Summary for the final report

Economic & technological qualification of metallic 3D printing for hygienic application in plants of the food and pharmaceutical industry (3D printing in the food industry - HygAM)

In hygiene-critical industries, such as the food and pharmaceutical sectors, there are particularly high demands on the design of the components used, especially in the part of the product that comes into contact with it. In addition to material-specific requirements such as corrosion resistance, the use of sufficiently large diameters and the minimisation of weld joints by reducing the number of components are also important. However, this leads to high effort and costs in manufacturing with conventional processes, as many processing steps are necessary to produce complex individual components. Therefore, hygienic design is often compromised in order to achieve more cost-effective production, which ultimately has a negative impact on food safety.

By using additive manufacturing processes (LPBF - Laser Powder Bed Fusion) it is almost irrelevant how complex a component is. The design of the components does not increase the production effort. Compromises that have a negative influence on food safety, e.g. the connection of several assemblies via weld seams, can be avoided in this way. On the other hand, there are the guideline values of average roughness values (Ra 0.8 µm), which are important for cleanability in the context of the pharmaceutical and food industries, which cannot be implemented by LPBF.

The HygAM research project aims to close this gap and develop design instructions, including suitable post-processing methods, which enable the development of components for hygienic applications using metallic 3D printing. This includes, above all, the integration of cleaning-supporting macrostructures, which is possible for the first time through the use of additive manufacturing processes. Thus, an acceptable surface quality will be achieved for partially or completely inaccessible cavities and channels inside a component in order to open up new fields of application and thus new markets and industries for the additive manufacturing process of metallic 3D printing.

Initially, a selection was made from a large number of standard geometries in consultation with the project-supervised committee (pbA), which were used as test bodies for LPBF 3D printing. These formed the foundation for the successfully manufactured demonstrator shown in Figure 1. As part of HygAM, a complex welding assembly with 4 valves (cf. Figure 1) was converted into a 3D printing-optimised version. The assembly has a parting plane and flange connections necessary for the cleaning tests. Due to the geometric diversity of 3D printing, the geometry could be optimised in terms of flow conditions. Based on this, unnecessary space and unloaded running behaviour are improved. By limiting the material to the necessary structures, there is also a reduction in weight compared to a milled valve made from a solid block (cf. Figure 1).

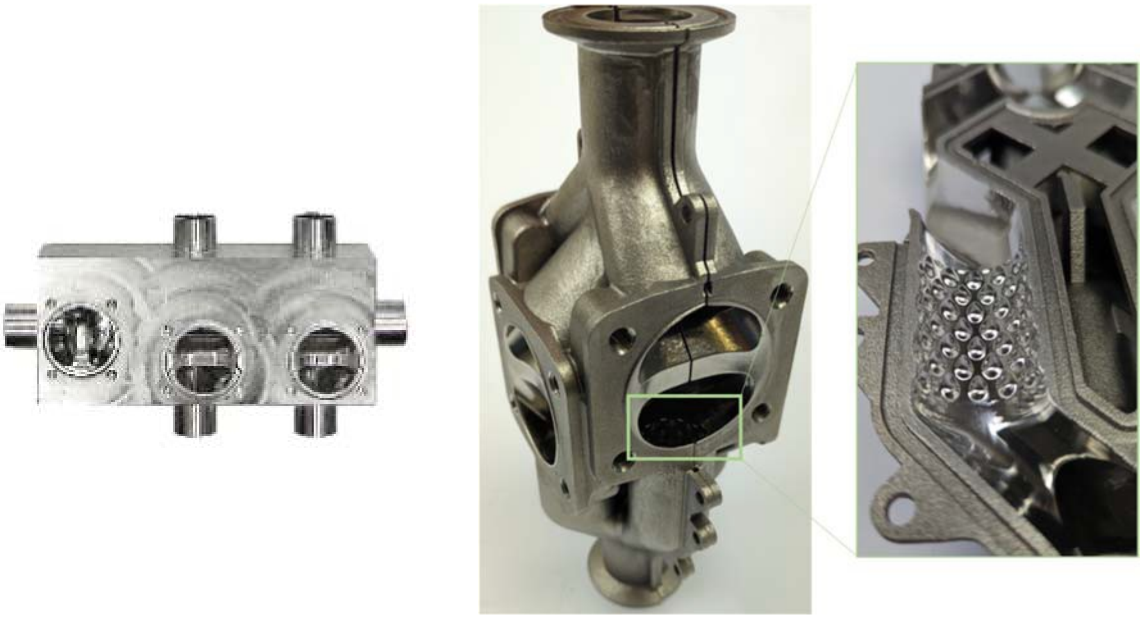

Figure 1: Milled and conventional valve block (left) and valve assembly optimised for the LPBF process as HygAM demonstrator (middle and right). The inner channel geometry has a curved structure for improved cleanability.

For the dimples and bulges, two different types of geometries were considered: spherical and drop-shaped dimples/ bulges. The relevant geometric parameters are (i) the height h of the bulge (respectively the depth t for the dimple), (ii) the width w of the bulge and (iii) the radius of the imprinted sphere R. For the bulges they are schematically shown in figure 2.

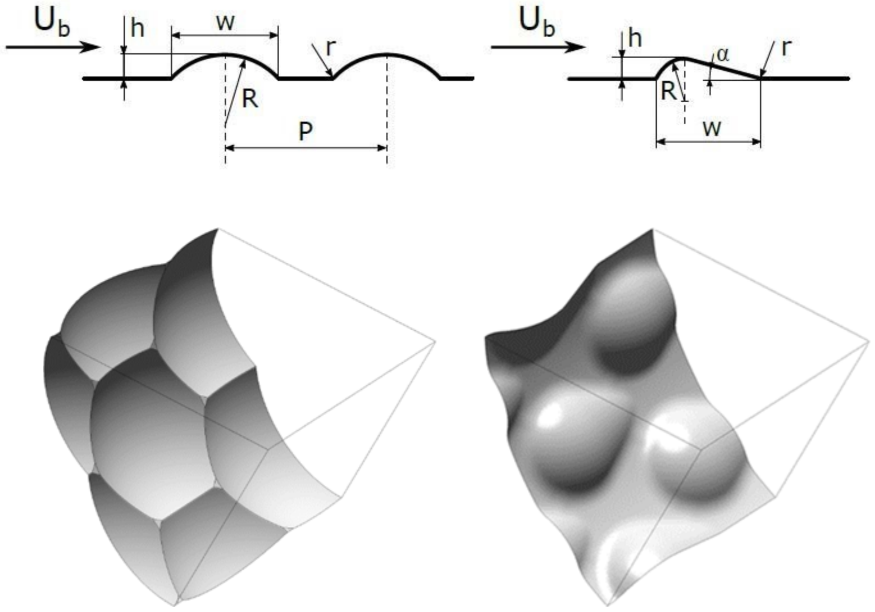

Figure 2: Geometric parameters of the structures. Left: spherical bulge; right: drop-shaped bulge

Numerical investigations on the displacement of viscous contaminants by water confirmed the positive influence of the structures. This takes place in two phases. The first phase represents the rapid displacement of the contamination inside the pipe, the second phase is the removal of the remaining thin layer of dirt on the wall. In general, the behaviour described is similar for all investigated geometric shapes and is consistent with the literature. While the first phase of the cleaning process is almost identical for all variants, considerable differences between the different geometric shapes can be seen in the second phase. The drop-shaped structures are cleaned the fastest, even faster than the smooth pipe.

The parallel consideration of overhang surfaces within metal 3D printing was carried out in addition to this, as there are process-related restrictions with regard to finishability and surface quality. On the one hand, the stair-step effect is relevant, on the other hand, the reduced heat dissipation with increasing angle. For this reason, a system- and material-specific limiting angle is introduced. Through a specially adapted exposure strategy, the surface roughness could be significantly improved (see figure 3).

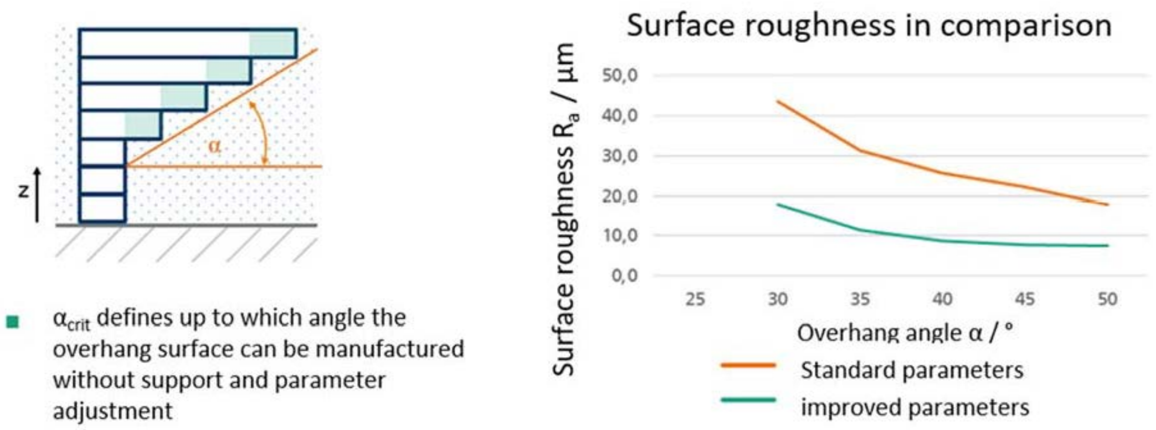

Figure 3: Limit angle definition in the LPBF process (left) and the improvement of the surface roughness (Ra min) by applying an adapted exposure strategy (right).

Furthermore, investigations were carried out into finishing processes. For this purpose, the standard geometries were finished by means of electropolishing, flow grinding and shearing and then examined with regard to surface quality. The geometries have a parting plane and a flange so that cleaning tests could be carried out afterwards. Based on the simulation results, the straight lines were provided with suitable microstructuring within the framework of HygAM. In order to ensure comparability according to the EHEDG guideline, which specifies an Ra value of 0.8, this was carried out on the basis of a line measurement in the relevant components in accordance with ISO 4287 / ISO 4288.

Within the tested geometries, the guideline value of Ra = 0.8 µm described by the EHEDG Guideline could be achieved with the flow grinding method. Due to the best post-processing results, flow grinding was used for the post-processing of the structured straight lines. Within the structures, a profile measurement and 3D recording was carried out for the dimpel as well as camber structure (see Figure 4).

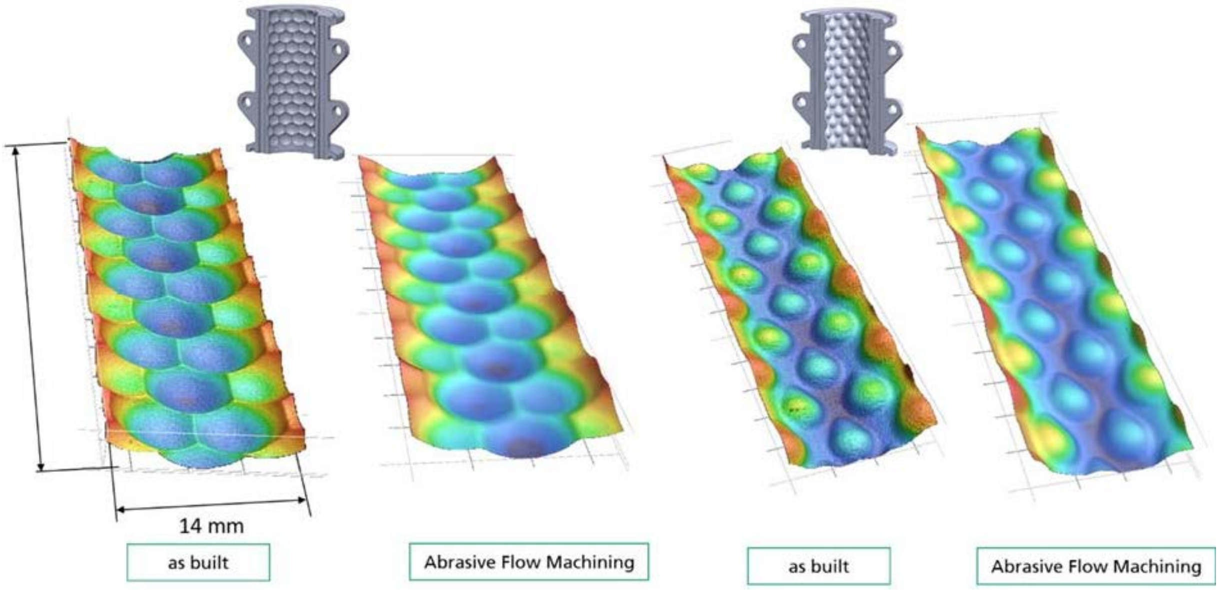

Figure 4: 3D image of the two structures, as built and flow-grinded

The minimization of the melt spatter and the associated homogenisation of the surface can be clearly seen in both structures. The flattening of the dimple structure, as shown in the profile measurement, can also be confirmed optically.

In the further progress of the project, the correlation between surface topography and cleanability could be determined. Based on the results from WP 4 and WP 5 and the comparison carried out, initial recommendations for action can be derived.

- Each of the post-processing methods carried out is suitable for cleaning macroscopically soiled 3D-printed straight lines.
- The targeted, geometric structuring of fluid-carrying channels is target-oriented for microbial cleaning.
- The post-processing procedure should be chosen in such a way that the geometry of the macrostructures is preserved as far as possible.

Microbial contamination decreases with decreasing roughness value.

Due to the rounding of the sharp edges of the dimpel structures and the associated significant profile change, the positive cleaning effect determined in the simulation is lost after the finishing process. The combination of flow grinding and sharp-edged dimples cannot be recommended in this case. For the curved surfaces, on the other hand, an improvement of the surface roughness through reworking also has a positive effect on the cleaning effect (see figure 5).

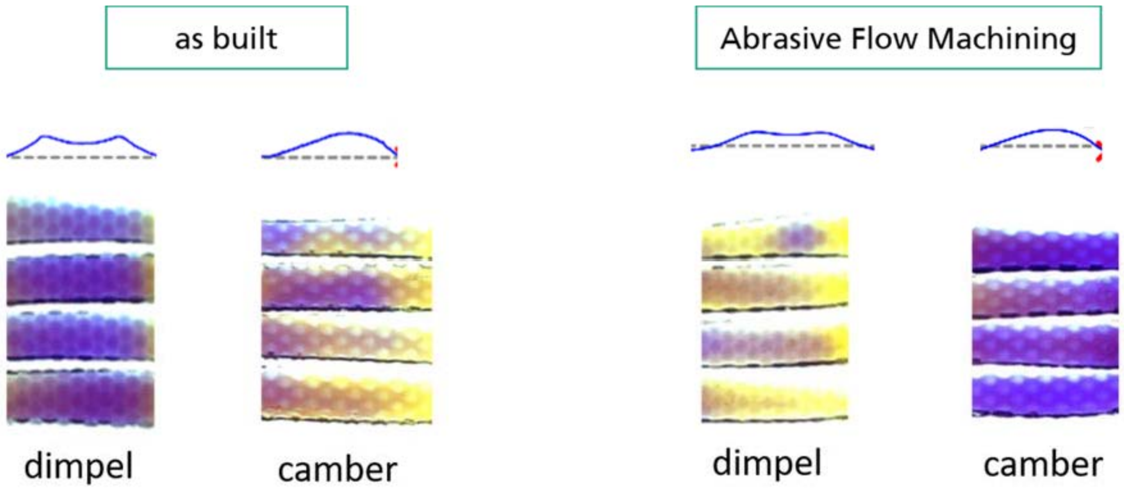

Figure 5: Effect of the changed profile due to reworking on the microbial cleaning of the structured straight geometry (purple = bacterially clean / yellow = bacterially contaminated)

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