Potentials of Generative Manufactured Components for Gaining Resource Efficiency of Production Facilities

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Abstract

A sustainable management of resources is getting more and more essential to reduce the ecological damage, to increase the guarantee of resources and to reduce production costs for an enhanced competition position. Therefore, an optimized use of energy and resources along the whole product life cycle is necessary. This paper shows the potentials of generative manufacturing processes to reach this goal in the sections production and utilization. Two approaches for that purpose are the usage of lightweight components and the manufacturing of multi-material components.

1 Resource efficiency of production facilities within their product life cycle

A sustainable use of natural resources is increasingly getting important. This is founded in the fact that the global demand of raw material like oil, coal, steel, aluminum or copper has grown continuously within the last thirty years [1].

This increased request in combination with the limited availability of most resources leads to a lot of arguments for a sustainable usage of resources. First of all, there can be reached a severe reduction of ecological damage concerning the consumption of energy and the wastage of material. Secondly, the supply guarantee of resources gets increased and finally, the reduction of material and energy wastage leads to reduced production costs and therefore to an enhanced competitive position [1], [2].

The required sustainable resource management can be achieved best by a well-directed use of energy and material in all phases the product life cycle [2], whereas this paper especially addresses the sections production and utilization phase (Figure 1).

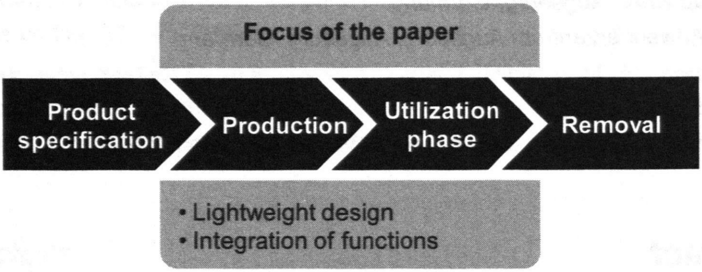

Figure 1: *Product life cycle of production facilities and focus of the paper*

Possible approaches to reach resource efficiency within these two sections of the life cycle are lightweight design and integration of functions [3]. In case of production, this results in a reduction of material, especially in case of rare and expensive substances. While the operation of production facilities, the reduced weight leads to less accelerated masses and therefore to a lower energy consumption.

2 *Potentials of additive layer manufacturing*

For a realization of the approaches, described in topic one, conventional manufacturing processes show a multitude of limitations concerning the geometrical freedom in part design as well as the usability and combinability of materials.

Alternatively to those production techniques like milling, turning or grinding, a new category of manufacturing methods has established since the year 1986: additive layer manufacturing (ALM) [4].

In ALM-processes, the joining of individual volume elements is getting adopted to build up a part. In "Selective Laser Melting" (SLM), for example, the process begins with the application of a layer of powder on a construction platform. Afterwards, the powder material is getting solidified (e.g. by melting with a laser). This is followed by a lowering of the platform for the thickness of one layer and the anew adoption of powder material. This cycle is getting repeated until the part is finished [5].

This process features fewer restrictions in the geometric design of lightweight parts and allows the combination of multiple materials within one part.

2.1 Lightweight designing for resource efficiency

As shown in topic one, the approach to use lightweight design components in manufacturing facilities has several advantages. This concerns the reduction of their material and energy consumption when they are getting produced as well as during their utilization. A precondition for an efficient weight reduction, however, is a sufficient design space. Hence, especially massive parts with few constraints (e.g. thermal properties) besides their mechanical requirements show the most potential.

The approaches can be differentiated in three categories: microscopic, mesoscopic and macroscopic lightweight construction principles. Microscopic design on the one hand addresses the well-directed manipulation of the microstructure of one and the same material, which can be reached for example by specific process parameters. This subject is not addressed in this paper. The following sections will outline possibilities for macroscopic and mesoscopic lightweight design principles, whereas their potentials will be illustrated by beams, which have been manufactured and tested for their bending stiffness. Like in numerous cases, the stiffness-to-mass-ratio is a good indicator for the potential of each approach, at which a high stiffness in combination with low masses leads to a good value.

2.1.1 Macroscopic lightweight design approaches

Macroscopic lightweight design addresses for example the optimization of the part geometry in relation to the loads applied to it. This can be performed by computer supported methods like the finite elements method (FEM) based topology optimization.

The topology optimization is a numerical simulation process with the aim to calculate an ideal distribution of material inside a predetermined design space. Its output is a draft of the treated part, which fulfills the requirements concerning stability, and which does not show any unnecessary concentrations of material in low stressed part areas.

Unfortunately, those ideal design solutions can mostly not be manufactured with conventional processes, because there have to be expected several boundary conditions like accessibility for cutting processes or draft angles in casting. However, in ALM, there exist only minor constraints, so most solutions from the topology optimization process can be adopted almost directly.

This was executed for a beam (Figure 2 left) and the output (Figure 2 right) was subjected to a bending test to obtain its stiffness.

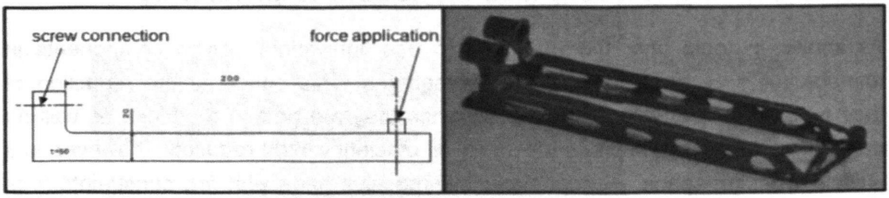

Figure 2: *Beam for optimization tasks (left) and beam after topology optimization (right)*

As a result of this experiment, it could be recognized, that the topology optimized beam showed a stiffness of 148 N/mm at a weight of 108 g, while a comparable standard beam with the same stiffness would have a weight of 339 g.

2.1.2 Mesoscopic lightweight design approaches

In comparison to macroscopic approaches, at mesoscopic lightweight design, the structure of the material is getting varied according to the applied loads. Here, bionic patterns like honeycombs, foams or lattice structures can be mentioned.

These cellular materials exhibit some very advantageous properties like low density, and therefore low mass, along with high strength and stiffness [6].

To show the potentials of cellular structures, the beam from Figure 2 left was designed with a body consisting of regular lattice structures, while the screw connection was kept massive (Figure 3).

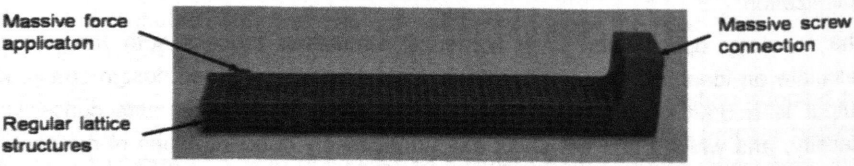

Figure 3: *Beam with a body consisting of lattice structures*

This specimen was also built up in an SLM-process and tested. In this case, there could be measured a stiffness of 71 N/mm at a weight of the structure of 100 g. The body of a regular beam with the same stiffness would exhibit a weight of 166 g.

2.1.3 Combination of a topology optimization and lattice structures

In the prior topic, a beam with a steady body out of regular lattice structures was tested. In this case, there are even trusses at positions, where we can find only less stress. To improve the results, a topology optimization was executed on the steady body, and afterwards, it was filled with the pattern (Figure 4).

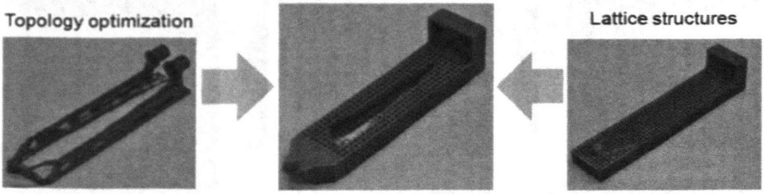

Figure 4: *Combination of a topology optimization and the usage of lattice structures*

Due to this approach, a stiffness of 59 N/mm was achieved at a weight of 46 g. The body of a regular beam with that stiffness would exhibit a mass of 151 g.

So, this approach – together with the topology optimization – shows the best stiffness to mass ratio.

But there are still possibilities to improve the results. All the structures shown in this paper have a regular design. This leads to shear forces within the trusses. However, in an ideal lattice, only push and pull forces appear. Therefore, in future works, there will be tried to orientate the bars along the flux of force to reach this stress state. Furthermore, the diameter of each bar will be adapted to its strain.

2.2 Resource efficiency by manufacturing multi-material components

As mentioned before, ALM-processes have not only a high potential to manufacture geometric complex parts. They rather can melt quite different materials at once. Using this instance, new product quality can be produced by combining two or more varying materials [7].

2.2.1 Combination of materials

Additive Layer Manufacturing (ALM) can handle nearly each meltable material. Fusing two different materials in one layer requires extensive knowhow of both materials. Each material has a specific process window, which is essential for the following multi-material process [8], [9]. Process parameters can be chosen individually for each material during the melting process.

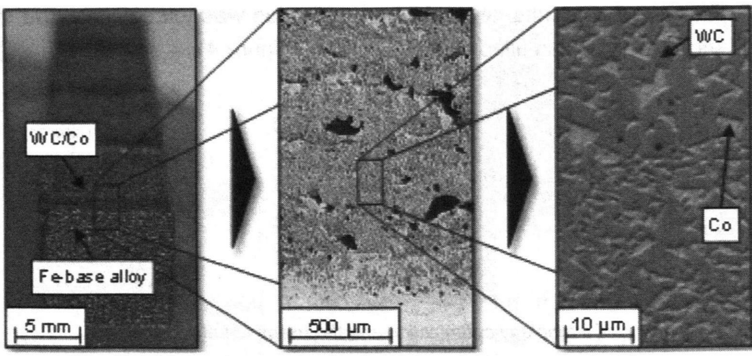

Figure 5: *Combination of Fe-base alloy (1.2709) and tungsten carbide cobalt (WC/Co)*

Hence, it is possible to join two different materials, e. g. a wear resistant material like tungsten carbide and Fe-base alloy (Figure 5). By using a laser beam adhesive bond between these materials can be realized. This leads to a higher bonding strength, as form fitting mechanism. Multi-material structures have a potential to optimize economic efficiency, as the following two examples will show.

2.2.2 Integrated heat pipes

The combination of two or more materials can purpose different aims. Mold and die production are anxious to reduce cycle time of injection molding [10]. Even by using conformal cooling structures the canals need to keep a distance of some millimeters to the surface to guarantee mechanical stability. By using two materials – one with low and a second one with high conductivity of heat – controlled three dimensional heat pipes can be integrated.

2.2.3 Coating of surfaces

Functional surfaces, which are internal or difficult to access, can hardly be treated with conventional coating mechanisms. To reduce abrasive wear and guarantee high durability of highly stressed parts, ALM can be chosen to build up a part with a wear resistant coating included (Figure 6).

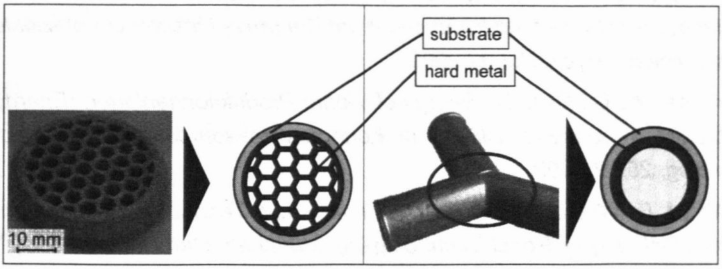

Figure 6: *Examples of use for multi-material parts*

Instead of manufacturing the whole part out of one expensive hard metal, the combination of two materials helps to reduce product costs.

3 Conclusion and acknowledgement

The importance of a sustainable use of natural resources has been shown. In case of production facilities, this can be achieved best by a well directed use of material and energy along the whole product live cycle. Because of its procedural advantages like the high freedom in geometrical design and the combinability of two or more materials, ALM-processes have a great potential to reduce the wastage of energy and material. This has been shown using the examples of lightweight design and multi-material structures.

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