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Study of the suitability of 3D printing for Ultra-High Vacuum applications

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Abstract. In the recent year additive manufacturing (3D printing) has revolutionized mechanical engineering by allowing the quick production of mechanical components with complex shapes. So far most of these components are made in plastic and therefore can not be used in accelerator beam pipes. We have investigated samples printed using a metal 3D printer to study their behavior under vacuum. We report on our first tests showing that such samples are vacuum compatible and comparing pumping time.

1. Introduction

The introduction of additive manufacturing has significantly reduced the time required to produce a mechanical part to be used in an accelerator. When a situation requires it a part, even with a complex shape, can be designed and printed within a few hours of the need for it arising. Additive manufacturing also allows the manufacturing of parts with shapes that can not be built using traditional tools.

We have been using 3D printed parts for more than a year in an accelerator environment satisfactorily. Some of these complex parts, made of plastics, have been exposed to large levels of radiation for several months (for example in [1]) without loss of mechanical performances.

However at the moments the benefits of additive manufacturing can not be extended to parts that are inserted in vacuum as the UHV compatibility of 3D printing still has to be established. Some preliminary measurements have already been reported [2] but we are not aware of any systematic campaign of measurement.

2. Method

To tests the suitability of 3D printing to UHV applications we have acquired 130 mm long DN40KF tubes with the same drawing (shown on figure III) from two different manufacturer (BV Proto[1] and AGS Fusion[2]) of metal 3D printed objects and also from a reputable manufacturer of

[1] See `http://bvproto.eu`
[2] See `http://www.ags-fusion.fr`

conventional vacuum equipment. Table 1 lists these tubes and their specific treatment. All these parts have been leak tested with helium and then mounted on a test stand using a synthetic rubber (Viton) gasket. On the test stand the parts have been pumped to measure the limit pressure that could be reached and then left under vacuum without pumping to measure the pressure increase. As described in table 1 some of the 3D printed parts have been tested directly whereas others have been machined on a lathe to improve the surface quality of the flange. The tests have been limited so far to quick flanges (KF) as manufacturing the knife of a conflat flange (CF) is more difficult with conventional tools (and not possible in 3D printing).

The tubes have all been manufactured using Selective Laser Melting (SLM) with a stainless steel 316L powder. They have all been manufactured vertically (horizontal layers). If the tubes had been manufactured horizontally they would have been printed faster but they would probably have sagged under their own weight during the printing or required the addition of many supports (that must then be removed in a time consuming process). The tubes made by BV proto were manufactured using a layer thickness of 0.04 mm and took about 30 hours to print (all 4 tubes together). The tubes made by AGS Fusion were manufactured using a layer thickness of 0.02 mm and took about 60 hours to print (all 4 tubes together).

The raw tubes after printing can be seen on figure I and II.

Figure 1. Raw tubes on their support just after printing at BV proto.

As after printing the tubes are attached to their support it is necessary either to saw them at one end (BV proto) or to wire-cut them out of their support (AGS Fusion).

As expected the surface quality of 3D printed tubes is very different of that obtained from conventional techniques, so for each manufacturer we investigated raw tubes but also tubes with typical surface finishing (bead blasting and lathing). In the case of lathing, we investigated both the case where only the flanges are lathed (see figure III) and the case where both the flanges and the inside are lathed (see figure IV).

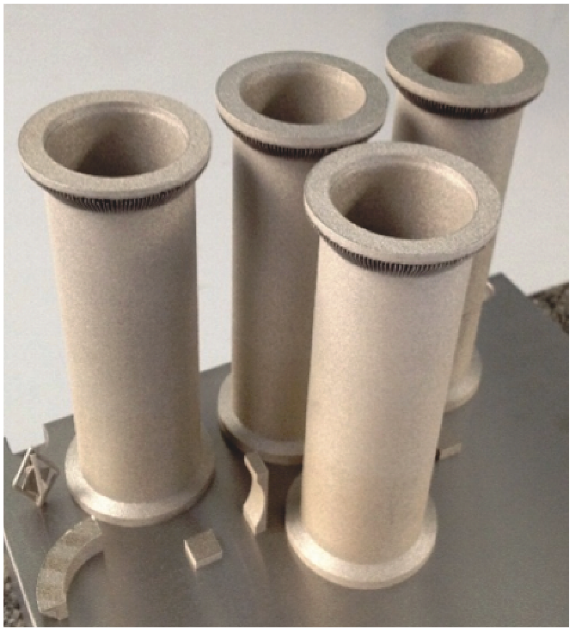

Figure 2. Tubes removed from their support at AGS Fusion.

The surface roughness of the raw tubes from BV proto was measured to be Ra $= 8.5\,\mu$m to $10\,\mu$m and for AGS fusion Ra $= 6\,\mu$m to $7.5\,\mu$m.

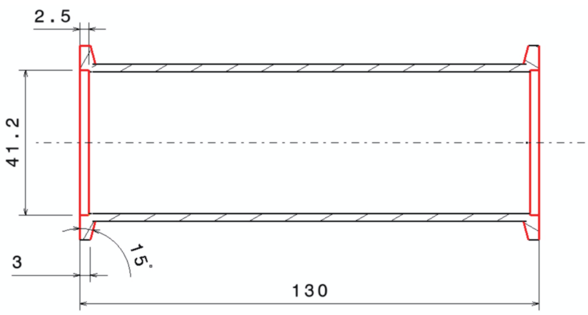

Figure 3. Drawing of the tubes and in red the area that was lathed on the flanges in the case of BV3 and AG3.

3. Results

The results of our measurements are summarized in table 1 and for the tubes for which no leaks were detected on figure V. As can be expected the tubes were a leak had been detected (BV1, BV2, AG1 and AG2) did not stay under static vacuum for very long.

It is important to stress that for all tubes the leak testing did not show any leak on the body of the tubes and the leaks detected for BV1, BV2, AG1 and AG2 were due to the poor quality of the flange surface. These results show that a raw tube produced by selective laser melting (SLM) is not directly vacuum compatible. However once the flanges of the tube have been lathed, such tube had vacuum performances comparable to those of commercial product.

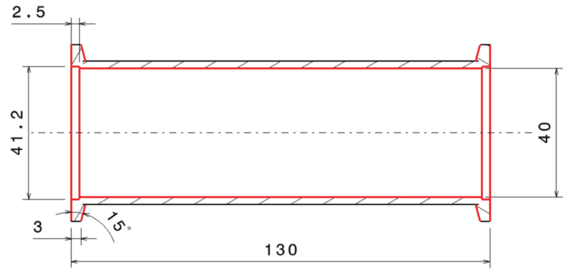

Figure 4. Drawing of the tubes and in red the area that was lathed (flanges and inside) in the case of BV4 and AG4.

The fact that no differences were seen between the two types of lathed tubes shows that the lathing of the inside of the tube is not necessary.

Additive manufacturing is best suited for extruded shapes as such shapes do not require any supports to be realized when built in vertical position (horizontal layers been added one after the other). In the case of the tube presented below (see figure III and IV) the main difficulty is the 15° chamfer required for the tightening clamp. To make this chamfer we used a support (deposited during the printing process) but this required to use tools to remove the support after printing. From our results we conclude that it would have been better to make a 45° chamfer that would then have been rectified during the lathing process.

We plan to continue our study using metal gasket that will allow us to go to lower pressure

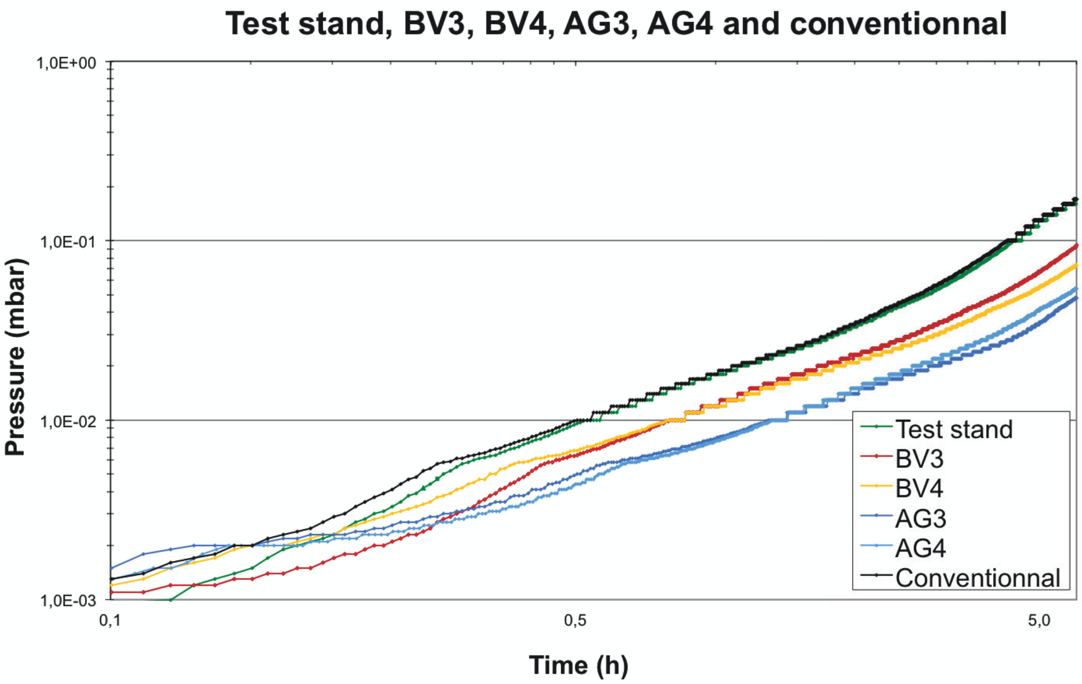

Figure 5. The static vacuum pressure measured as function of time for each of the samples that passed the leak testing. We can see that these sample perform as well as the reference sample in these tests (within measurement uncertainty).

Table 1. List of tubes tested in this study and the helium leak test and limit pressure (Penning) test results.

Manufacturer	Part name	Surface finishing	He leak test	Limit pressure
BV Proto	BV1	Sawing at one end	Raw: 1×10^{-7} mbar l/s Sawed: $> 1 \times 10^{-5}$ mbar l/s	1.7×10^{-4} mbar
	BV2	Minor processing with hand tools	$> 1 \times 10^{-5}$ mbar l/s	8.6×10^{-4} mbar
	BV3	Lathing of both flanges	No leak detected	1.2×10^{-5} mbar*
	BV4	Lathing of both flanges and the internal surface	No leak detected	1.2×10^{-5} mbar*
AGS Fusion	AG1	Wire-cutting at one end	Raw: 3×10^{-7} mbar l/s Wire-cut: $> 1 \times 10^{-5}$ mbar l/s	8.5×10^{-4} mbar
	AG2	Wire-cutting at one end	2×10^{-7} mbar l/s Wire-cut: $> 2.8 \times 10^{-7}$ mbar l/s	1.2×10^{-3} mbar
	AG3	Lathing of both flanges	6.2×10^{-8} mbar l/s No leak detected	1.5×10^{-5} mbar*
	AG4	Lathing of both flanges and the internal surface	No leak detected	9.6×10^{-6} mbar*
Vacom	Reference	Conventional	No leak detected	1.8×10^{-5} mbar*

* This is equivalent to the limit pressure of the test stand.

and test these tubes in the Ultra High Vacuum range.

References

[1] Khodnevych V and Delerue N 2017 *IPAC2017* These proceedings p MOPAB026
[2] Rummery P 2015 Tests carried out on st.5t cube private communication