ADDITIVE MANUFACTURING TECHNOLOGIES

BLAST™ Boundary Layer Automated Smoothing Technology

PERFORMANCE SLS PRINTED NYLON 11 PARTS: FROM GOOD TO GREAT WITH POSTPRO3D

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ABSTRACT

The mechanical properties of 3D printed Nylon 11 tensile bars made via Selective Laser Sintering (SLS) and post-processed with Boundary Layer Automated Smoothing Technology (BLAST) have been evaluated. BLAST, a physical-chemical based process, can smooth a variety of thermoplastic polymers; hence, achieving an injection molding finish that allows for control of surface roughness, textures and gloss. Consequently, the effect on mechanical properties of additive manufactured parts is controlled. Thermoplastic 3D printed parts via powder bed fusion (PBF) have surface imperfections such as internal voids, residue powder, or partially fused powder among the most common. Post-processing through BLAST significantly enhances the mechanical performance of 3D printed parts. The results of this revolutionary technology show the improvement in elongation at break after post-processing Nylon 11 parts.

BLAST AND POSTPRO3D

Boundary Layer Automated Smoothing Technology (BLAST) is a proprietary physiochemical process from Additive Manufacturing Technologies (AMT). The process can dissolve polymers using sustainable chemistry in a controlled manner to smooth the surface of 3D printed parts. Surface imperfections are erased from parts including complex geometries with internal cavities and other non-visible internal structures.

AMT's PostPro3D is a patented machine technology that uses BLAST to provide a highly controllable, automated and sustainable post-processing solution. PostPro3D in-tegrates applied science and technology to deliver sustainable chemistry and a scientific approach to surface engineering for polymers. PostPro3D achieves reproducible smooth parts with no degradation to mechanical properties for thermoplastic 3D printed parts. This is a safe, environmentally friendly, affordable and repeatable approach to achieve en-hanced mechanical properties and part-performance via additive manufacturing [1].

PostPro3D can be integrated into the manufacturing workflow to reduce production lead-times and operational costs in the chain. The combination of Arkema's Rilsan® PA11 per-formance-powder for laser sintered parts and AMT's post-process strengthens the value proposition of PA11 for any 3D printing application [9].

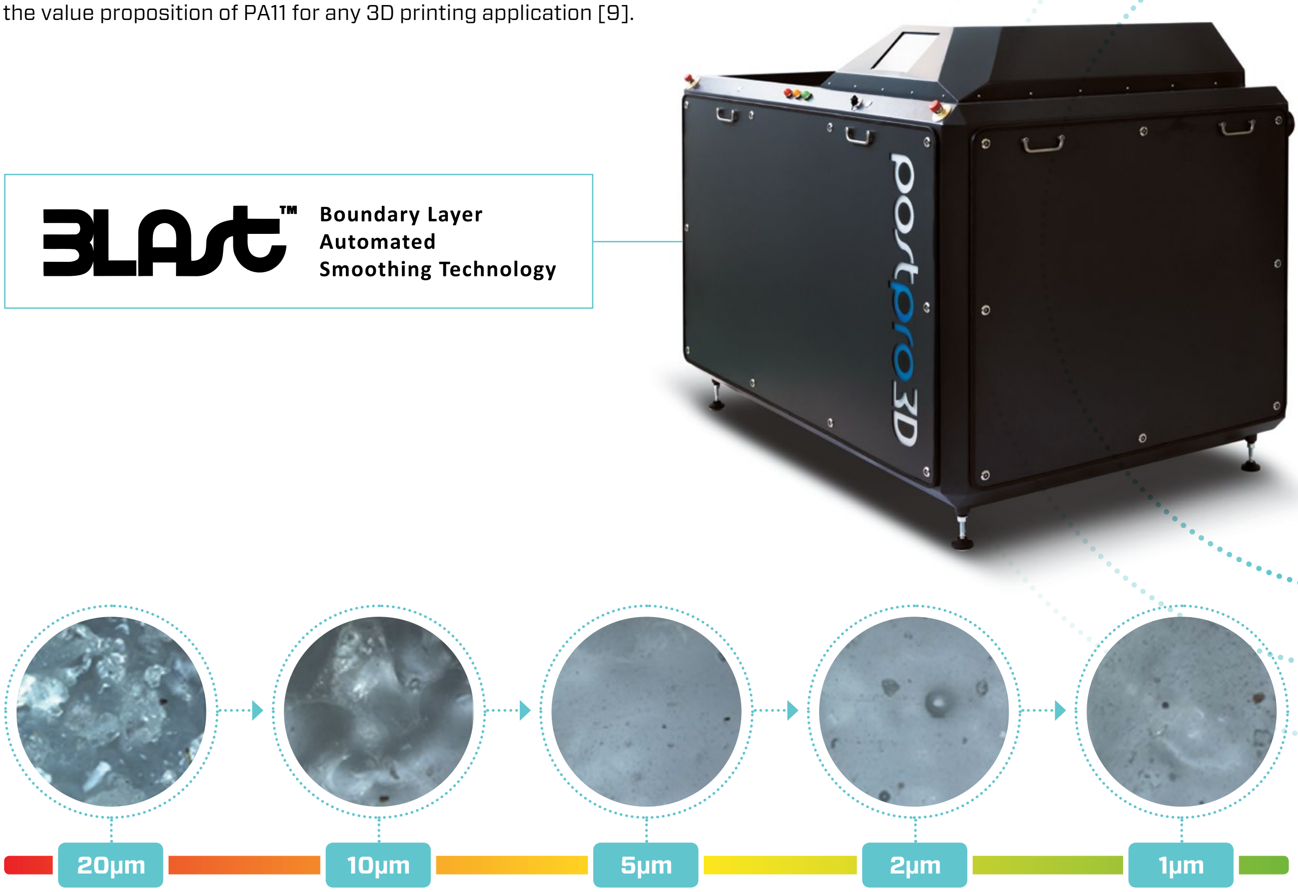


FIGURE 1. AMT's PostPro3D machine and Micrographs depicting the effect of BLAST (Boundary Layer Automated Smoothing Technology) on the surface of powder-bed printed parts in general.

MATERIALS

PostPro3 has been designed to process a wide range of thermoplastic polymer materials including Polyamides (Nylons) (6,11,12). This white paper focusses on the industry's most sustainable Nylon, Arkema's Rilsan® Polyamide (PA11), for performance applications via Selective Laser Sintering (SLS).

Arkema's 100% renewable (ASTM D6866) Rilsan Polyamide comes from the castor plant. Harvested in semi-arid to sub-tropical conditions and rotation farming adjustable for annual or short cycles. The castor plant origins make the production of PA11 completely sustainable for large scale manufacturing [4].

Laser sintered parts made of this bio-based polymer resin provide superior elasticity, ductility and impact resistance when compared to laser sintered PA12 [2, 3]. Certain grades of Nylon 11 including Arkema's Rilsan® Invent Natural meet USP Class VI requirements and displays excellent processing characteristics in powder bed fusion systems. The elongation achieved on SLS parts is up to three times superior to that of PA12 (see Figure 2). The layer-by-layer SLS process tends to generate non-uniform mechanical properties for most materials in the X, Y, and Z axis. Properties in Z axis tend to be the weakest compared to properties in X & Y axis [5]. Figure 2 shows the difference in elongation at break between X&Y and the Z axis to be approximately 8% for both PA11 and PA12 when compared individually. The mechanical properties of PA11 in the Z orientation alone outperform the mechanical properties of PA12 in X&Y (specially elongation at break).

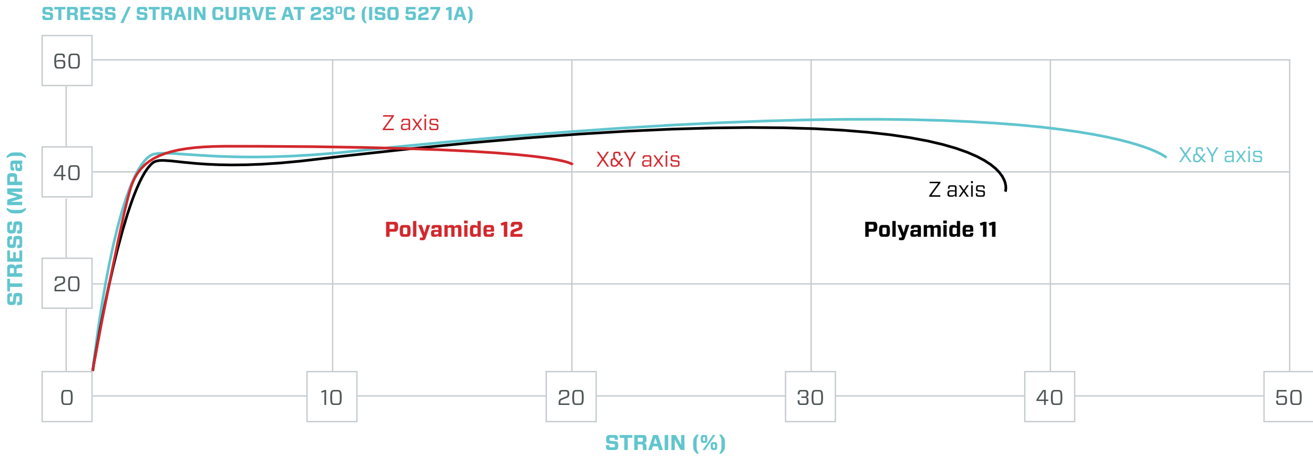


FIGURE 2. Tensile stress/strain curve comparison between Polyamide 12 (PA12) and Arkema's Rilsan Polyamide 11 (PA11) for laser sintered parts. Source: Arkema) [2].

The performance of printed SLS PA11 parts was tested. Specifically, the monotonic loading and fatigue response of PA 11 SLS tensile bars [7]. Similarly, Arkema's comprehensive analysis of PA11 performance against PA12 found that performance of PA11 is better suited for a wide range of applications such as automotive, medical, tooling, functional prototyping, and aerospace.

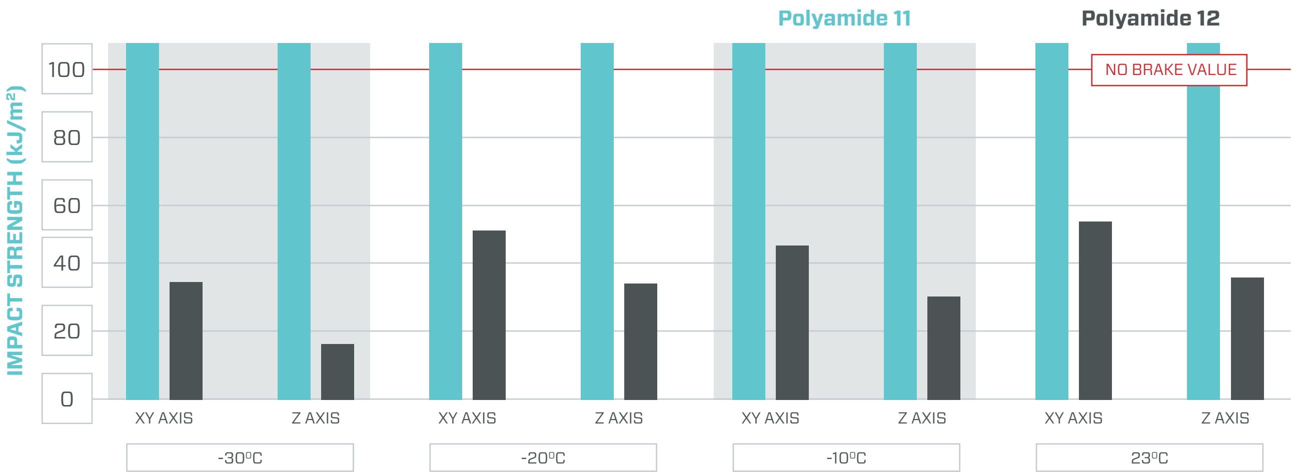


FIGURE 3. Charpy unnotched impact test ISO 179/1eU comparison and the influence of temperature on laser sintered parts' impact resistance for Nylon 12 (PA12) and Arkema's Rilsan Polyamide 11 (PA11) Source: Arkema [2].

Commercial aerospace applications have some of the most rigorous qualification testing requirements for implementation. In partnership between ALM and Boeing [6], FR-106 a PA11 based material was developed to take advantage of SLS manufacturing capabilities combined with a material that has inherently excellent mechanical properties.

DESIGN CONSIDERATIONS

PostPro3D's BLAST process re-distributes the surface material instead of removing it; it does not damage the delicate structures of the parts. This non-abrasive process allows bores with 0.3 mm in diameter to be smoothed. However, the minimum part thickness that can reliably be processed varies depending on the material and printing conditions. Generally, the recommended part thickness for best processing results is no less than 1 mm. Processing uniformity of printed parts depends on the thickness of wall sections, and significant variation in wall thickness may result in difficulty during post-processing.

TEST METHOD

Three sets of Rilsan Nylon 11 tensile test specimens were printed via Selective Laser Sintering (SLS). The samples were printed using an SLS 3D printer and supplied by Arkema. These were then processed with specific settings tailored to a pre-defined level of surface finish denoted as Finish 1 through 3. The study was performed in accordance with ISO-527 to study the tensile performance through evaluation of tensile strength, tensile modulus and tensile stress/strain relationship.

Simultaneously, the tensile test samples were processed for the evaluation of surface roughness in accordance with ISO standard ASTM D7127, dimensional tolerance and mechanical property changes.

Prior to processing with PostPro3D all part were depowered for best results. The pictures below in Figure 4 show the typical surface conditions of 3D printed parts after de-powdering (as printed). A Scanning Electron Micrograph (SEM) at 750X shows the partially fused agglomerates of polymer powder adhered to the fused polymer matrix.

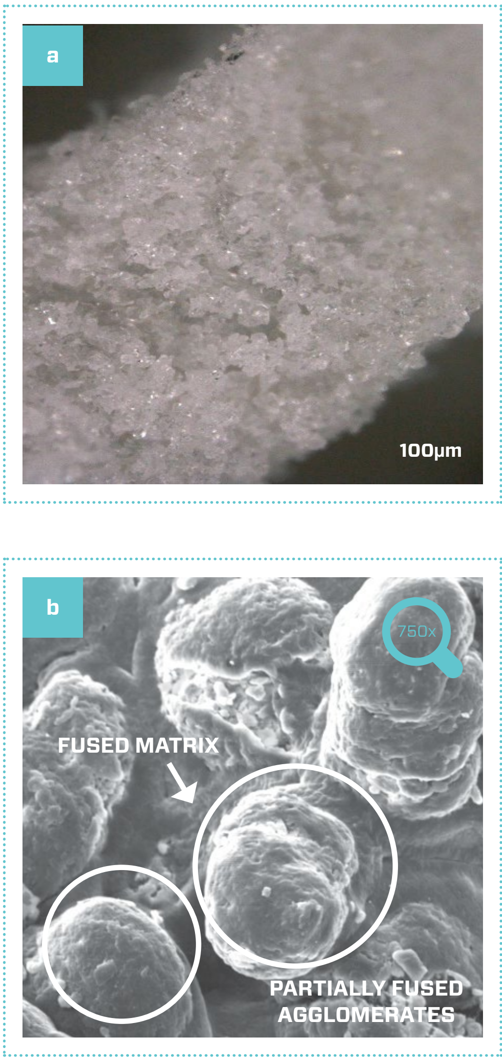


FIGURE 4. a) Micrograph picture of the surface of the laser sintered part, **b)** Scanning Electron Micrograph (SEM) of the laser sintered part surface showing the fused matrix and the partially fused agglomerates (in white circle).

SURFACE ROUGHNESS

The PostPro3D technology smooths the surface of a polymer part using a program with a selection of a predefined set of parameters. Each set of samples was processed in a separate batch using a different parameter set, with a 1-hour completion time for each process run.

The surface roughness of the samples was measured using a Mitutoyo Surftest SJ-210 with a stylus tip radius of 2µm, 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 taken. The three standard surface finishes are compared to unprocessed (as printed) surfaces as shown below.

The BLAST process removed defects (mm scale) observed on surfaces of unprocessed parts. Finish parts 2 and 3 seem to have the smoother surface compared to the finish part 1. This result is consistent with the visible change and lack of roughness of the processed specimens.

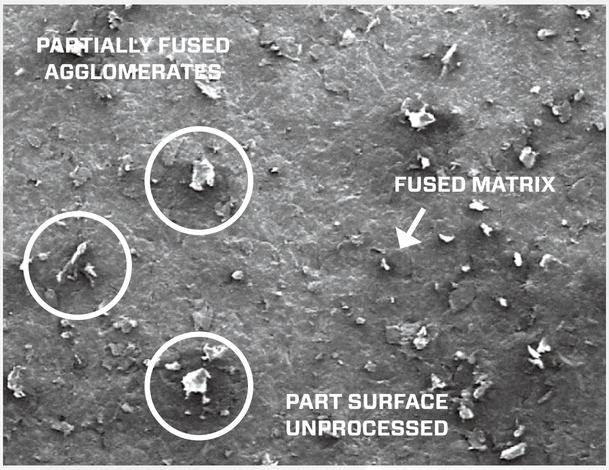


FIGURE 5. SEM of the laser sintered PA11 unprocessed surface as printed and cleaned . Partially fused agglomerates observed as white contrast specks on the fused matrix surface. Roughness measured was 6.56µm.

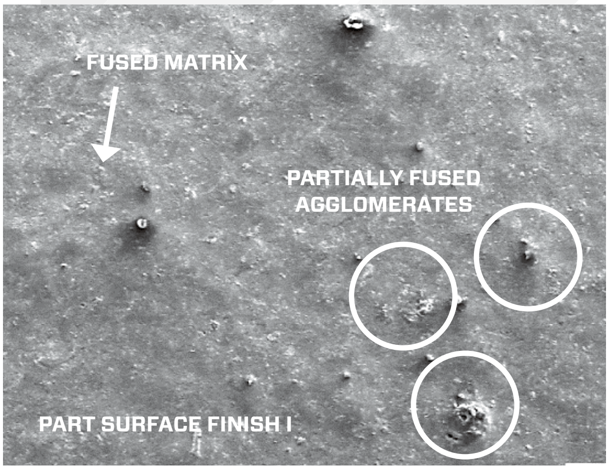


FIGURE 6. SEM of the laser sintered PA11 BLAST post-processed surface for Finish I. Partially fused agglomerates (in circles) are reduced on the fused matrix. Surface roughness measured at 1.45µm.

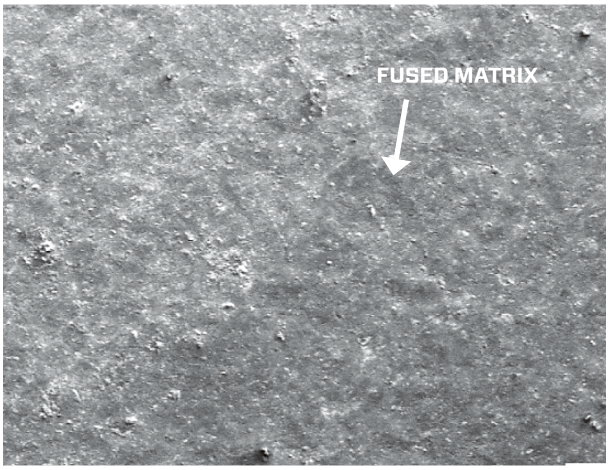


FIGURE 7. SEM of the laser sintered PA11 BLAST post-processed surface for Finish II. Partially fused agglomerates are further reduced with a surface roughness measured at 1.23µm.

PART SURFACE FINISH II.

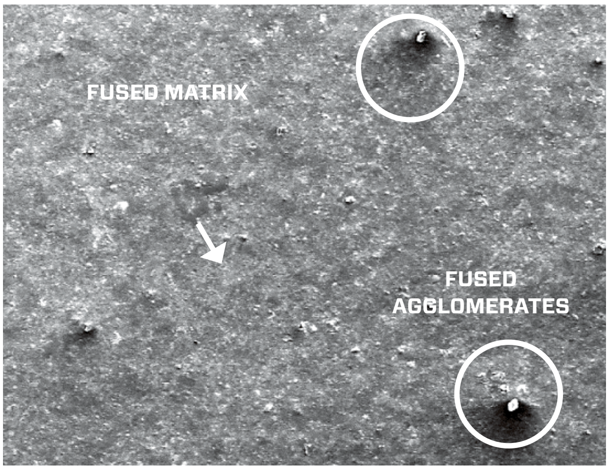


FIGURE 8. SEM of the laser sintered PA11 BLAST post-processed surface for Finish III. The roughness measured 0.78µm. Agglomerates shown in circles are fused into the fused matrix and no longer partially attached to the surface.

The repeatability of the smoothed surfaces for each set of samples is demonstrated by the small variation achieved in the measurements. A conventional injection molded surface roughness for polyamides can be found to be within 0.1 – 1.6µm Ra. The average roughness for unprocessed specimens was measured to be 6.56µm Ra while the measured roughness for finish 1 – 3 were found to be within the 0.78 and 1.45 µm Ra.

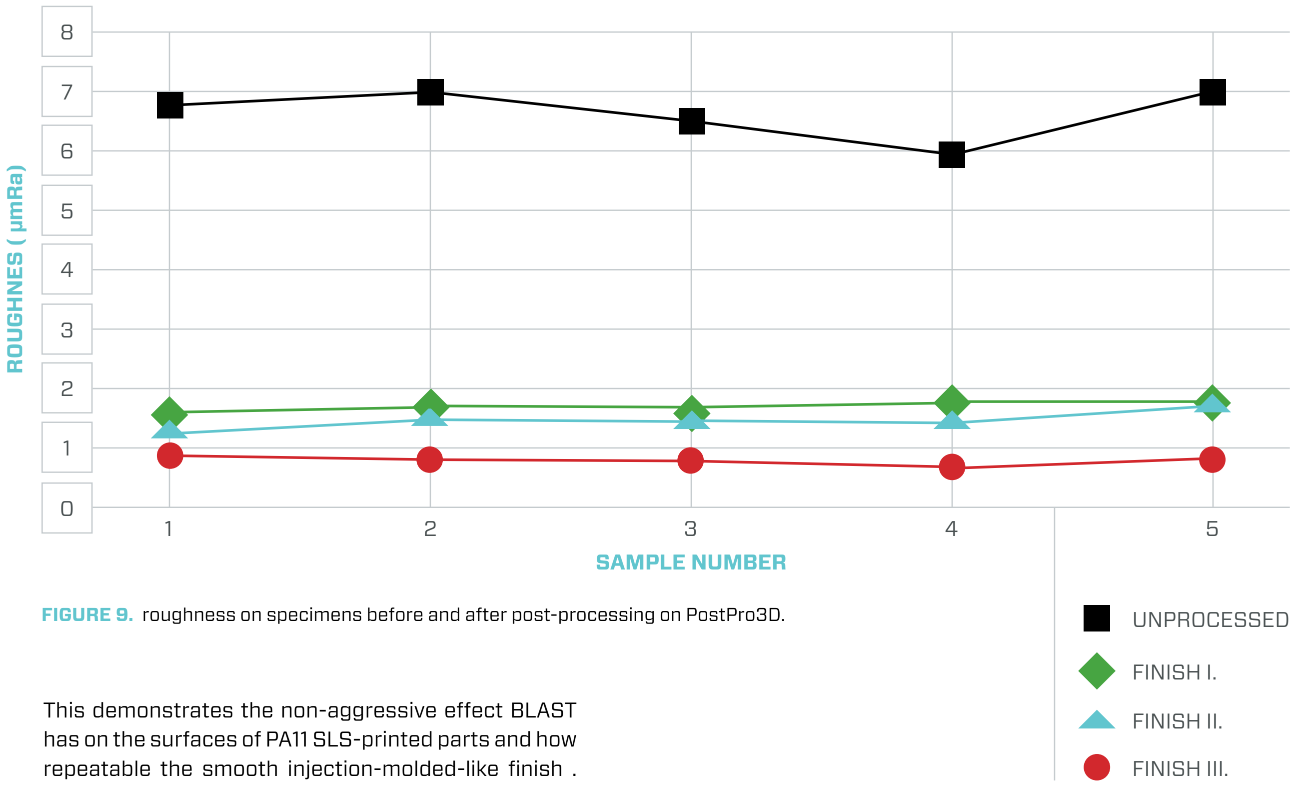


FIGURE 9. roughness on specimens before and after post-processing on PostPro3D.

This demonstrates the non-aggressive effect BLAST has on the surfaces of PA11 SLS-printed parts and how repeatable the smooth injection-molded-like finish . Significant improvement in tensile elongation of the test parts is observed as the surface roughness is reduced and crack initiation sites are removed.

MECHANICAL PROPERTIES

The improvement in mechanical properties can be immediately observed after the test specimens undergo the BLAST process to achieve Finish 1. The average elongation at break for unprocessed tensile specimens was measured at approximately 67%, and the Finished 1 recorded an average elongation at break of approximately 248%. This is an immediate increase of approximately three and a half times its raw-as-printed printed elongation. Finish 2 and 3 also show a significant increase in elongation at break after processing the test specimens. It is important to note that the modulus does not show a significant change among the different finishes achieved. Table 1 summarizes the changes in mechanical properties as they are processed with the different settings with the PostPro3D.

FINISH	SURFACE ROUGHNESS (μM)	ELONGATION AT BREAK (%)	YIELD STRESS (MPA)	MAX TENSILE STRESS (MPA)	MODULUS (MPA)
Unprocessed	6.56	67	49	50	1603 ± 17
PP3D Finish I	1.45	248	50	55	1556 ± 34
PP3D Finish II	1.23	227	49	56	1582 ± 30
PP3D Finish III	0.78	238	49	57	1552 ± 37

TABLE 1. Mechanical properties measured on laser sintered PA11 tested before and after BLAST post-processing.

The improvement in the elongation at break observed after BLAST post processing reaches an elongation increase that cannot be achieved by annealing the printed parts for hours at elevated temperatures as reported for post-SLS-build annealing of Nylon 11 [8].

FIGURE 10. Elongation at break (%) comparison for laser sintered PA11 tested before and after BLAST post-processing via PostPro3D with three different finishes.

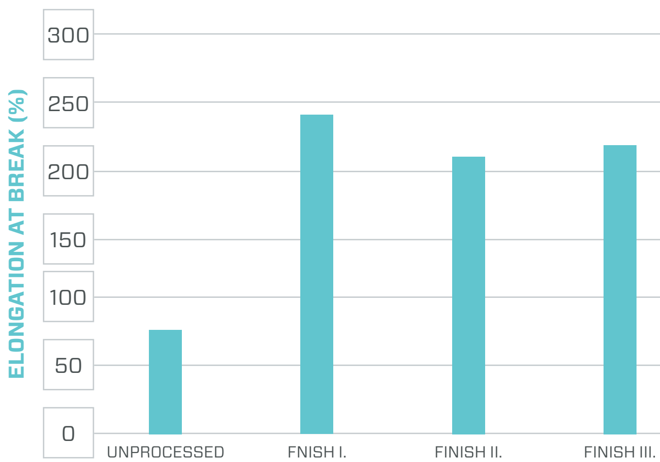


FIGURE 11. Yield stress (MPa) and maximum tensile stress (MPa) comparison for laser sintered PA11 tested before and after BLAST post-processing via PostPro3D with three different finishes.

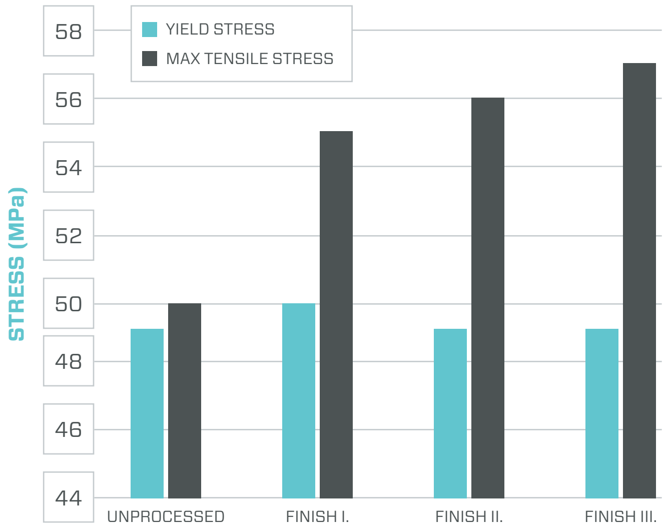
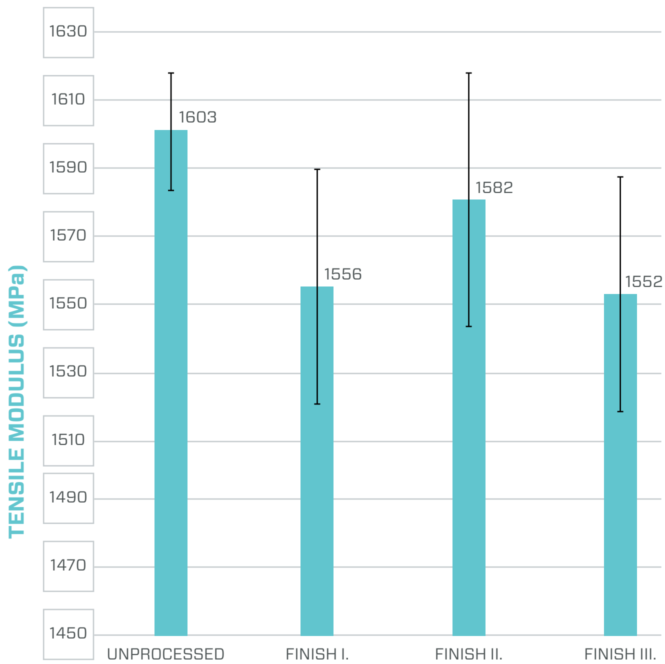


FIGURE 12. Tensile Modulus (MPa) comparison for laser sintered PA11 tested before and after BLAST post-processing via PostPro3D® with three different finishes.



The removal of crack-initiation sites on the surface of parts and the uniformity of the finish achieved with the PostPro3D demonstrates the ability to significantly increase the performance potential of parts produced with SLS. Figure 13 shows the ductile fracture failure characteristic nature of PA11and observed in the specimens with different post-process. The elongation at break values observed after AMT's BLAST post-process are outside the natural performance of SLS as-printed Nylon 11.

FIGURE 13. Photograph of the ductile fracture failure observed in the laser sintered specimens before and after BLAST post-processing with the PostPro3D.

CONCLUSION

Thermoplastic 3D printed parts via SLS have surface imperfections that suppress the mechanical properties potential of the part. Post processing through BLAST unlocks that potential with a turnkey solution that heightens the value of a fast, superior, affordable and reliable automated post-processing, In combination with a 100% bio-based material expected to perform in some of the most extreme environments, PostPro3Ds BLAST process provides the ultimate sustainable approach for additive manufacturing of performance materials that is based on a sustainable approach.

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