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RICOH'S POLYPROPYLENE PARTS POST-PROCESSED VIA AMT'S SMOOTHING TECHNOLOGY

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ABSTRACT

Surface smoothing has found applications in a large variety of amorphous and semicrystalline thermoplastics. BLAST (Boundary Layer Automated Smoothing Technology), a physico-chemical based process, can smooth a variety of thermoplastic polymers including PA12, PA11, TPU, ABS and many more; hence, achieving an injection moulded-like finish that allows for control of surface roughness, texture, and mechanical property enhancement of additively manufactured parts. However, Polypropylene (PP), a polyolefin used in non-polar systems, exhibits extreme chemical resistance to polar solvents making it challenging to chemically process, if not using hazardous solvents, at high temperatures.

Ricoh has been providing 3D printed PP parts since 2015 with its unique PP material processed on the RICOH AMS5500P machine. Typically, the parts are manufactured for prototype applications for form, fit and function. RICOH's PP material has properties making it suitable for end use applications, however, one of the many blockers for using PP in certain applications, such as medical, is due to the rough surface.

AMT has invented a new innovative process to smooth RICOH's PP 3D printed parts and have shown that both the mechanical performance and surface characteristics of the parts are dramatically improved. 3D printed PP testing parts made via Selective Laser Sintering (SLS) and post-processed using AMT's proprietary technology have been evaluated and the results show significant improvement of elongation at break and break stress.

SMOOTHING TECHNOLOGY

AMT has developed a proprietary smoothing process that integrates applied science and technology to deliver surface engineering for 3D printed polymers.

AMT's smoothing process eliminates surface imperfections of parts including complex geometries with internal cavities and other non-visible structures. The patent-pending process achieves reproducible results with no degradation to mechanical properties for Polypropylene 3D printed parts.

The smoothing technology can be integrated into the manufacturing workflow to reduce production lead-times and operational costs in the supply chain. The combination of RICOH's PP performance-powder for laser sintered parts and AMT's post-process strengthens the value proposition of PP in any 3D printing application.

MATERIALS

This white paper focuses on the industry's most sustainable Polypropylene, RICOH's PP, for performance applications via Selective Laser Sintering (SLS). Ricoh's versatile translucent off-white material is one of the most commonly used polymers in the manufacturing industry, with comparable properties to injection moulded PP. Durable, fatigue-resistant and lightweight, it is uniquely representative of the end part and therefore offers precise form, fit and functional testing. This unique PP also boasts chemical resistance, with WRAS (Water Regulation Advisory Scheme) approval and complete recyclability. 3D printed PP has extremely high elongation at break and is therefore perfectly suited to applications including functional prototypes for snap-fit, automotive assemblies or living hinges, packaging and consumer goods.

TEST METHOD

Parts used during this study have been printed on a RICOH AM selective laser sintering printer. Parts were printed using a 10% virgin and 90% refreshed polypropylene mixture.

At the end of the printing process, parts were manually removed from the build cake and excess powder removed using an automated tumble blaster.

Parts used for testing are summarised in the table below:

PART	DIMENSIONS (MM)	PURPOSE
Cube	60 x 60 x 60	Dimensional variation / solvent uptake
Tensile rod	75 x 10 x 2	Mechanical testing
Blocs	80 x 20 x 1	Surface roughness and cytotoxicity tests

The mechanical properties of test specimens were determined using an AGS-X 10kN tensile tester (Shimadzu) according to accordance DIN EN ISO 527-2 and at a speed of 50 mm/min. Five samples for each condition (before and after post-processing), printed in the XY printing direction, were tested and their Young's modulus, tensile strength, break stress and elongation at break evaluated.

SURFACE ROUGHNESS

The surface roughness R_a of the samples was measured using a Mitutoyo Surftest SJ-210 with a stylus tip radius of $2\mu\text{m}$, tip angle 60° and measuring force 0.75kN . Five measurements at different areas of each surface were made before and after processing and the average calculated. The resulting surface finish after the post-processing compared to unprocessed (as printed) surface as shown below (Fig. 1).

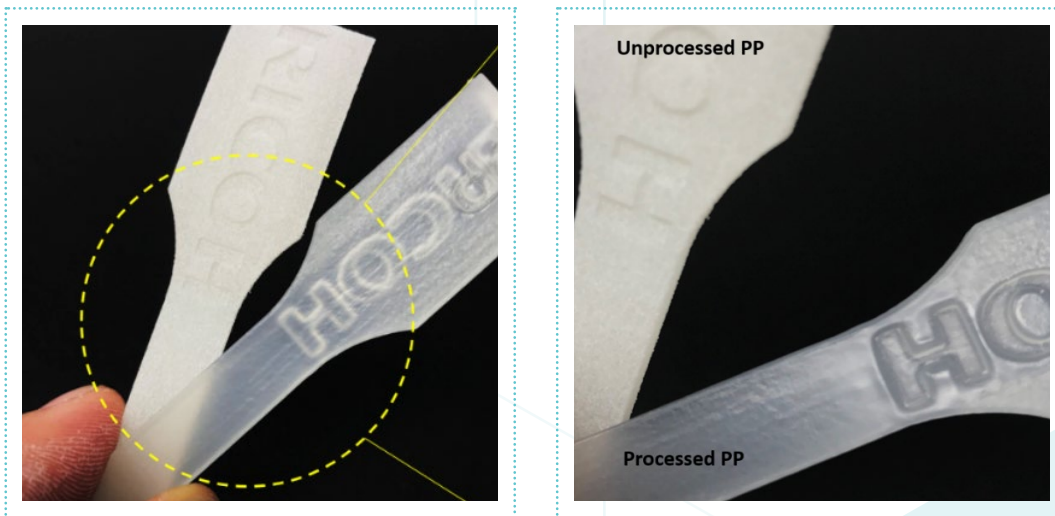


Figure 1: Digital image of RICOH's PP tensile bar before and after processing.

The smoothing process removed defects (μm scale) observed on surfaces of unprocessed parts (Fig. 2 a, c). The surface roughness of the processed parts decreased significantly with a reduction of around 95% (Fig. 3).

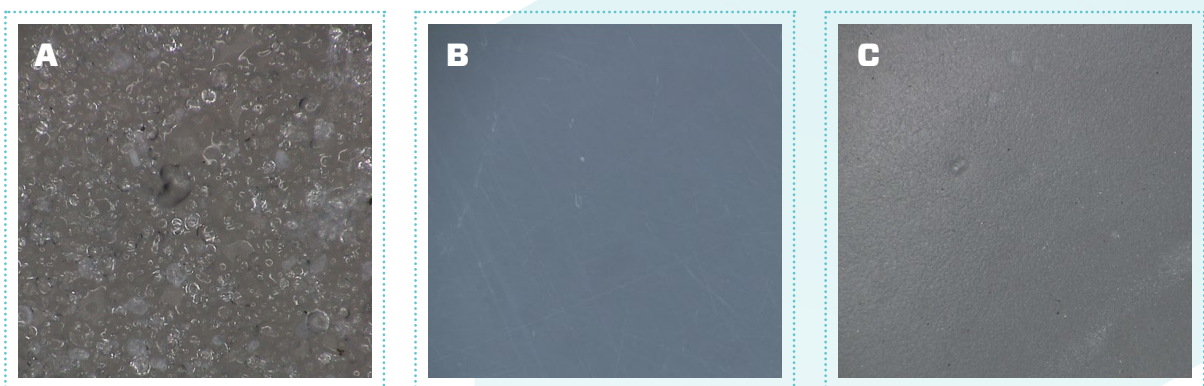


Figure 2: a) Optical microscope images of the surface of RICOH's **unprocessed** PP part; b) **injection-moulded** PP surface; and c) surface of RICOH's **processed** part.

The repeatability of the smoothed surfaces for each set of samples is demonstrated by the reduction in the standard deviation between Ra values (Fig. 3). A conventional injection moulded surface roughness Ra for polypropylene can be found to be within 0.1 – 0.5 μ m. The average roughness Ra for unprocessed specimens was measured to be 12.35 μ m while the measured roughness Ra for the final finish was found to be within the 0.46 and 1.80 μ m.

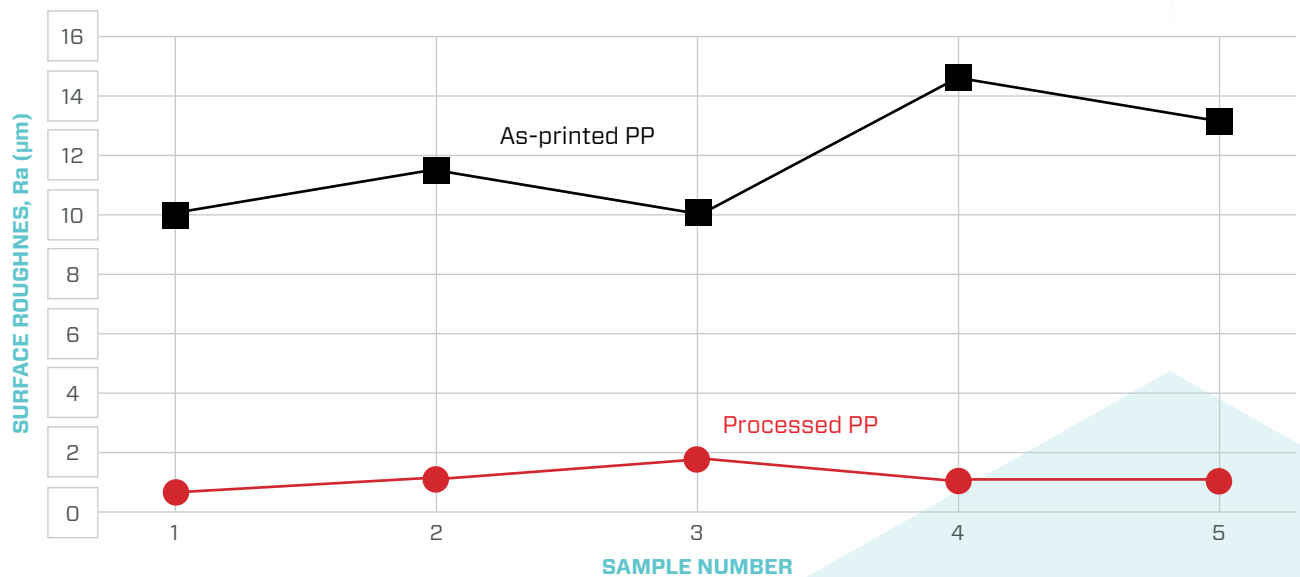


Figure 3: Surface roughness of RICOH's PP parts before and after processing.

The values shown in Figure 3 demonstrate the impact of the smoothing process on the surfaces of PP SLS-printed parts.

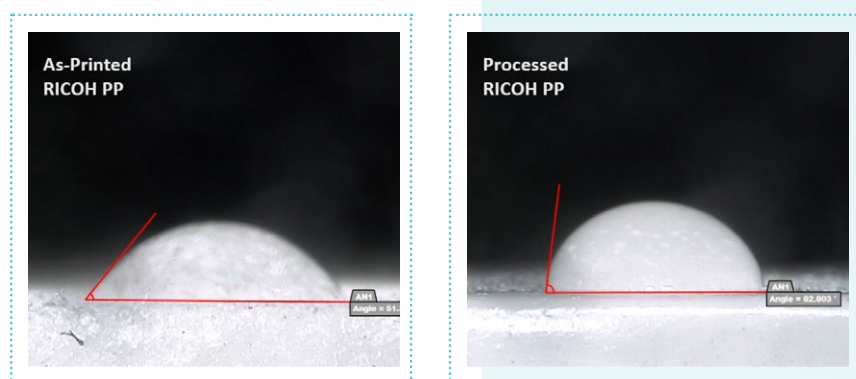


Figure 4: Surface roughness of RICOH's PP parts before and after processing.

The contact angle of processed and unprocessed surfaces was compared demonstrating that the finish increased the hydrophobicity of the PP surface. This can be explained by the elimination of surface porosity and total reduction of the surface area.

DIMENSIONAL VARIATION

Five samples were analysed in terms of dimensions in the X, Y and Z directions before and after processing. The analysis has shown that no significant dimensional variation on the parts has occurred allowing the retention of part tolerances and fine feature details. The dimensional analysis values along with the solvent uptake values are presented in Table 1.

Sample	X (MM)		Y (MM)		Z (MM)	
	Before smoothing	After smoothing	Before smoothing	After smoothing	Before smoothing	After smoothing
1	60,00	60,04	60,46	60,38	60,11	60,15
2	60,09	59,9	60,07	60,01	60,01	59,97
3	60,17	60,04	60,19	60,25	60,1	60,03
4	60,35	60,27	60,18	60,10	60,19	60,20
5	59,88	59,78	60,03	60,01	59,96	59,97

Table 1: Dimensions of RICOH's PP parts before and after surface processing.

MECHANICAL PROPERTIES

The improvement in mechanical properties can be immediately observed after the test specimens undergo the smoothing process. The average elongation at break for unprocessed tensile specimens was measured at approximately 93%, and the processed ones recorded an average elongation at break of approximately 355%. This is an increase of almost three and a half times its raw-as-printed elongation (Fig. 5).

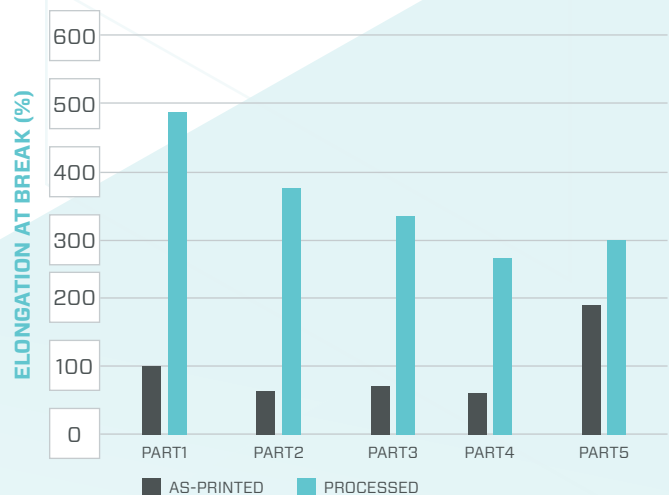


Figure 5: Elongation at break (%) comparison for laser sintered PP parts tested before and after post-processing.

An improvement was observed at the break stress as well with the processed parts to show an average value of 19MPa versus the unprocessed parts showing 13MPa (Fig. 6).

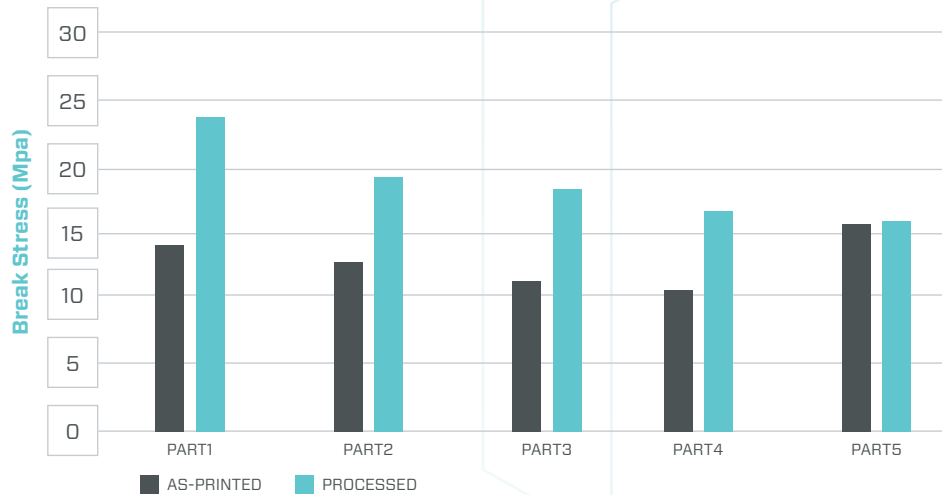


Figure 6: Break stress (MPa) comparison for laser sintered PP parts tested before and after post-processing.

It is important to note a slight increase was observed in Tensile strength of the processed parts while Young modulus did not show any significant change (Figs. 7 & 8).

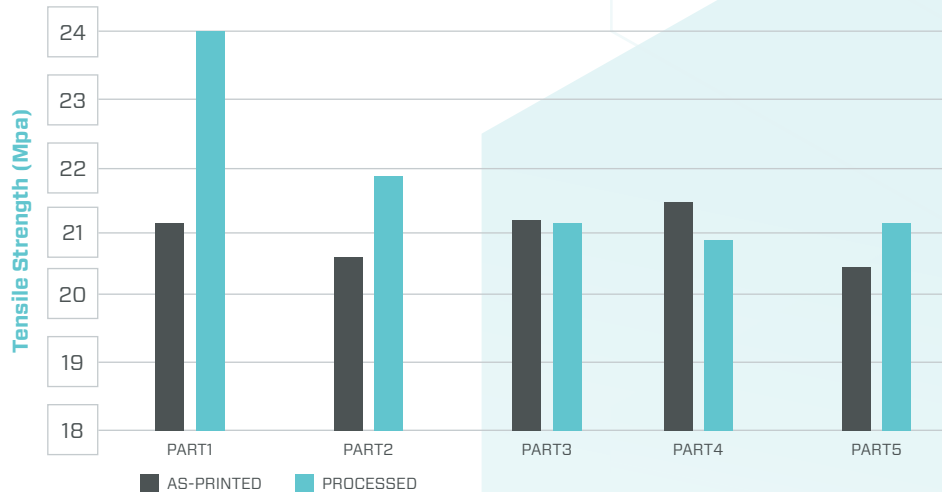


Figure 7: Tensile strength (MPa) comparison for laser sintered PP parts tested before and after post-processing.

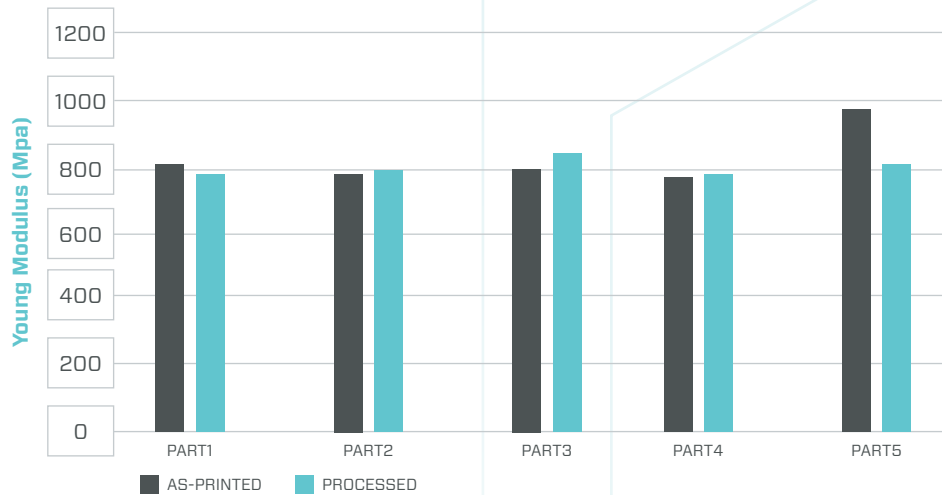


Figure 8: Young modulus (MPa) comparison for laser sintered PP parts tested before and after post-processing.

CYTOTOXICITY ANALYSIS

The cytotoxicity test is a biological evaluation and screening test that uses tissue cells in vitro to observe the cell growth, reproduction and morphological effects by medical devices. Cytotoxicity is an important indicator for toxicity evaluation of medical devices as it is simple, fast and has a high sensitivity. Cytotoxicity tests were carried out at an external European laboratory to Normative References: ISO 10993-5 (2009); ISO 10993-1 (2018); ISO 10993-12 (2012).

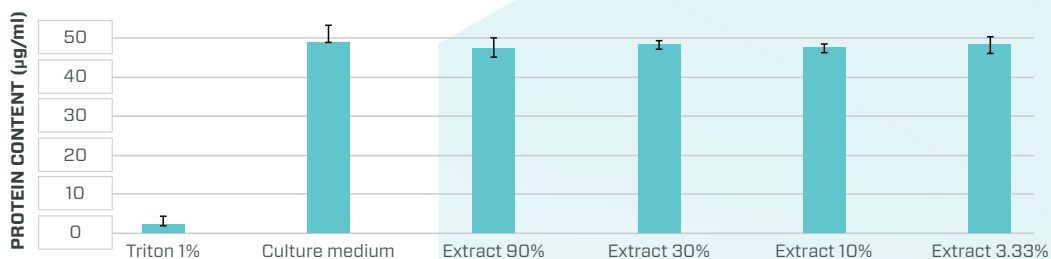


Figure 9: Protein content of the cell culture for different extract dilutions.

The results in Figure 9 show that in the presence of Triton X 100 in the cell culture medium, 6.0 % of the protein content compared to the negative control was reached. This value is within the valid range of 15 % protein content or less compared to the negative control. Materials are considered cytotoxic, if the material extract leads to a protein content of the test cells of less than 70 % compared to the negative control. This was not the case in this test. The material extract therefore does not show a cytotoxic effect.



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CONCLUSIONS

Ricoh's Selectively Laser Sintered (SLS) PP parts have a grainy like rough surface as well as surface imperfections that suppress the mechanical properties potential. Ricoh's 3D printed PP parts were successfully processed using AMT's proprietary technology; the surface and mechanical properties were evaluated, and the results showed that the AMT post treatment enhanced the performance of the parts both mechanically and aesthetically.

The biggest drawback of SLS PP in many applications including medical and automotive is the visual appearance with the surface finish always lacking compared to its injection moulded counterparts. This whitepaper has shown that the development of AMT's post-processing technology will bridge the gap between injection moulding and 3D printing by allowing for many more applications to make use of Ricoh's PP due to the extraordinary surface finish and increased mechanical properties. The combination of Ricoh's outstanding PP material properties and AMT's automated finishing will allow for PP components to be manufactured for end use applications. The commercialisation of AMT's PP post-treatment will also mean that end use parts can be produced in serial production with minimal labour and reduced post-processing costs.

1 W. S. Syam, K. Rybalcenko, A. Gaio, J.G. Crabtree, R. K. Leach, In-process measurement of the surface quality for a novel finishing process for polymer additive manufacturing. *Procedia CIRP* 2018; Vol 75, pp. 108-113. **2** RICOH Imagine.Change. Polypropylene – Selective Laser Sintering (SLS) - <https://rapidfab.ricoh-europe.com/materials/sls-printing/pp/>

For more information about Ricoh, visit:
<https://rapidfab.ricoh-europe.com/>



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