3D PRINTING FOR HIGH VACUUM APPLICATIONS

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Abstract

The 3D printing technology has made the leap from a home-based private practice to industrial manufacturing. Due to the increasing reliability of printers and increasing material diversity, especially in the metal sector, double-digit percentage growth rates are possible in the future.

This thesis deals with the manufacturing of parts made by 3D printing for high vacuum application. Different components are printed and examined for their vacuum compatibility.

As shown furthermore, conventionally made standard components can be vacuum tight welded to printed parts. This enables a cost-effective production with more complex components, such as a vacuum chamber. In addition, functional components can already be realized in the manufacturing process. The integration of a system of flow channels directly into the wall of a chamber is just one example. Thus, such a chamber can be heated during evacuation and effectively cooled in later operation.

INTRODUCTION

There is almost nothing left today that cannot be created by 3D printers. This doesn't only apply to the private sector, but increasingly also to the industrial environment.

The reason for this is the growing reliability of the process. Industrial 3D printers are fully automated machines that today can produce more cheaply, more reliably, and faster. Table 1 shows growth rates of 13 - 23% per year, with a market volume of 22.5 billion euros in 2030 [1].

Table 1: Compound Annual Growth Rate

Business	**CAGR until 2030**	**Market Vol. 2015 in Billion €**	**Market Vol. 2030 in Billion €**
Aerospace	23%	0.43	9.59
Medicine	23%	0.26	5.59
Automotive	15%	0.34	2.61
Industry	14%	0.44	2.98
Retail Trade	13%	0.30	1.89

Advantages of 3D printing

The 3D printing technology allows a lot of freedom in the design. In addition, the geometry of the component can be optimized so that a significant weight saving is possible and the part still meets the requirements of the strength. This topology optimization leads to a lightweight design of the parts, which is particularly important in the aerospace industry. In addition, compared to the milling out of the solid, a significant material savings is achieved here because no superfluous material (with the exception of any support structures) must be removed and and nearly no waste material is produced during production.

Since no moldings and other tools are necessary for the production of 3D printed components, there are no further costs. Another advantage results from the possibility of adding hollow and lattice structures, which can be used for the integration of a cooling system.

The fact that, apart from plastic, more and more materials are available, especially metals such as stainless steel, aluminum, titanium or similar and open new areas of application for 3D printing. Thus, in the present thesis, the application of this method in vacuum technology is examined.

Vacuums

When talking about vacuum technology, one has to specify the term vacuum more precisely (e.g., Fig. 1) because the different pressure ranges [2] place different demands on equipment and materials.

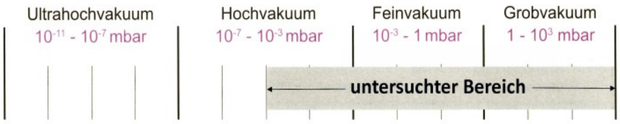

Figure 1: Pressure ranges.

This work is limited to the area of high vacuum. The limitation is due to the simple handling of the components and the existing pumping station, with which a minimum of 10^{-5} mbar is not undercut.

PRINTING OF THE COMPONENTS

LaserCUSING

The components investigated in this thesis were made of stainless steel 1.4404 using the process named LaserCUSING® patented by Concept Laser.

LaserCUSING® is an additive process in which components based on CAD data are produced layer by layer from the finest metal powder. The powdered metal is directly melted by a laser, which moves off the component cross-section. As a result of the subsequent cooling, the material solidifies. After a layer has been produced in this way, the building platform is lowered, a new layer of powder is applied and generated analogously to the next component cross-section. The structure of the part thus takes place layer by layer with a layer thickness of 15-500 microns.

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The Printed Connector

The first 3D-printed component was a simple connector with two flanges DN40 on each side - here called the "3D-printed KF-SC DN-40".

Due to the use of powder in the production, 3D-printed parts have a certain surface roughness, which must be smoothed by reworking.

Another consequence of the layered structure is the fact that in overhangs with an angle smaller than 45° support structures - as shown in Fig. 2 - are necessary. They must be removed in the aftermath.

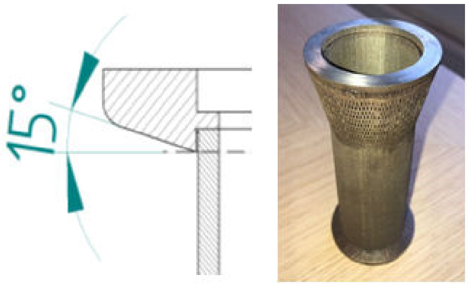

Figure 2: Support structures.

The Welded Connector

Due to an elaborate post-processing, it is clear that the 3D printing of standard components will hardly be worthwhile. Consequently, in order to achieve an economic use of this technology, it is necessary to retrofit the printed components with standard parts from conventional manufacturing.

For this purpose, a simple tube with an outside diameter of 41 mm and an inside diameter of 38 mm was printed and completed on one end by a welding flange and on the other side by a flange with a tube (e.g., Fig. 3).

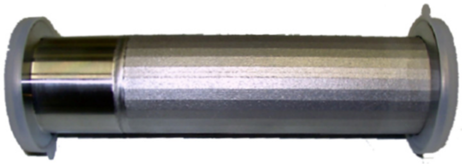

Figure 3: 3D-welded KF-SC DN-40.

The two different welds could be attached without problems. This meant that no further reworking was required. The present pipe - hereinafter referred to as "3D-welded KF-SC DN-40" - has the dimensions: r_i = 19 mm (inner radius) and h = 160 mm (length). This results in a volume V of 0.18 liters and an (inner) surface of 0.019 m^2.

With both parts a high vacuum of $1.5 \cdot 10^{-5}$ mbar was reached without problems.

LEAKAGE RATE MEASUREMENT

Experimental Setup and Implementation

To test the vacuum capability of the 3D-printed components by measuring the leak rate, the company VACOM offers the necessary equipment. The experimental set-up is shown in Figs. 4 a) and b).

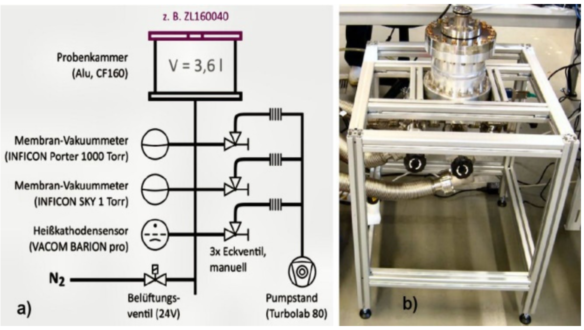

Figure 4: Experimental setup.

Before the actual examination a background measurement of the chamber without specimen was performed. Here, as with the test objects, the pressure increase Δp was recorded over a period of Δt = 24 h (e.g., Fig. 5). With the pressure increase rate Δp / Δt, taken from the corresponding diagram, the leak rate Q for the test component is calculated according to the equation:

$$Q = \frac{\Delta p}{\Delta t} \cdot V - Q_{background}$$

As a comparison to the printed component, a straight connector KF-SC DN-40 (V = 0.145 l) made of stainless steel is used. Furthermore, the influence of a pretreatment can be checked by cleaning the 3D-welded KF-SC DN-40 with isopropanol in an ultrasonic bath and rerun the pressure increase measurement.

Evaluation

The measurement results are shown in Fig. 5.

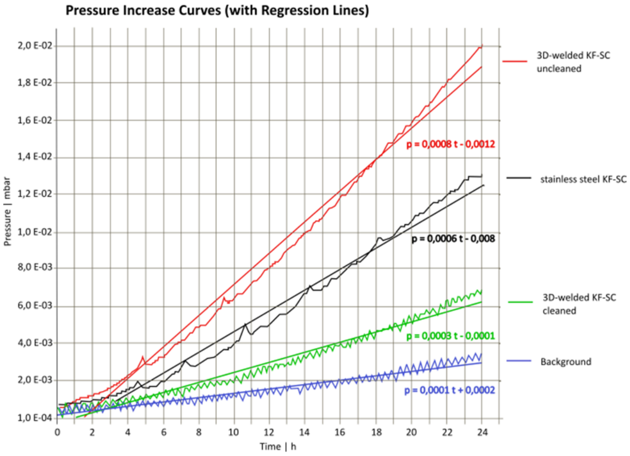

Figure 5: Leak rates.

As can be seen from Table 2, the 3D-welded KF-SC DN-40 in the uncleaned state behaves slightly worse than a conventionally manufactured component KF-SC DN-40 made of stainless steel.

When cleaned, the 3D printed part is even better than the conventional one.

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Table 2: Leakage Rates

Component	Pressure Increase mbar/s	Leakage Rate mbar·l/s
Background	$2.78 \cdot 10^{-8}$	$1.00 \cdot 10^{-7}$
3D Welded KF-SC DN40 uncleaned	$2.22 \cdot 10^{-7}$	$7.39 \cdot 10^{-7}$
Edelstahl KF-SC DN40	$1.67 \cdot 10^{-7}$	$5.25 \cdot 10^{-7}$
3D Welded KF-SC DN40 cleaned	$8.33 \cdot 10^{-8}$	$2.15 \cdot 10^{-7}$

THE VACUUM CHAMBER

Following the successful test of the 3D-welded KF-SC DN-40, the 3D-printing of a complete vacuum chamber took place using the main advantages of 3D-printing, i.e. form independence and integration of functionality. The basic body of the vacuum chamber was supplemented with a complex geometry and integrated flow channels and completed by welding standard components. In addition to a cost-effective production by avoiding unnecessary rework, this method also has the advantage of a flexible adaptation to different customer requirements.

Figure 6 a) and b) show different CAD models of the vacuum chamber and Fig. 7 gives an insight into the manufacturing process of the base body of the recipient from the powder bed.

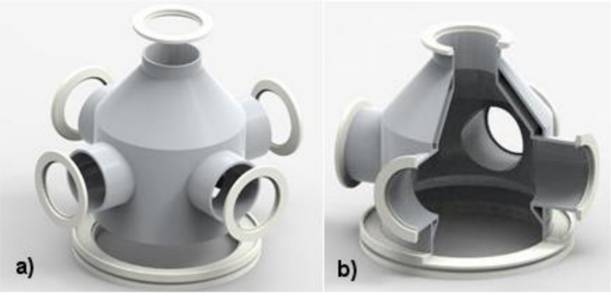

Figure 6: CAD-models of the chamber.

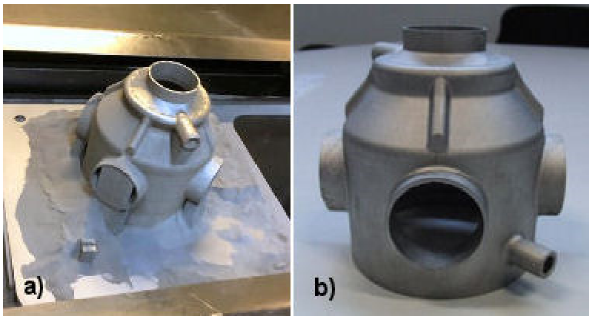

Figure 7: Production of the chamber.

Figure 8 shows the system of flow channels as an example of possible functional integration. Through the flow channels, the recipient can be heated during evacuation and alternatively cooled when needed in operation.

The exact shape of the channels was determined by a CFD-program to ensure optimal flow conditions.

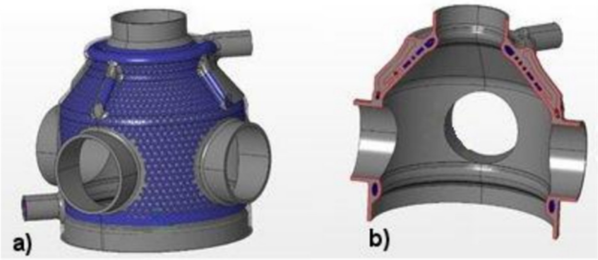

Figure 8: Flow channels.

Figure 9 shows the 3D-printed vacuum chamber ready for practical laboratory use.

Figure 9: 3D-printed vacuum chamber.

CONCLUSION

The present work shows that metal-based 3D printing can meet the requirements of vacuum technology in the area of high vacuum. Now the step is in the ultrahigh vacuum, i.e., in pressure ranges smaller than 10^{-7} mbar. While in high vacuum the leakage rate is essentially attributable to the Viton flange gaskets and the material properties, for example the roughness of the surface, are not yet effective, they will have a decisive influence when the pressure falls below 10^{-7} mbar. How big this influence ultimately is, must result in appropriate tests, which require a much greater effort.

The use of the described production technology will actually depend on how the advantages can be used properly. Especially for single production and prototypes, 3D printing technology can be of considerable benefit. This is particularly due to the freedom in geometry and the possibility of function integration, such as the realization of a surface heating system.

The interest of the cooperation companies is expressed in Mr. Dinkel's (company Robert Hofmann GmbH) quote: “For us the field of vacuum technology is a highly attractive market because often individually complex components with materials available in 3D printing are needed”.

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