

WHITE PAPER

Performance Improvements Of Vapour Smoothed SLS PA2200 Parts

ABSTRACT

Hansgrohe, in cooperation with Additive Manufacturing Technologies (AMT), strive to achieve optimal performance and provide the best manufacturing ecosystem for their products. In many situations, the surface roughness, material strength and lack of a sealed surface of 3D printed parts are considered a major constraint for many end-use applications. This work, therefore, aims to understand the improvements that can be gained from AMT's patented vapour smoothing technology for SLS PA2200 material, in relation to production parts used in consumer fixtures and fittings manufactured by Hansgrohe.

This study investigates how vapour smoothing impacts the mechanical properties of a 3D printed material through tensile testing, the surface roughness changes through tactile measurements, microscopic analysis, and the water burst pressure. Finally, to validate the dimensional variation of printed parts vs. post-processed.

METHODOLOGY

Identifying the key characteristic improvements outlined above was done through five different tests that have been identified in Table 1 which follows:

Table 1 – Test Summary

Test Number	Test Summary	Sample Type	No. Of Samples
1	Mechanical Testing	ASTM D638 Type I	12 Pieces
2	Surface Roughness	3D Test Part	5 Pieces
3	Dimensional Variation	3D Test Part	5 Pieces
4	Microscopy Analysis	3D Test Part	5 Pieces
5	Bursting Pressure Test	Bursting Test Part	20 Pieces

Each of these samples were printed by Hansgrohe using their SLS EOS P396 and then smoothed using the AMT vapor smoothing machine. Each sample was carefully designed and handled to ensure that accurate data could be recorded during each test. The following sections outline each of these tests in more detail along with discussing the results.

TEST ONE: MECHANICAL TESTING

In the realm of 3D printing, mechanical testing, particularly tensile testing and elongation, stand as critical characteristics to evaluate the integrity and performance of parts. By subjecting 3D-printed materials to these tests, we gain valuable insights into their strength, durability, and suitability for specific applications.

In these tests, ASTM D638 Type I parts were used as shown in Figure 1 which follows. The tensile testing was also conducted for both horizontal and vertical print directions to identify whether an improvement could be achieved regardless of orientation. Within the test, each "Dog Bone" was clamped into the tensioning tool shown in Figure 2, and the traction speed was set to 0.05mm/s until the parts failed. The results that were recorded can be seen in Table 2.



Figure 1

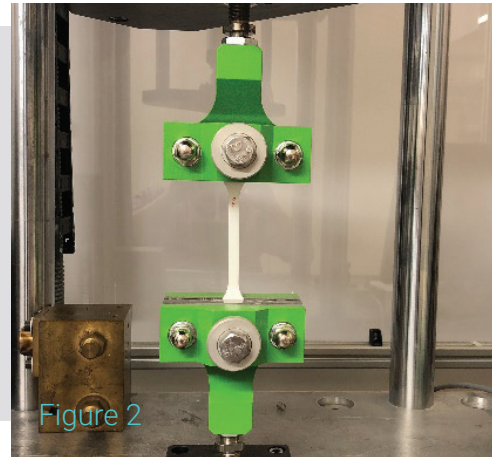


Figure 2

Table 2 – Mechanical Test Summary

Sample	Version	Fmax. [N]	Elongation [mm]
1	Horizontal - Not Smoothed	1913	18.07
2		1913	17.75
3		1836	16.13
4	Horizontal - Smoothed	1932	20.86
5		1888	16.41
6		1938	20.09
7	Vertical - Not Smoothed	1631	7.97
8		1715	10.52
9		1719	10.25
10	Vertical - Smoothed	1747	12.31
11		1738	11.82
12		1747	11.66

As is expected, the performance of horizontally printed parts was significantly better when compared to that of the vertically printed both with regards to the Fmax and elongation at break. When comparing the smoothed and unsmoothed parts, the performance improvements shown in Table 3 were achieved.

Table 3 – Mechanical Improvements

Version	Fmax. Improvement	Elongation Improvement
Horizontal	1.67%	9.4%
Vertical	3.19%	19.7%

In both printing directions, an improvement to both the Fmax and the elongation at break can be seen. This can be attributed to the elimination of crack initiation points between the layers, compared to the unprocessed parts.

TEST TWO: SURFACE ROUGHNESS

AMT's vapor smoothing has the ability to significantly reduce the surface roughness of parts regardless of geometry thanks to the none-line-of-sight technique. In order to identify the improvement to different print orientations the parts were designed in such way that each sample part has multiple flat surfaces with different orientations. Based on these multiple orientations the surface roughness could be measured considering the original print orientation. Figure 3 and 4 which follow show the part along with the respective orientation (A – Bottom, B – Vertical and C – Top).

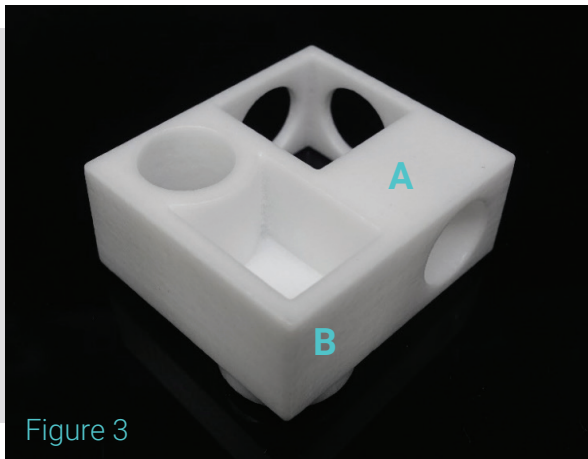


Figure 3

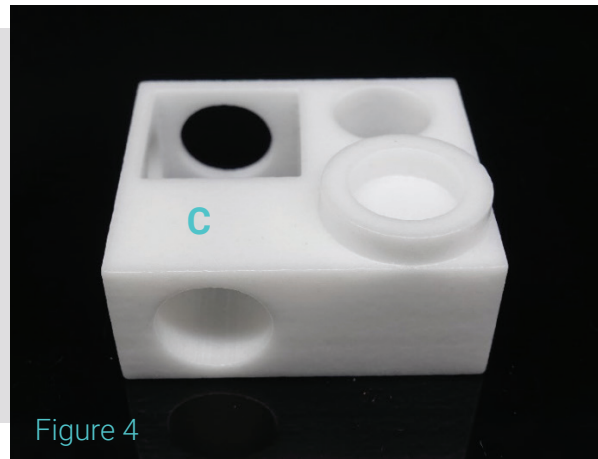


Figure 4

The surface roughness (Ra Value) was recorded for the parts both before, and after processing using a Mitutoyo Surftest SJ-210 with a stylus tip radius of $2\mu\text{m}$, tip angle 60° and measuring force 0.75mN . Three measurements were taken over different areas of the parts to understand how the printing direction affected the surface roughness. The results for the surface roughness tests before and after vapour smoothing, in addition to the percentage improvement, can be seen in the Table 4 which follows:

Table 4 – Surface Finish Improvement

Measurement Location	Ra Before Smoothing	Ra After Smoothing	Ra Improvement
Bottom Surface (A)	6.53	1.98	69.6%
Vertical Surface (B)	7.84	2.27	71.0%
Top Surface (C)	7.40	2.30	69.0%

As expected, the bottom surface had the lowest Ra value in both pre and post-processing. It was noted that overall each type of surface had a similar % improvement to the Ra value. This demonstrates that the use of vapor smoothing can effectively improve the surface finish regardless of the geometry and printing orientation.

TEST THREE: DIMENSIONAL VARIATION

A primary advantage of AMT vapor smoothing is its preservation of dimensional accuracy, eliminating the need for design adjustments commonly associated with tumbling. Using the aforementioned part, the dimensional variations were calculated using a Mitutoyo 150mm Digital Caliper with 0.01mm resolution. As before, each print orientation was considered in addition to the circular features to understand the extent of variation. The measurement points are illustrated in Figures 5 and 6, while the corresponding results can be found in Table 5.

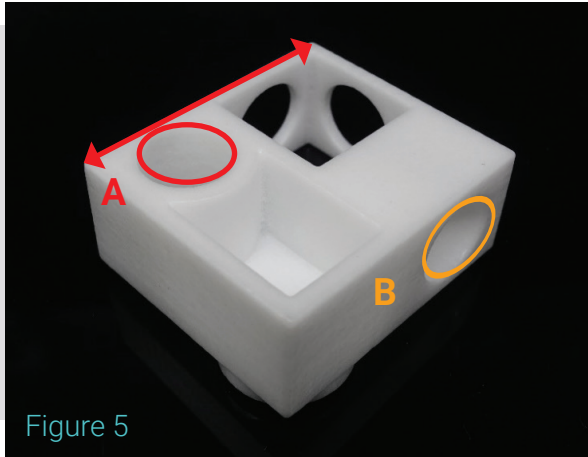


Figure 5

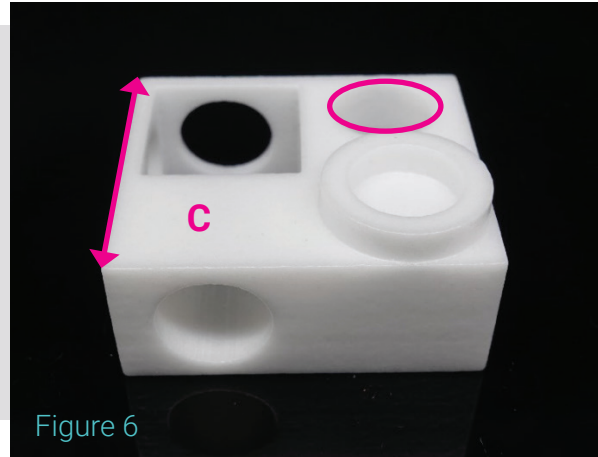


Figure 6

Table 5 – Dimensional Variation

Measurement Location	Dimension Before (mm)	Dimension After (mm)	Dimensional Variation
Length A	33.95	33.88	0.2%
Length B	17.00	16.94	0.4%
Length C	29.95	29.86	0.3%
Diameter A	9.84	9.86	-0.2%
Diameter B	9.90	9.93	-0.3%
Diameter C	9.82	9.82	0.0%

For linear measurements, there was a variance of up to 0.4% on Length B and as low as 0.2% on Length A. Given that the variations arise from the levelling of layer lines (peaks and valleys), it's logical that larger dimensions exhibit a relatively smaller percentage of change.

Interestingly, all linear measurement values have a positive variation whereas the diameter ones have a negative. This supports the theory of the layer lines levelling.

Based on the results, it can be concluded that the dimensional variance from vapor smoothing is negligible. Furthermore, the variation which was observed is within all powder bed 3D printers tolerance thus, no dimensional considerations need to be applied to ensure the end part is to specification.

TEST FOUR: MICROSCOPY ANALYSIS

Another major benefit of AMT vapor smoothing is its ability to seal the surface, creating a water-tight and sterilisable surface suitable for a range of new, previously unachievable applications. To visualise this, surface microscopy was carried out using Hirox KH-8700 digital microscope with MX(G)-2016Z lens. The part surfaces were analysed at a magnification of 140x in the same surfaces as Test 2 to ensure continuity. Photographs of each area, before and after smoothing showed near identical improvement, so Figures 7 and 8 show an example of the results for reference.

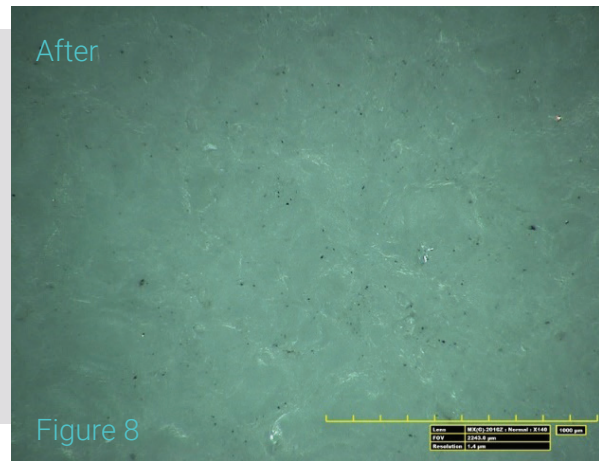
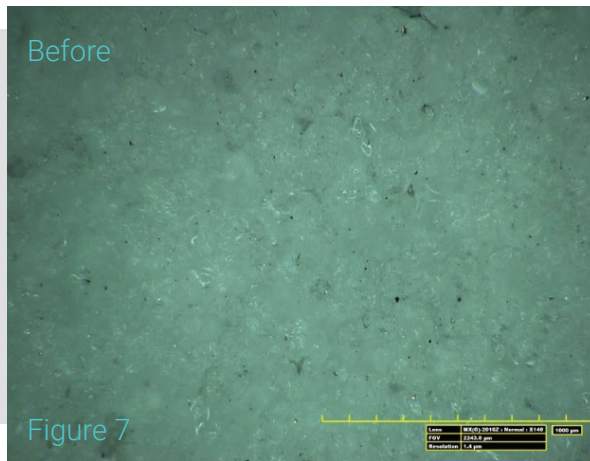


Figure 7 reveals the abundance of un-sintered material, microfractures and surface porosity on the surface as printed (this can be seen as shadowing on the surface). After the parts were vapour smoothed, these defects were completely removed leaving a surface which is smooth and uniform. Furthermore, there are similar improvements across all orientations which demonstrate the uniformity achievable through vapor smoothing.

TEST FIVE: BURSTING PRESSURE

To ensure Hangrohe products perform at the highest levels and provide the best results for their customers, extensive testing is repeatedly carried out on all components. One such test is referred to as the Bursting pressure in which extremely high water pressure is applied through a component until it fails. During this test, the water pressure is recorded and analysed to ensure that the parts are fully sealed with no leaks. The test part which is used can be seen in Figure 13 along with a failed part in Figure 14.



Throughout this testing, a total of 20 parts were tested, the results for the Z orientation parts can be seen in Table 6.

Table 6 – Bursting Pressure Summary

Surface Finish	Wall Thickness (mm)	Average Tightness (bar)	Max Tightness (bar)	Min Tightness (mm)
Not Smoothed	1.5	128	129	126
Smoothed	1.5	136	139	134
Not Smoothed	1.0	74	79	70
Smoothed	1.0	79	86	74

Based on the test, both 1.5mm and 1.0mm wall thickness showed an improvement in the water tightness performance by withstanding a higher average pressure after smoothing. Moreover, they were also able to achieve a higher maximum and minimum pressure showing that the entire data set was skewed positively. Table 7 which follows shows the performance increase for each as a percentage change of the printed sample.

Table 7 – Bursting Pressure Improvements

Thickness	Average Tightness Improvement	Max Tightness Improvement	Min Tightness Improvement
1.5mm	6.25%	7.75%	6.35%
1.0mm	6.76%	8.86%	5.71%

Irrespective of the wall thickness, there was a consistent performance boost from vapor smoothing. This highlights that even optimally performing components can experience further enhancement through vapor smoothing.

CONCLUSION

From the experiments conducted in this report, we can underline the following advantages of AMT's vapor smoothing for SLS PA 2200 components:

- The tested samples showed an enhancement in tensile strength and elongation at break, with improvements reaching up to 3.19% and 19.7% respectively.
- Surface roughness was reduced by as much as 71% across all print orientations, eliminating the need for manual polishing or further processing.
- Dimensional alterations were minimal, with the most significant change being just 0.4%, which comfortably sits within the standard tolerance range of 3D printers.
- The average bursting pressure saw an increase of up to 6.75% due to vapor smoothing, offering opportunities for material and design size optimizations at the design phase.



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