated, as the cell may be to small to be manufactured using an FDM machine.

In order to simulate the shrinkage behavior at first several information must be gathered. For the simulations it is crucial to know the temperature of the material the moment it leaves the nozzle. The temperature of the nozzle is displayed by the machine. Due to the continuous feed of new material through the filament and the positioning of the temperature sensor, the temperature of the material at the point of leaving the nozzle is expected to be lower than the displayed nozzle temperature. To determine the correct material temperature, in addition to physical temperature measurements, a simulation shall be carried out.

For all the simulations certain material properties must be known. These are for example the Young's modulus, Poisson's ratio, thermal conductivity and thermal diffusity, heat capacity as well as the coefficient of linear expansion.

As soon as the temperature of the material leaving the nozzle is identified, the simulation of the cooling behaviour can be conducted. For this the software Abaqus by Dassault Systèmes is used. This software enables the user not only to consider the thermal conduction, shrinkage and cooling behaviour but also the evaluation of surpressed shrinkage by the allready cooled strands and the resulting residual stress.

These results shall then be validated. For this, thermal sensors can be placed inside the component to be build during the building process. This can be achieved by pausing the process and inserting the thermal sensors at defined locations on the current layer of the component. As the building process is continued the thermal sensor is embedded into the component. With this the temperature profile can be tracked and compared to the results of the simulation. Not only the correct simulation of the temperature profiles but also the resulting geometrical deviations shall be validated. Therefore, several specimens with different geometries shall be manufactured using the FDM process. Subsequently the geometrical properties of these specimen are to be measured using a coordinate measuring machine. A comparison of these measurements with the results of the simulation provides conclusions about the informative value of the simulation regarding the shrinkage of components manufactured with the FDM process.

Using these results a method for determing ideal scaling factors to compensate the shrinkage prior to the manufacturing process is to be found. In a further step local scaling factors are to be determined as they vary depending on the nominal length of the considered section of a component. These local scaling factors are to be validated using two demonstrators shown in Figure 1. Furthermore the possibility of an automated adaption of the CAD models for complex parts using the identified scaling factors will be investigated.