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Adapted approach of the product development process for hybrid manufactured parts

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Abstract

The researched hybrid manufacturing process presents a solution in the field of tension between pure additive manufacturing processes like selective laser melting and pure subtractive manufacturing processes like milling or turning. With the goal to further reduce time and costs, a product development process has been developed, where the advantages of the laser metal deposition (LMD) process have been used to optimize the part structure towards a minimum of used resources.

LMD is a layer-by-layer additive manufacturing process building parts based on a nozzle-fed powder by laser assisted solidification. The LMD technology offers unique advantages for the production of near net-shape parts. In most cases near net-shape parts require a turning or milling process in order to get to the final shape. The LMD is the perfect partner in a hybrid manufacturing process using additive and subtractive processes in synergy.

The researched hybrid manufacturing process is manufacturing a part by partly a raw stock and additive material added by the LMD process. During or after this process, a subtractive milling process is commonly used to finish the part towards the final contour.

The product development process for additive manufacturing usually contains the steps of the part design in CAD, the slicing and the manufacturing of the part. In the hybrid manufacturing process, the design step needs an additional optimization of the ratio between the raw stock and the LMD added material after the part design in CAD and an optional FEM optimization. The three design steps CAD design, FEM optimization and manufacturing optimization have an influence on each other, thus have to be processed in an iterative way.

Keywords: LMD; additive manufacturing; hybrid manufacturing; product development process

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1. Introduction

Today's lightweight parts manufactured by milling loses up to 95% of the raw stock material as waste. Producing parts like this costs time and energy and is not sustainable. (Allen, 2006)

The buy-to-fly ratio is the rate between the raw stock material and the final part. 3D printed parts have a buy-to-fly ratio of nearly 1, just functional planes have to be post processed by milling. In contrast fully milled parts can have a buy-to-fly ratio of up to 20 if 95% of the raw stock have been machined. 3D printing lacks in productivity compared with milling, only parts with high buy-to-fly ratio can be produced economic by 3D printing. (Allen, 2006)

The researched hybrid manufacturing process combines the laser metal deposition (LMD) with mechanical machining. Zhu et al., 2013 assign the process to the hybrid manufacturing group "hybrid additive and subtractive manufacturing processes". This hybrid manufacturing class use the additive process to build a near-net shape which will be machined to its final shape. (Zhu et al., 2013)

LMD is a layer-by-layer manufacturing process for the production of three-dimensional complex parts (Ravi et al., 2013). LMD is an additive process were nozzle fed powder is solidified by a laser.

The repair of high value parts was shown by Brandl, 2010 and Thijs et al., 2010. The additive manufacturing process offers a high geometrical flexibility in comparison to conventional manufacturing technologies like Laser Additive Manufacturing (LAM) (Brandl, 2010).

The advantage of LMD as additive manufacturing process is that no powder bed is necessary. This allows the repair of a damaged part or building material on a raw stock material.

The researched hybrid manufacturing process enables the application of the mentioned advantage. The near-net shape part consists of partly raw stock and LMD added material. The final shape will be machined by the subtractive process. Using the mentioned hybrid manufacturing process enables the chance to design and manufacture parts individual in the field of tension between pure subtractive machining and pure additive manufacturing. The positioning of a part in this field of tension based on its shape allows an optimization of the manufacturing time and costs. Figure 1 shows the field of tension as a sketch. A solid line around the sketched part describes a raw stock part. A dashed line means the near-net shape added material. The buy-to-fly ratio is near 1 in the pure additive part, shown in figure 1 (c). The complete subtractive part in figure 1 (a) has a worse buy-to-fly ratio. The hybrid manufactured part, shown in figure 1 (b), has a buy-to-fly ratio near to the pure additive manufactured part with the advantage that the raw stock material is cheaper than a comparable additive manufactured material. A hybrid manufactured part provide the potential to be produced with less time and cost compared to the other mentioned manufacturing processes.

The hybrid manufacturing process requires an adapted design approach to use its full potential. Containing the degree of freedom in design using the LMD process, the optimal ratio between raw stock and LMD added material as well as the limitations of the subtractive process.

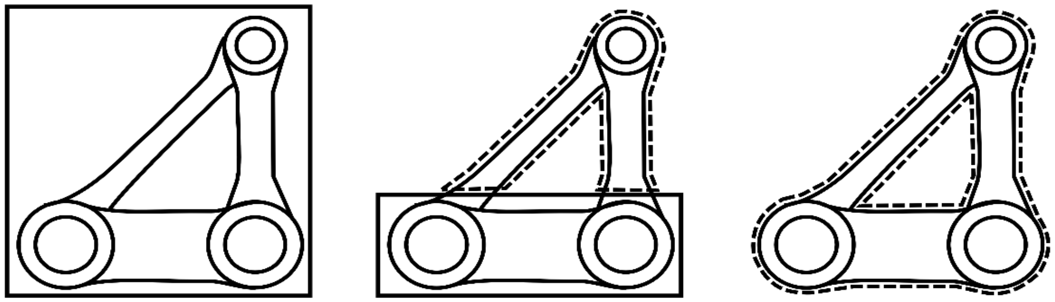

Fig. 1. Sketch of (a) subtractive manufactured part, (b) hybrid manufactured part and (c) additive manufactured part

2. Adapted product development process

The starting point for the product development process was the product development process according to the VDI 2221. The design of a part is described in the step 4 to 6 of the VDI guideline. In detail the VDI 2223 look on these three steps. In step 4 the requirements and conditions influencing the form design have to be identified. These and the connection conditions fixed during modularization of the product build the result of step 4. Step 5 contains the preliminary design of the parts. In step 6 the design of the product and all containing parts get finalized. (VDI 2221, VDI 2223)

In difference to a usual part development the hybrid manufacturing forces an early view on the manufacturability of the part. Therefore, design guidelines for all influencing parts of the production have to be considered. Beneath this resource the decision of the proportion of the raw stock have a high influence on the whole manufacturing process and although on the part design.

The example, shown in figure 1 (b), demonstrate the potential of the hybrid manufacturing process by optimizing the ratio of the raw stock material. On the one handy it is possible to reduce massively the buy-to-fly in contrast to a subtractive manufacturing process and on the other hand to minimize the added material.

The adapted product development process is shown in figure 2. It divides the part design process into two categories with overall six steps. The first category contains the shape design of the part, while the second part addresses the manufacturing optimization. Both categories and their steps have to be processed iteratively like it is shown in the figure 2.

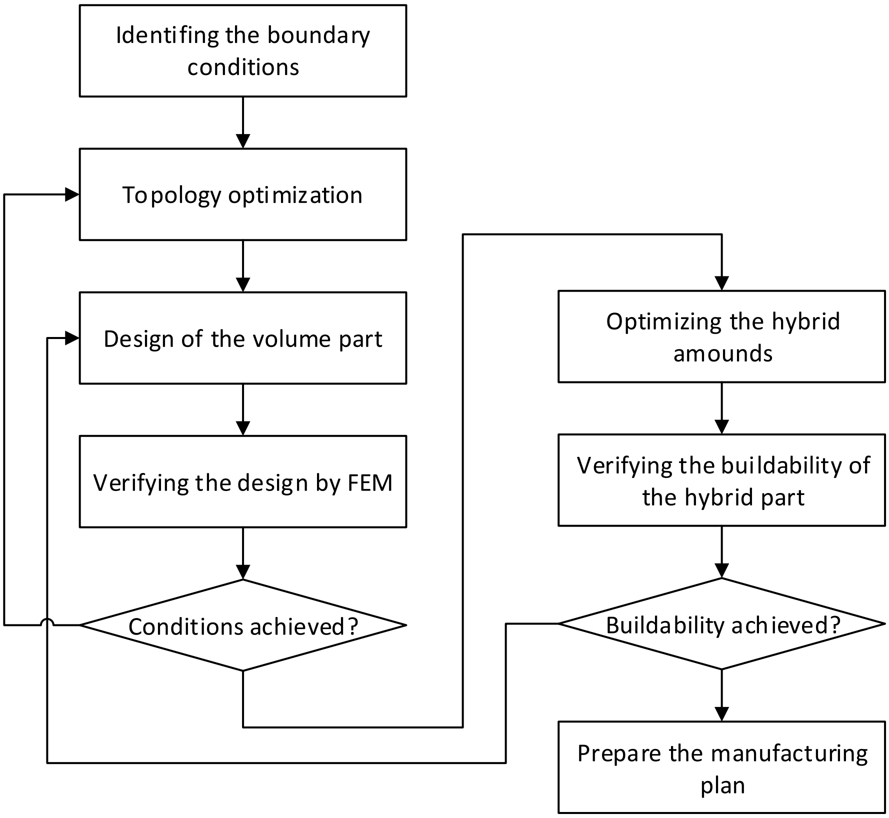

Fig. 2. Flowchart of the adapted product development process

First the boundary conditions of the part have to be defined. This include the connection condition and the material. The connection requirements define the maximum measure of the construction space, the applied forces as well as the detailed variant of the forces introduction, for example by bolds. The definition of the material specifies the mechanical properties of the part that is needed for the topology optimization.

2.1. Shape optimization

The topology optimization uses the boundary conditions as starting parameters. It is useful to restrict a minimum of the construction space to identify the flux of the forces. Common topology optimization tools can be used.

Typical tools for topology optimization uses the soft kill option method based on the principle of bone growth. Herein the algorithm modifies the elasticity modulus of areas with little stress. The iterative modification finishes if the termination condition is reached. The result can be plotted as density model of the construction space, where areas with high stresses have a high density and the ones with little stresses have a low density. (VDI 6224-2)

The generated density model of the part will be transferred to a volume part in CAD. During this design process the construction and manufacturing restrictions have to be considered to generate a suitable part design. Design guidelines of the manufacturing processes can be used to generate these restrictions.

Following this, the designed part will be verified by a FEM simulation. The FEM simulation is used to identify oversizing in the part as well as to verify areas of the part which have been modified in comparison to the topology optimization due to restrictions.

The shape optimization ends with the decision if the designed part accomplish to the boundary constraints and the process restrictions. A negative results leads to a redesign of the part, an iterative loop to the topology optimization or the part design step.

2.2. Manufacturing optimization

The designed part has to be optimized for the hybrid process. In this hybrid manufacturing process, the near-net shape part is a combination of a raw stock material and additive added material. To save costs and time in manufacturing the ratio between raw stock and added material has to be optimized. Manufacturing time and cost driver are the time to add the material and the amount of time to remove the material from the raw stock towards the shape of the part. Aim of the optimization is the minimization of both cost driver.

After the determination of the ratio between raw stock and added material, the manufacturing sequence will be defined. The sequence is influenced by the complexity of the part shape and the degree of freedom of the manufacturing machines. On the one hand it can be possible that the near-net shape part will be manufactured in one step and will be machined afterwards, on the other hand it can be necessary to machine the raw stock before adding material in case of undercuts. Also large build-ups can require a sequential additive manufacturing because of the reachability of the subtractive machining tools.

The last step of the manufacturing optimization is the decision if the found ratio between the raw stock, the additive material and the derived manufacturing sequence accomplish to all the defined requirements and conditions. The verification of the buildability of the part is made on the basis of

- Availability of the raw stock material
- Restriction of the additive LMD process
- Restriction of the subtractive machining process
- Fulfillment of the boundary condition

Result of the verification present the further optimization potential or necessity of the designed part. Depending on the following decision the product design can be pursuit or a back step is needed. Pending on the result the back step can require a partly redesign of the volume part up to a complete new shape optimization.

3. Summary

The researched hybrid manufacturing process forces an adapted design approach. The combination of LMD as additive manufacturing process and machining as subtractive manufacturing process offers a high potential to optimize the manufacturing of parts. The researched product development process enables the construction of parts optimized for the hybrid manufacturing process.

The described product development process enables a rise in productivity by combining the advantages of the additive LMD process and the subtractive milling process. The advantage of the subtractive process is a high productivity by removing material, while the advantage of the additive process the near-net shape added material is. Both processes in addition of raw stock material offers an optimization of the manufacturing by minimizing the additive and subtractive manufacturing processes.

In summary the following results have been developed,

- A definition of a hybrid manufacturing process using raw stock beside LMD added material and a subtractive manufacturing process,

- The advantages of the hybrid manufacturing process have been listed,
- An adapted product development process has been developed to use the advantages of the mentioned hybrid manufacturing process.

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