



Improving Evonik TPA Part Properties with PostPro[®] Vapor Smoothing

The novel PostPro® vapor smoothing technology is an automated post-processing solution to surface treat thermoplastic polymer 3D-printed parts. PostPro® is a patented and enabling technology, which reduces lead-time and operational/maintenance costs, providing the 'missing piece' in the digital manufacturing chain. PostPro® achieves an injection molded surface quality, improved airtightness, as well as bacteria protection on parts printed using Laser Sintering, HP Multi Jet Fusion, High Speed Sintering, or Fused Deposition Modelling technology.

Extensive testing was done to characterize the effect of novel chemical vapor smoothing technology by AMT on material properties of parts printed with Evonik TPA. The testing focused on surface quality, mechanical properties, and dimensional variation. The results revealed that the compatibility of Evonik TPA material with PostPro® technology, produce high performance parts.

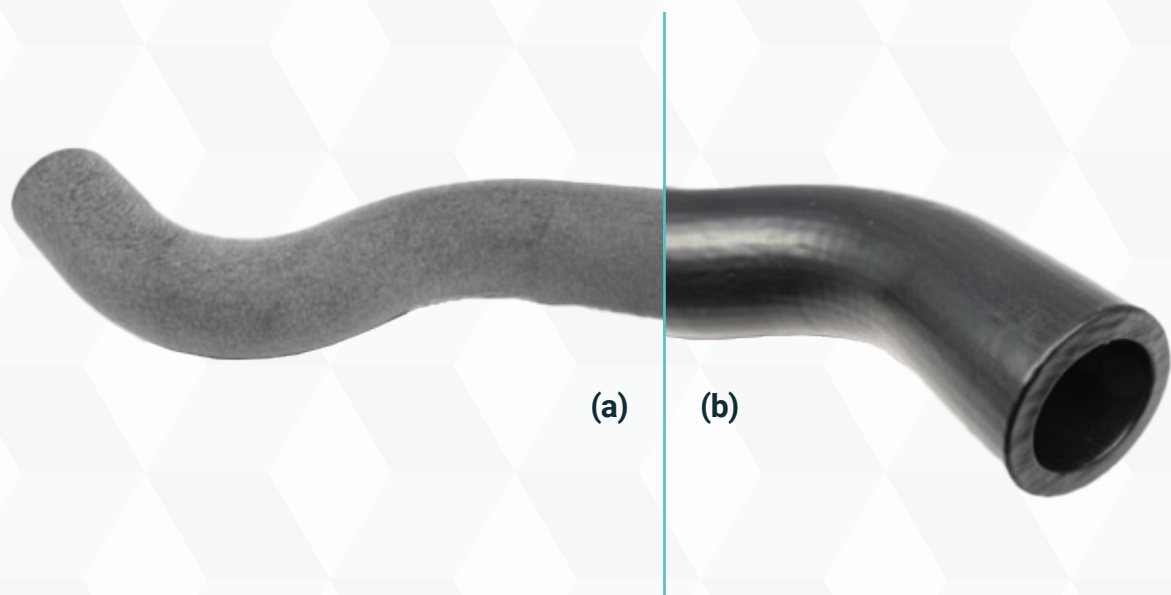


Figure 1. As-printed (a) and processed (b) Evonik TPA parts

EVONIK TPA

Evonik and HP's co-branded TPA powder is a flexible polyamide (PA) elastomer with a very low density of 1.01 g/cm³ and a Shore A Hardness of 91. The high-performance powder is excellently suited for production of functional high-tech 3D plastic parts – prototypes as well as series products – that call for high extensibility and energy return, such as equipment or automobile components. It has enhanced rebound resilience, elongation at break and is easy to process with high refresh ration of 80% (recycled material).

POSTPRO® CHEMICAL SMOOTHING TECHNOLOGY

As-printed material surfaces exhibit rough, powdery and porous surfaces, limiting the use of such parts in various applications. AMT's PostPro chemical vapor smoothing process is able to solve these issues and produce smooth and sealed surfaces, removing any loose un-sintered powder. The patented physico-chemical process can smooth a variety of thermoplastic polymers such as PA12, PA11, PA6, TPU, TPE, TPA, ABS and many other materials printed using Powder Bed Fusion (PBF) or Fused Filament Fabrication (FFF) methods.

The process works by creating favorable thermodynamic conditions for the parts to process. During the process, the top layer surface material becomes mobile and is rearranged creating a sealed and smooth surface. The accuracy of the smoothing is controlled using tailored conditions within the process chamber to achieve the required surface finish.

AMT's PostPro chemical vapor smoothing provides a sustainable post-processing solution to deliver repeatable and smooth parts with almost no dimensional variation and sealed surfaces avoiding liquid or gas uptake. Processed parts not only achieve high aesthetical standards but also are easier to dye and coat, while their mechanical properties are improved. The system combines applied science and easy-to-use technology that can be integrated into automatic production lines to deliver enhanced polymer performance at scale [1, 2, 3].

TESTING METHODOLOGY

Parts used during this study have been printed on a HP MJF 4200 printer. The parts have been de-powdered and cleaned of the loose powder before the smoothing. In total, 17 different tests were performed for both as-printed and post-processed parts summarized below in Table 1.

Test	Sample type and test standard	Number of samples	Unprocessed	Processed
Tensile test	DIN 53504	40XY + 40XZ	20XY + 20XZ	20XY + 20XZ
Surface roughness	ASTM D638 Type I	40	20	20
Dimensional variation	Dimensional pyramids	40	20	20
Izod Impact resistance	Notched ASTM D256	40XY + 40XZ	20XY + 20XZ	20XY + 20XZ
Part Density	ASTM D792	4	2	2
Compression Set	ASTM D395 Method A	6XY + 6XZ	3XY+3XZ	3XY+3XZ
SEM image analysis	10mm ² squaress	2	1	1
Microscopy analysis	10mm ² square	2	1	1
Ross Flex Test Cold Temp	Evonik internal method 250k cycles, -10 °C	40XY + 40XZ	20XY + 20XZ	20XY + 20XZ
Hardness Shore A	ASTM D2240	2	1	1
Flexural Modulus	ASTM D790	40XY + 40XZ	20XY + 20XZ	20XY + 20XZ
Tear Resistance (Trouser)	ASTM D624 Type T	40	20	20
Tear Resistance (Graves)	ASTM D624 Type C	40	20	20
Rebound Resilience	ASTM D7121	40	20	20
Abrasion Resistance	ASTM D4060	40	20	20
Vicat Temperature	ASTM D1525, 10N 120°C/h, A120	40	20	20
UV exposure testing	ASTM G155, 300 hours of exposure (one sample for 200 hours and one sample at 300) including Grey-scale assessments pre and post-test	4	2	2

SURFACE ROUGHNESS

The surface roughness (Ra) of the samples was measured using a Mitutoyo Surftest SJ-210 with a stylus tip radius of 2 μ m, tip angle 60° and measuring force 0.75kN. Five measurements at different areas of each surface were made before and after processing for 10 samples for both XY and Z directions. The averages are given Figures 2 and 3.

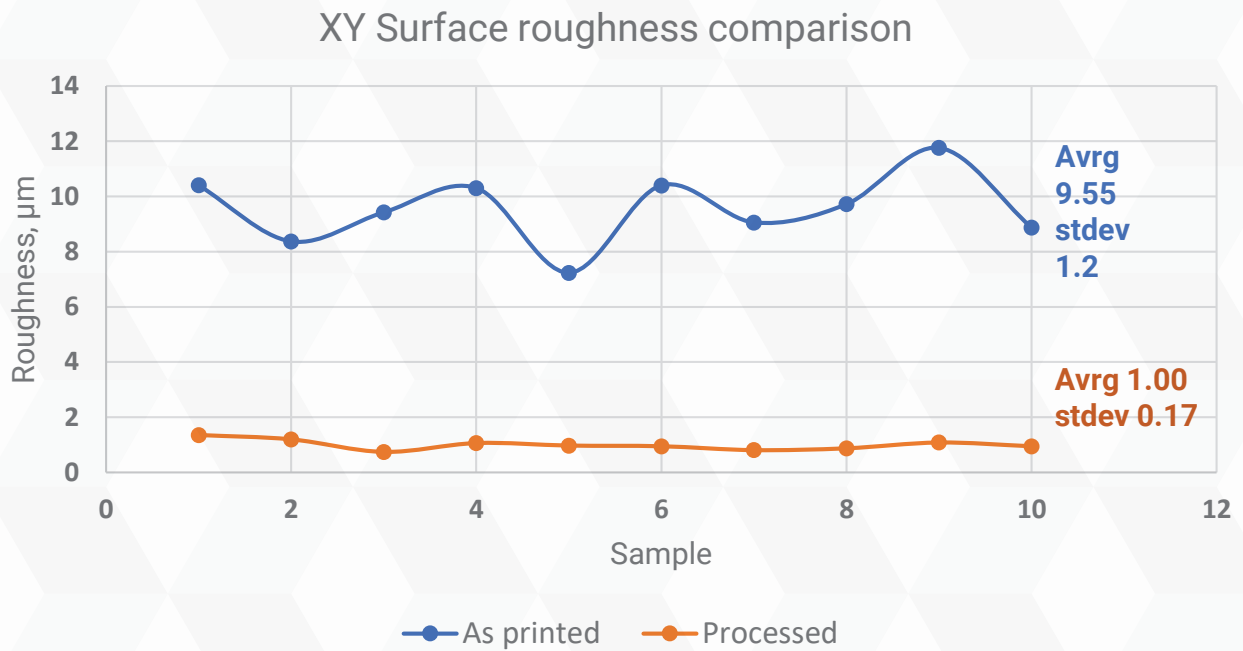


Figure 2. Surface roughness Ra results for the samples printed in XY direction

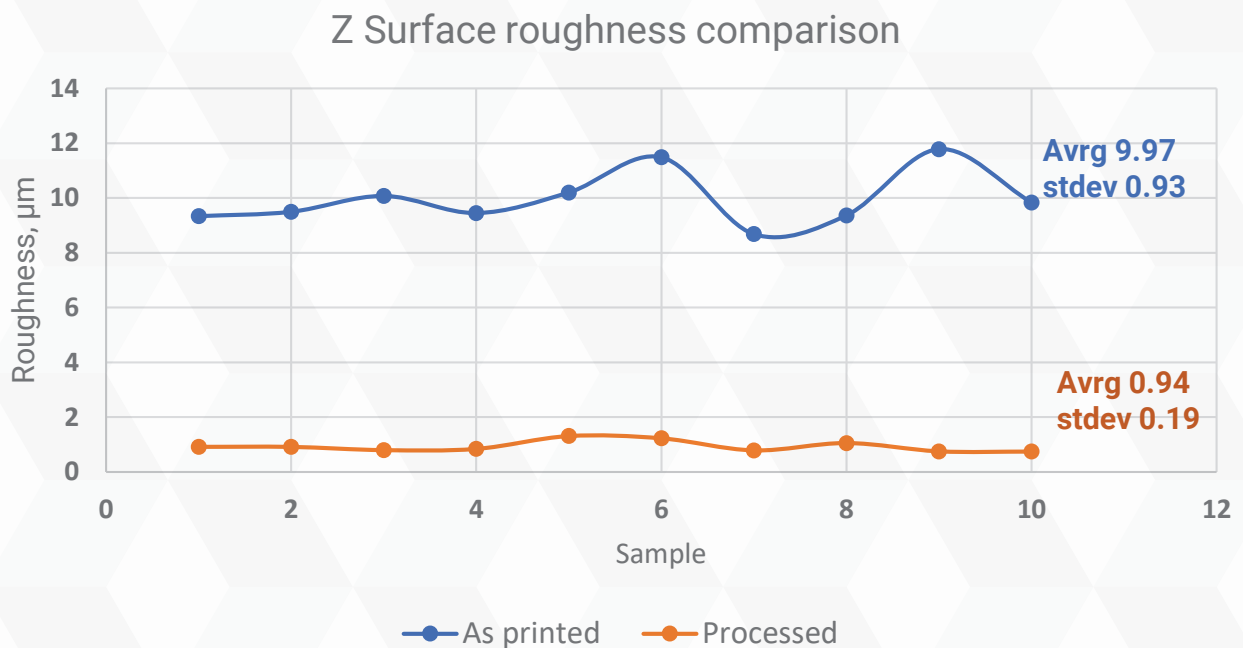


Figure 3. Surface roughness Ra results for the samples printed in Z direction

The average roughness Ra improved from around $9.55\mu\text{m}$ to $1.00\mu\text{m}$ for XY and from $9.97\mu\text{m}$ to $0.94\mu\text{m}$ for Z direction. This roughness improvement is provided uniformly across the part independent of its geometry. This is demonstrated by the reduction in the standard deviation between Ra values across the surface from 1.00 and 0.93 to just 0.17 and 0.19 for XY and Z respectively. The improvements come due to controlled re-flow of the surface, removing imperfections, un-sintered material and micro-cracks.

MICROSCOPY AND SEM IMAGE

Surface microscopy of Evonik TPA surfaces smoothed using the PostPro chemical vapor smoothing was done using a Hirox KH-8700 digital microscope with MX(G)-2016Z lens. Analysis was done at magnifications of 40x and 100x. The results are shown in the Figures 4 (a, b, c, d).

Microscopy images (μm scale) reveal abundant presence of un-sintered material and surface porosity on the as-printed Evonik TPA surfaces (Figures 4 a and c). These artefacts are completely removed by the PostPro chemical vapor smoothing process, leaving the surface smooth and uniform.

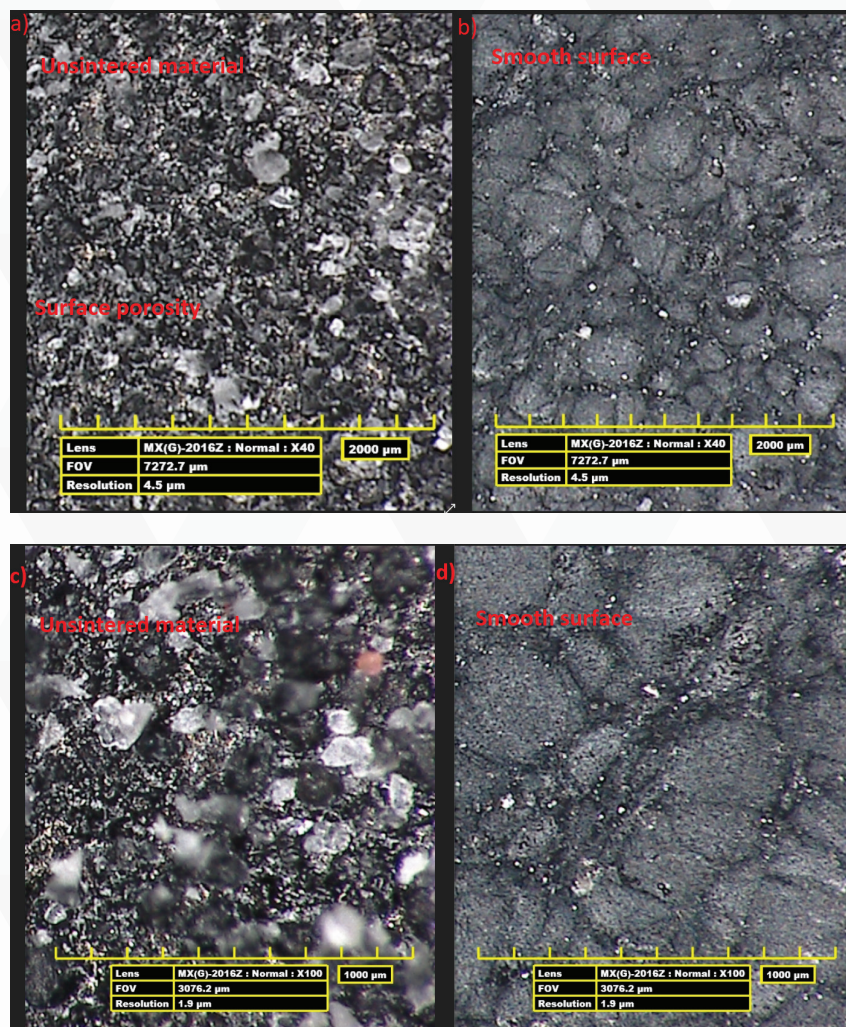


Figure 4. Surface microscopy of as-printed (a and c) and processed (b and d) parts at x 40 magnification, as well as x 100 magnification.

SEM image comparison in Figure 5 shows a vast difference in the surface topography between unprocessed (a and c) and processed (b and d) surfaces. Detached and partially fused polymer agglomerates can be seen covering the surface of unprocessed parts. In contrast, processed surfaces are smooth and appear free of any semi-fused or detached particles, crevices and surface porosity. Differently shaded regions in processed surface outline the areas around polymer particles that were dissolved during the smoothing.

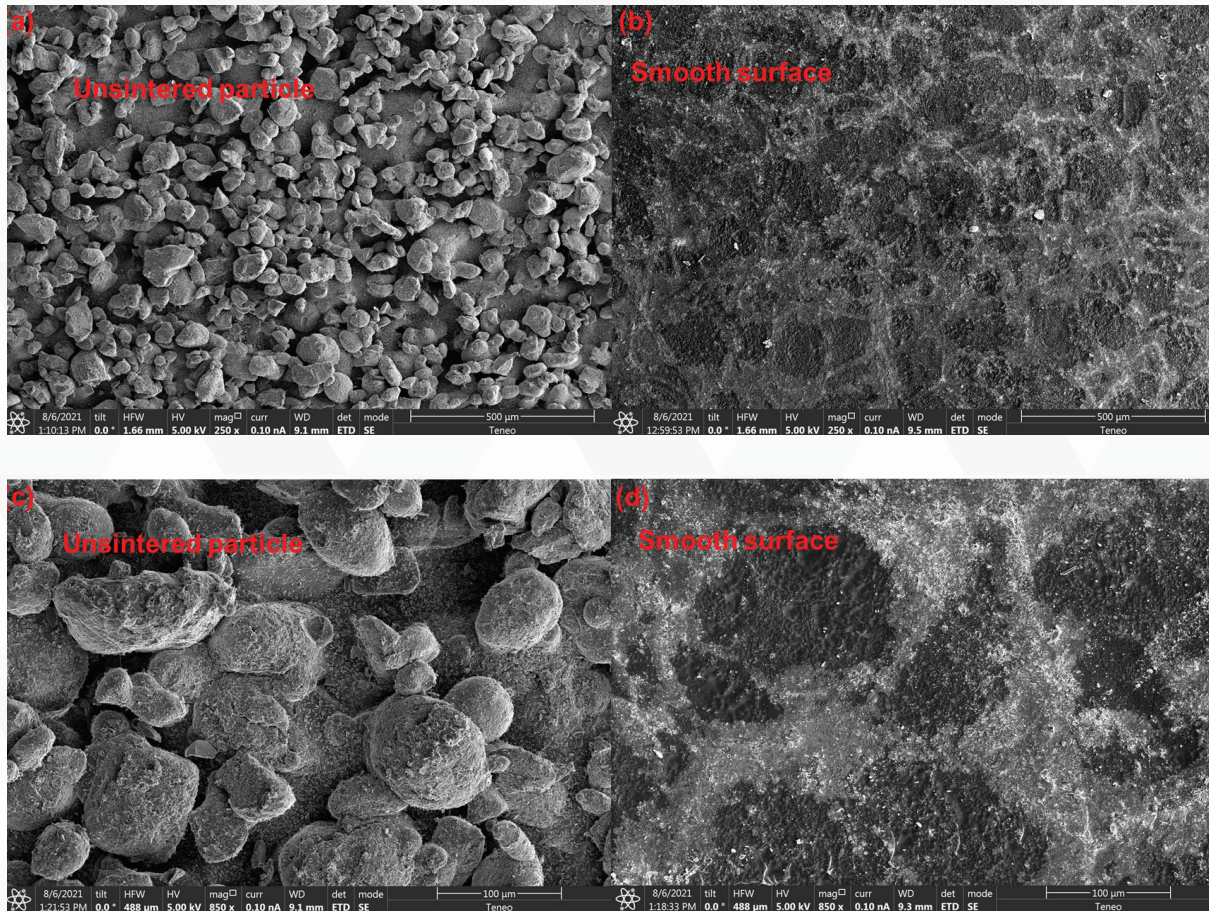


Figure 5. Surface SEM of as-printed (a and c) and processed (b and d) parts at x 250 magnification, as well as x 850 magnification.

DIMENSIONAL VARIATION

20 dimensional samples with a bounding box of 25.00 x 25.00 x 25.00 mm were printed to compare the effect of using chemical smoothing as post-processing on part dimensions. Each part was measured using digital callipers before and after chemical smoothing at three different reference locations (5mm, 15mm and 25mm) in X and Y directions as shown in Figure 5.

Results are presented in Figures 6 and 7. On average the results reveal a slight shrinkage in both X and Y directions after processing compared to the as-printed parts.

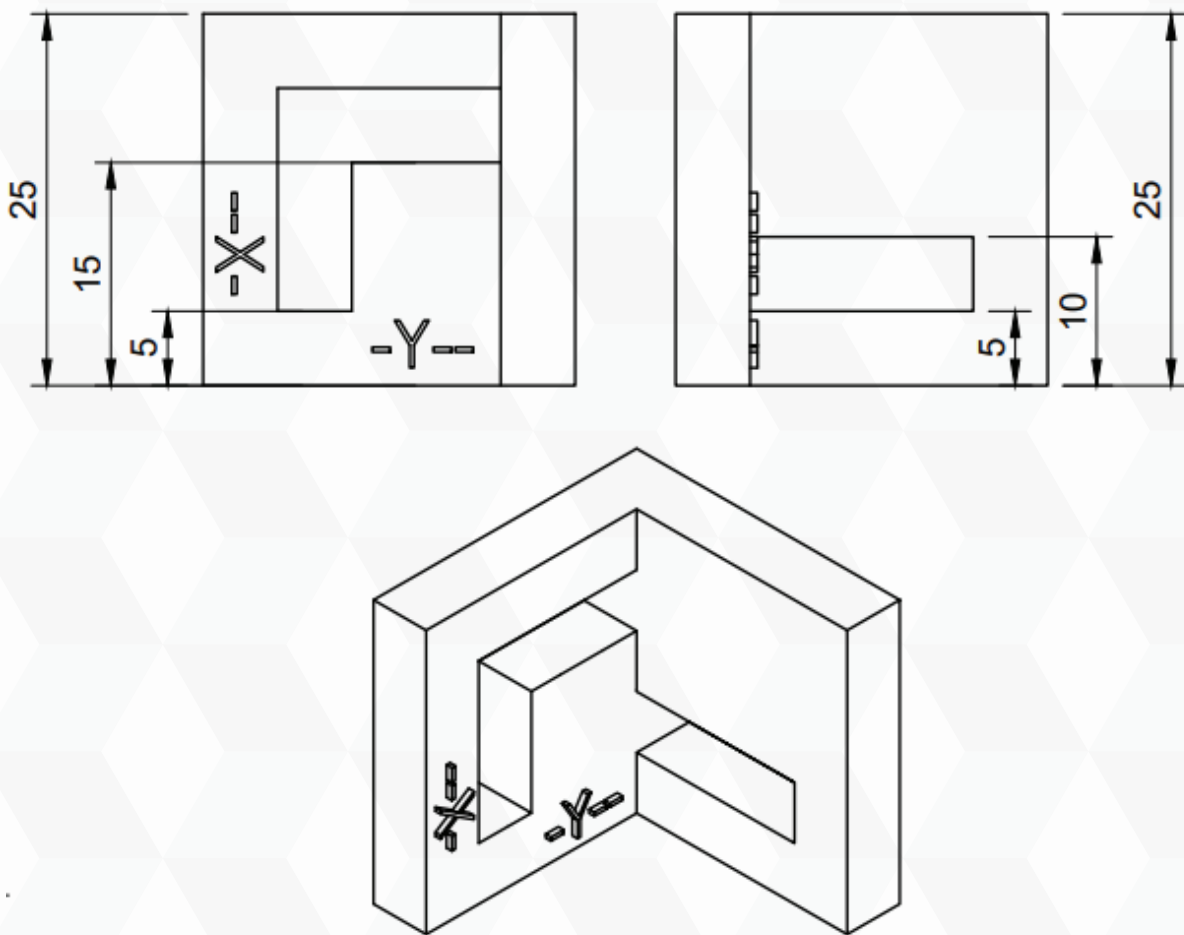


Figure 5. Dimensional sample and reference measurement locations

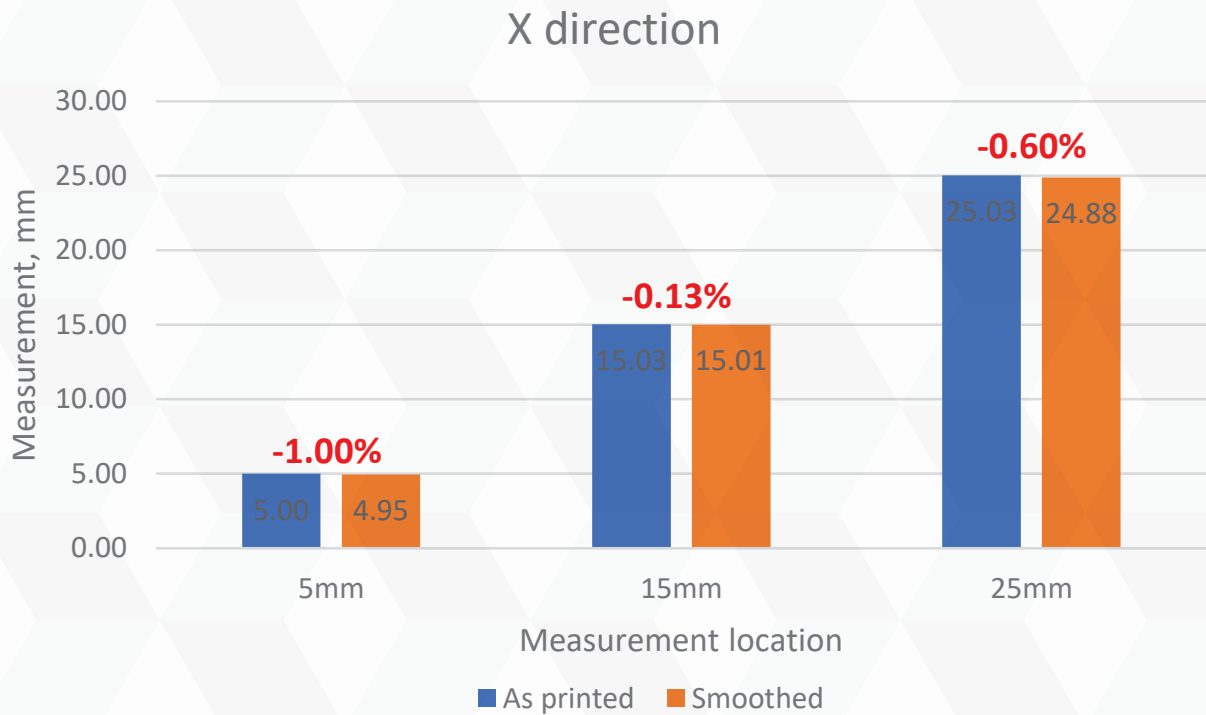


Figure 6: Dimensional variation in X direction between as-printed and processed parts

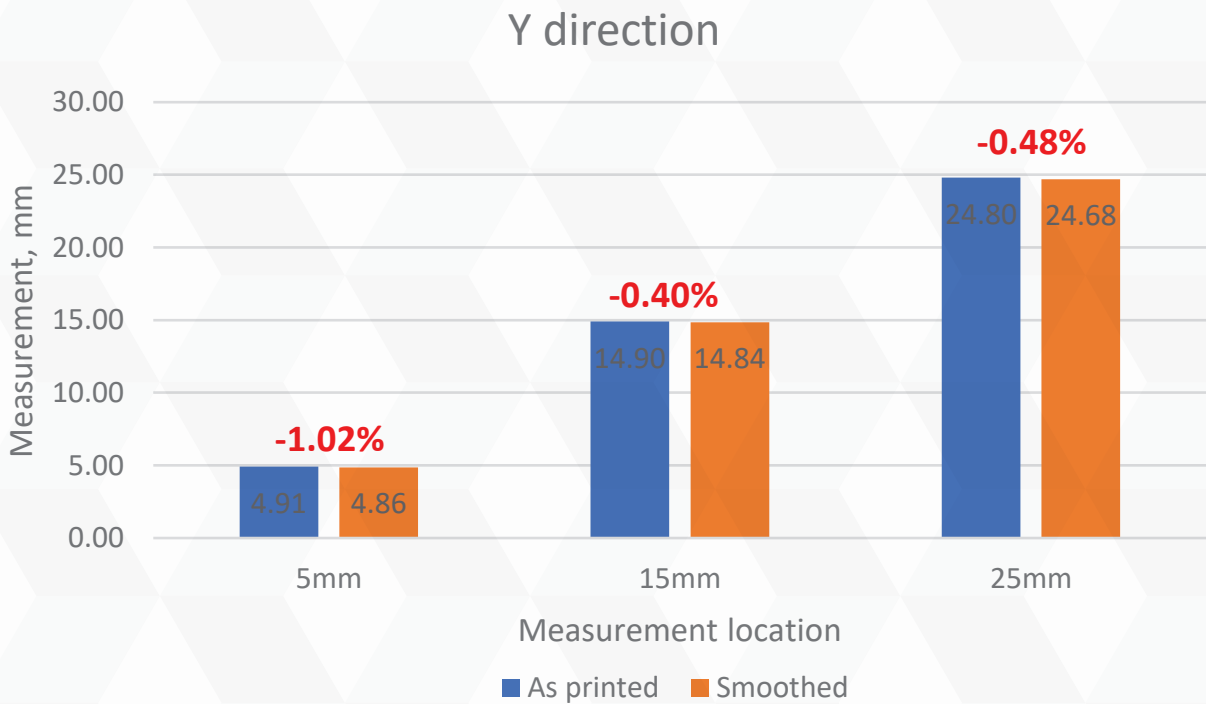


Figure 7: Dimensional variation in Y direction between as-printed and processed parts

MECHANICAL PROPERTIES

Twelve different mechanical tests were performed on the as-printed and processed parts (Table 1). Test results are given in following subsections. Generally, vapour smoothing does not produce significant deviations in mechanical properties. Among the biggest changes are improvements in Tear strength @23°C: 9.36% and 22.11% for XY and Z directions respectively under Die C category, 11.31% and 16.45% for XY and Z directions respectively under Die T category. Another noticeable improvement was shown by the compression set test, where rebound improved from 60% to 70% (40% and 30% respectively). This means processed samples demonstrate a better recovering behaviour to the original shape after removing the compression.

Testing	Standard	Unit	Before processing	After processing
Izod impact notched at 23°C	ASTM D256	kJ/m ²	XY: 27.0 (P) (*) Z: 26.2 (P)	XY: 27.4 (P) Z: 25.1 (P)
Tensile strength	DIN 53504	MPa	XY: 12.6 Z: 9.4	XY: 12.6 Z: 9.5
Tensile modulus	DIN 53504	MPa	XY: 96.5 Z: 104	XY: 86.0 Z: 95.1
Elongation at break	DIN 53504	%	XY: 304 Z: 68	XY: 296 Z: 68
Tear strength @23°C	ASTM D624 Die C	kN/m	XY: 62.9 Z: 39.8	XY: 69.4 Z: 51.1
Tear strength @23°C	ASTM D624 Die T	kN/m	XY: 33.7 Z: 19.3	XY: 38.0 Z: 23.1
Flexural strength	ASTM D790	MPa	XY: 3.9 Z: 4.4	XY: 4.0 Z: 4.5
Ross flex cold temp	Evonik internal method 250k cycles, -10 °C	N/A	No crack	No crack
Vicat softening Temperature A	ASTM D1525 Method A 10N, 50°C	°C	XY: 113 Z: 113	XY: 111 Z: 114
Compression set	ASTM D395 Type 1, Method B	%	XYZ: 40	XYZ: 30
Rebound resistance	ASTM D7121	%	XYZ: 72	XYZ: 71
Hardness Shore A	ASTM D2240		XYZ: 91	XYZ: 93
Density	ASTM D792	g/cm ³	XYZ: 1.01	XYZ: 1.01

(*):P - Partial break

UV TESTING

Samples with and without AMT smoothing process were exposed to UV light followed ASTM G155 standard for 200h and 300h, respectively. The color was measured in terms of CIELAB a^* , b^* , and L^* values as shown in Figure 8a. Test results are provided in Figures 8 (b, c and d). After the given UV exposure, processed parts show significantly lower colour change compared to the unprocessed parts in terms of a^* , b^* , and L^* , indicating much better color stability after processing.

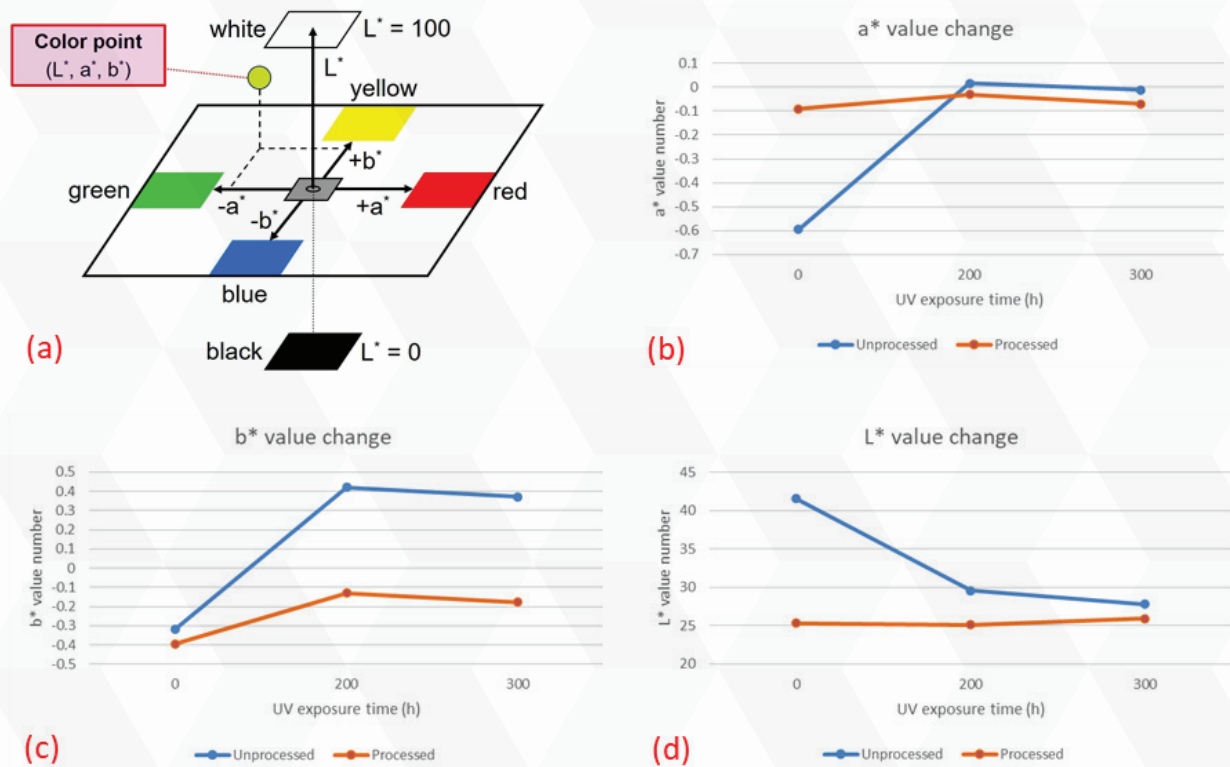


Figure 8: (a) The CIELAB color system; (b) ~ (d) are color a^* value, b^* value, and L^* value change for unprocessed and processed 3D parts, respectively

CONCLUSIONS

Evonik TPA material can be post-processed and is compatible with AMT PostPro chemical vapor smoothing technology. The process delivers significant improvements in surface smoothness, color consistency and compressional rebound behaviour while keeping key mechanical properties intact and dimensional variations within widely accepted tolerance limits. Evonik and HP's co-branded TPA powder has unique functional, flexible properties suited for production, and in combination with PostPro chemical vapor smoothing technology delivers superior performing 3D printed components, enabling high performing parts for a comprehensive range of applications.

REFERENCES

W. S. Syam, K. Rybalcenko, A. Gaio, J. G. Crabtree, R. K. Leach, 2018. In-process measurement of the surface quality for a novel finishing process for polymer additive manufacturing. Procedia CIRP 2018; Vol 75, pp. 108-113.

¹ W. S. Syam, K. Rybalcenko, A. Gaio, J. G. Crabtree, R. K. Leach, 2019. Methodology of the development of in-line optical surface measuring instruments with a case study for additive surface finishing. Optics and Lasers in Engineering; Vol 121, pp 271-288.

³ K. Rybalcenko, A. Gaio, L. Folgar, J. G. Crabtree, 2019. The use of smart in-process optical measuring instrument for the automation of Additive Manufacturing process. Proceedings SFF 2019; pp. 2046-2050

CONTRIBUTORS

Additive Manufacturing Technologies Ltd:

Dr. Konstantin Rybalcenko
Giorgio Ioannides
Luis Folgar

Evonik Corporation:

Yanfeng Lu, Ph.D.



Additive Manufacturing Technologies Ltd

Tinsley Park, Airport Business Park, Unit N,
Europa House
Sheffield S9 1XU, UK

amtechnologies.com



Evonik Industries AG

Rellinghauser Straße 1–11
45128 Essen
Germany