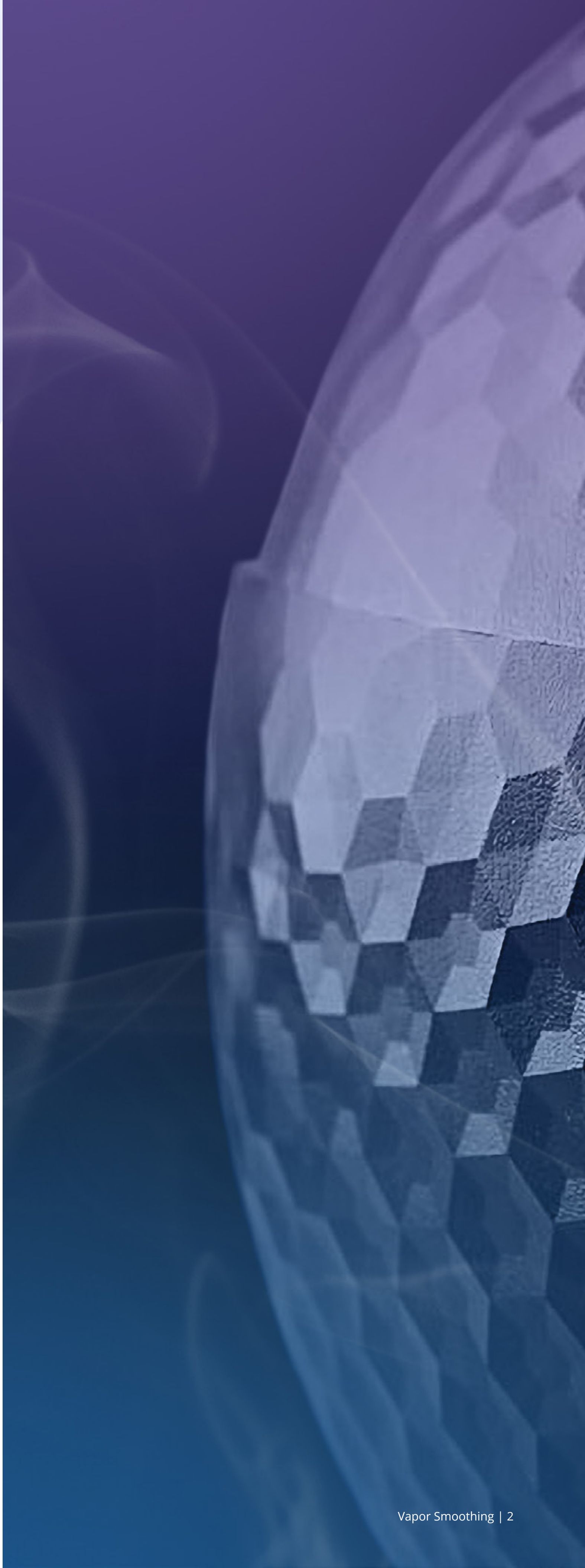
VAPOR SMOOTHING

The Post-Processing Finish that's Changing the Game in Additive Manufacturing of Plastics

Additive manufacturing captures the imagination with its potential—complexity, new designs for single parts that replace entire assemblies, freedom from the typical manufacturing constraints, including the costs of tooling and carrying inventory. In the decades since its earliest introduction, we've seen 3D printing used to produce prosthetics, dental and medical appliances and components, and a host of aerospace products, just to name a few.

Despite the benefits of additive manufacturing, it has not been as widely adopted as anticipated. Speed, aesthetics, porosity of the printed plastic parts, and reduced mechanical properties have challenged the use of 3D printing in scaled production; **vapor smoothing technology as a post-production process is changing the game.**



TECHNOLOGY METHODS AND PROCESS SPEED

Two technologies exist for making thermoplastic parts from powdered plastic: Selective Laser Sintering (SLS) and Multi Jet Fusion (MJF). SLS uses a laser to melt the powder into a solid part, building the part layer by layer. MJF also builds the part layer by layer, but prints a fusing agent on the powder for each layer. A heat lamp melts the powder containing the fusing agent across one whole layer at a time into a solid part.

The technology referred to as Fused Filament Fabrication (FFF) or Fused Deposition Modeling (FDM) is an additive manufacturing (AM) process in which thermoplastic material is pushed through a heated nozzle to create objects layer by layer.

In recent years, new additive manufacturing technologies like Multi Jet Fusion (MJF) have improved processing speed to make 3D printing more competitive for manufacturing. While it still is a layering build process, the time per layer has dropped from minutes to seconds. For slower technologies like Fused Filament Fabrication (FFF) the application of print farms producing the same part on multiple machines simultaneously also improves the throughput and achieves the same results for production purposes.

In using these technologies for additive manufacturing to produce parts for final production, it has become evident that speed is not the only issue preventing acceptance.

FINISHED PARTS WITH AN UNFINISHED SURFACE

With powder bed technologies like SLS and MJF the parts as produced have a chalk-like appearance with a grainy finish. The finished parts are porous and tend to absorb or leak fluids. Mechanical properties are lowered because of weaknesses introduced by the layer lines and the grainy surface that allows cracks to form more easily.

Parts made using FDM and FFF have a finish on top and bottom surfaces that looks like woven fabric and very visible layer lines on the sides. They are more porous than the parts produced using powder-based technologies and are very prone to mechanical failure at the layer lines.

SURFACE CHARACTERISTICS CHALLENGE SCALED PRODUCTION

Despite the flexibility and process advantages that 3D printing offers, in practice, using additive manufacturing for production of thermoplastic parts has been limited because of three key problems related to the surface characteristics:

AESTHETICS

As produced, 3D printed parts typically do not have a finish that is acceptable to meet the aesthetic standards for end-use components.

MATERIAL POROSITY

Printed parts are porous rather than watertight and, therefore, unsuitable for many applications without specific finishing steps.

REDUCED MECHANICAL PROPERTIES

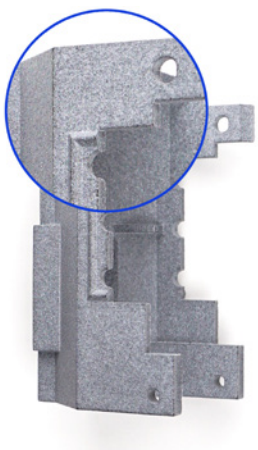
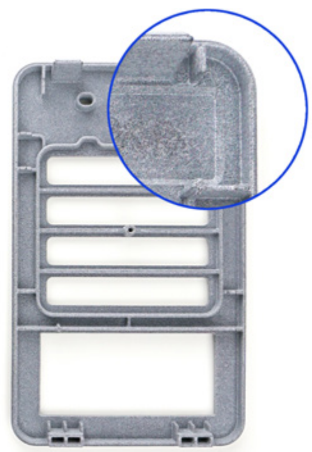
The layered building process common to all 3D printing methods produces a surface having potential surface cracks than can cause fractures.

In the discussion that follows, we will consider the pros and cons of various solutions currently being used and explore how vapor smoothing addresses these concerns.

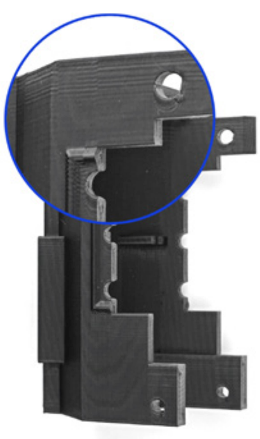
MORE THAN JUST A PRETTY FACE:
SMOOTHING THE SURFACE

The grainy, chalk-like finish of many 3D printing parts is far different than the smooth, glossy finish the end user would expect to see on an injection molded part. Standards of appearance for a production part can differ greatly from what would be acceptable as a prototype.

Parts shown in the photos below are examples of MJF parts as per the process; their dull, chalky surface is evident.


Examples of the same parts made using FFF are shown in the photos below. In these examples you can see the layer lines and the extrusion pattern on the top and bottom surfaces.



In order to achieve a finish that satisfies performance and aesthetic specifications post-production processing is required to remove the layer lines and polish the surface. Sanding, media tumbling, and vapor smoothing offer alternative methods.

Manually produced smoothness

SANDING

Hand sanding is a solution that is commonly used to polish parts and reduce surface roughness. Sanding can be used to remove the layer lines, the stepping of layers and to improve the appearance of top and bottom surfaces.

While sanding does yield a smooth surface and can retain fine detail, the process has several drawbacks.

Skilled labor is required for hand sanding, an expensive and time-consuming manual process that is highly dependent on the performance of the operator. As a finishing solution, it is not consistently repeatable, and is limited by the operator's field of view. Only visible surfaces can be sanded; complex interior surfaces may be inaccessible to the operator. Sanding also changes the dimensions of the part.

Automated and indiscriminate

MEDIA TUMBLING

Media tumbling is an automated solution that involves placing the 3D printed parts in a vibratory tumbler with abrasive media composed of ceramic, plastic, glass, wood or metal. The tumbling action removes material to smooth the parts. Further tumbling with other media may be used to enhance or polish the surface.

As compared to sanding, media tumbling has the advantage of eliminating the labor because the process in done in bulk by the machine. The process offers repeatability in that it is automated and not as dependent on operator skill.

As a solution for finishing functional parts, media tumbling, like sanding, presents specific problems. The tumbling process is indiscriminate, not only smoothing roughness, but removing all sharp edges and small details. It dimensionally changes the part, and it tends to break small features and delicate parts.

Automated, controllable, consistent surface finish:

VAPOR SMOOTHING

The vapor smoothing process involves exposing printed parts to a solvent vapor within a pressurized sealed chamber. Specialized equipment, such as the PostPro3D® from Additive Manufacturing Technologies (AMT) or Vapor Fuse technology from DyeMansion is necessary.

The process is both highly controllable and automated, capable of consistently producing a finish with the desired gloss or texture level and suited to the type of material being finished. Inside the chamber, the vapor condenses on and chemically melts the rough external surface of the parts causing the material to flow together on the surface. The vapor is then removed, and the material returns to a solid state leaving a sealed glossy surface.

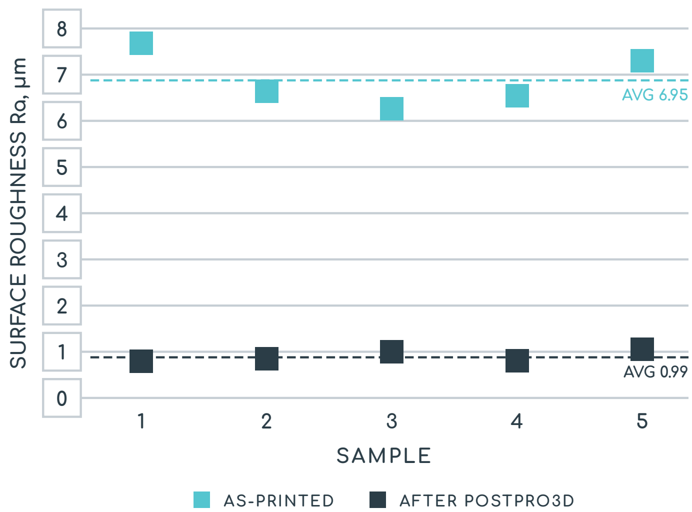
While vapor smoothing is shallow and not intended to hide large defects or heavy textures, it sufficiently melts the material to produce a surface as glossy as that of an injection molded product. Unlike the smoothing operations of sanding or media tumbling, vapor smoothing has little effect on dimensions.

> *"There are very few practical uses for 3D printing in the dental/medical space when it comes to functional, long-term, end-use parts. The variety of printable thermoplastics makes 3D Printing an attractive technology but the surface finish after printing creates limitations for accuracy, patient comfort and hygiene. Vapor smoothing addresses these problems by elevating surface quality to a level that would rival injection molded parts. As the leading service provider of 3D printed parts for dental use, the choice was obvious for us when it came to adopting vapor smoothing into our workflow. We can now produce better dental prosthetics in less time than other post-processing methods we had used in the past."*
>
> JUSTIN MARKS, CDT — FOUNDER AND CEO, ARFONA PRINTING SERVICES, LLC.

PERFORMANCE TESTING: SURFACE ROUGHNESS

AMT performed tests to document the changes in surface roughness of MJF PA12 nylon from a typical smoothing operation. Based on the samples tested, having an average roughness of 6.95 Ra µm before finishing and an average roughness of 0.99 Ra µm after vapor smoothing reflects a reduction in surface roughness of more than 85%. Results of the AMT test are given below. [1]

POSTPRO3D MJF PA12 FINISH 2

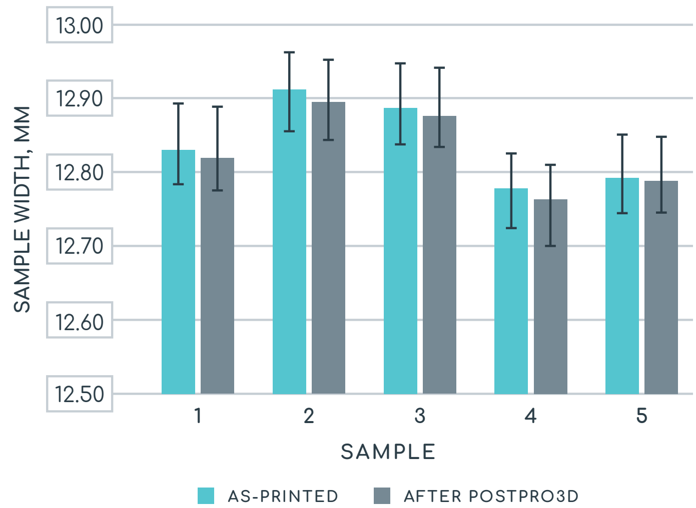


Source: Additive Manufacturing Technologies Limited (2015-2020)

85% REDUCTION IN SURFACE ROUGHNESS

PERFORMANCE TESTING: DIMENSIONAL VARIATION

Testing conducted by AMT on the dimensional variation on the parts is shown below. Results indicated that part tolerances and fine detail would be retained, exhibiting "no more than 0.4%-dimensional change irrespective of desired finish level." [2]



Source: Additive Manufacturing Technologies Limited (2015-2020)

<.04% DIMENSIONAL CHANGE

AESTHETICS: SOLUTION COMPARISON

In terms of meeting the aesthetic requirements of finishing, both hand sanding and media tumbling change the dimensions of the finished part. Sanding is inconsistent, labor intensive and costly; media tumbling, as an automated process reduces costs but also potentially sacrifices fine detail and could break fragile parts. Of the three, vapor smoothing offers both control and automation to consistently produce a smooth surface while retaining the requisite dimensions of the part and protecting delicate components from potential damage.

A SOLUTION THAT HOLDS WATER:

FROM POROUS TO SEALED

By their very nature, parts made through 3D printing are porous. For some prototype applications, porosity may not pose a problem. Shifting from a prototype to a production part means that the porosity of the part material becomes an issue that must be addressed.

Printed parts may have all the correct dimensions, but without an adequate seal, the porosity of the material may make the parts unsuitable for their intended purpose, such as the cups pictured here.

Four parts were made to test the sealing properties of Vaper Smoothing. Two cups were made from ABS with FFF, one is as per the process and the other sealed with vapor smoothing.

Another two cups were made from Nylon PA12 with MJF, one is as per the process and the other sealed with vapor smoothing.

To test the absorption of water the parts were weighed and then submerged in water for 72 hours.

Made of PA12 by MJF

Made of ABS by FFF

	FFF		MJF	
	Per Process	**Vapor Smoothed**	**Per Process**	**Vapor Smoothed**
Initial Parts Dry	5.7	5.95	6.3	5.3
After 72 Hours	5.8	5.95	6.55	5.3
% Increase	1.72%	0%	3.82%	0%

Weight in Grams

Layers of paint or lacquer

COATINGS

Paint or lacquer can be applied to seal 3D printed parts; however, this solution presents several drawbacks.

While paint or lacquer provides a degree of sealing, neither is fully watertight. Multiple coating layers may be needed to achieve the desired level of sealing because the coating is absorbed into the porous printed material. Each additional layer adds the cost of labor, material, and time.

Coating layers are sprayed on by an operator, with the result that the process is not consistently repeatable but rather is dependent upon the skill and technique of the operator. In addition, as coating layers are applied, the dimensional accuracy of the part can change.

From an aesthetic and functional perspective, coatings tend to discolor and crack over time, degrading the appearance of the part and potentially compromising whatever seal the coating originally provided.

Inconsistent results and dimensional changes

INFILTRATION

Rather than spraying a coating onto the surface, this process involves dipping the part into an epoxy or an acrylate and then using pressure or vacuum to get the material into the pores of the parts. As a method for sealing 3D printed parts, there are several problems related to infiltration.

Absorption can cause the part to swell, altering the dimensions of the part. Infiltration sealant may accumulate in certain areas of the part, also affecting the dimensions. The dipping process as well is not consistent, and dependent upon the operator, so the process is not accurately repeatable.

Temperature changes and mechanical stresses can cause the filling material to crack or de-bond from the primary material. While infiltration improves the sealing, it does not make the surface watertight, and its success can depend on the part geometry and method of application being used.

Watertight seal without dimensional change

VAPOR SMOOTHING

As detailed above, vapor smoothing is not an applied coating that will deteriorate over time; instead, external surfaces are chemically melted and solidified to form a sealed surface of the virgin material.

Solvent vapor seals the surface, including internal surfaces such as holes or internal tubes, to create a watertight surface. Part dimensions are unaffected. Unlike a spray or dip process, the vapor effectively reaches internal cavities and smooths areas that are not visible to an operator. As a single automated operation, labor is reduced, requiring only the loading and unloading of the processing chamber.

A watertight surface is a design criterion in systems such as internal manifolds where it's imperative that the fluid inside the structure does not evaporate or leak out through the walls of the enclosure. The watertight seal created by vapor smoothing allows printed parts to be used effectively in these and other applications.

PERFORMANCE TESTING: WATER ABSORPTION

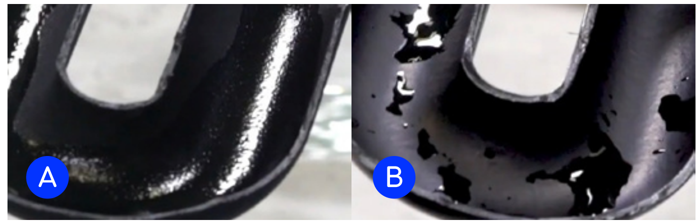
Testing conducted by AMT used water immersion experiments to measure how efficiently the process protected MJF PA12 surfaces from water absorption. Evaluation was based on measuring the weight of water that remained on the part surface after it had been submerged in water.

Results of the tests, given below, show that water had a tendency to remain on the surface of untreated samples after they were removed from the water, increasing the sample weight. Water was deflected from the surfaces of samples that were processed.

> *"Processed and non-processed samples with the surface area of 208 cm² were immersed in water and the weight of the samples was logged with time…The reason for water protective properties is low surface energy of the processed material, which in turn results in high contact angle between the processed surface and water."* [3]

DyeMansion produced a further demonstration of the protective benefits of vapor smoothing. The photos below show a comparison of water absorption on an untreated tubular part surface and on a surface that was treated using their VaporFuse technology. Water was run through the tube, then the tube was cut in half to expose the surfaces and illustrate the effectiveness of the process on even inner surfaces.[4]

No VaporFuse Surfacing **VaporFuse Surfacing**



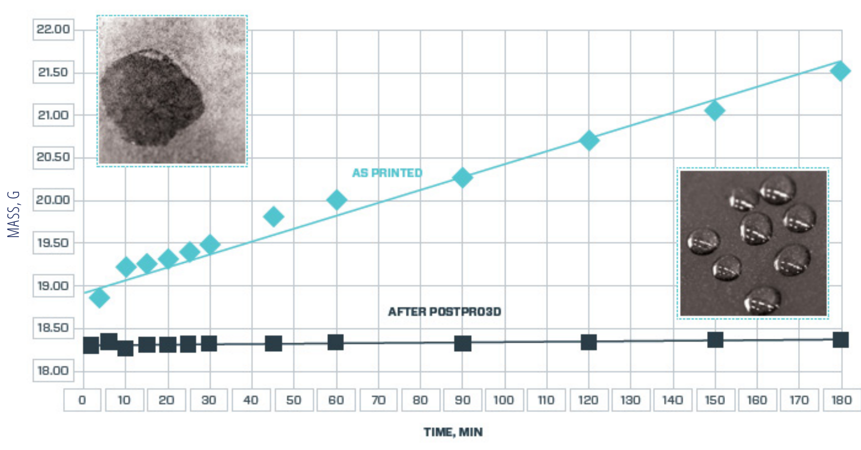
Source: DyeMansion

A. Water is absorbed into the surface of the tube not treated with vapor smoothing.
B. Surfaces treated with vapor smoothing are sealed and prevent absorption into the part.

SEALING: SOLUTION COMPARISON

Neither coating nor infiltration creates a fully watertight surface that protects against absorption as effectively as a vapor smoothed surface. Both coating and infiltration are subject to inconsistencies and are not repeatable post-processing methods; vapor smoothing offers automation, control and consistency. Furthermore, of the three, only vapor smoothing retains the part dimensions.

WATER ABSORPTION



Source: Additive Manufacturing Technologies Limited (2015-2020)

> *"Finatus cre etorisq uonsul vicepectum consum in dum host renati, quam. Ves? Sim ina veri pero teris; et resicavent. Nam. Lut re fuidentempor habefex mo unum in nul hum maio consus acchus nesse te perum rem urniciena, que det vit."*
>
> PLACEHOLDER NAME,
>
> COMPANY NAME

MORE STRENGTH, LESS BREAKAGE:
RESTORING MECHANICAL PROPERTIES

Additive manufacturing is a layering process. The strength along the z axis, perpendicular to the layer, is less than that in the x-y direction within the layer. For parts created with MJF, in which an entire layer is fused at once, the difference in strength is not as pronounced as in part created using FFF. With FFF, each layer of extruded material tends to cool before the next layer is applied, reducing the adhesion between the layers and diminishing the mechanical properties of the item.

The rough, porous surface 3D printed parts increases the potential for fracture initiation sites. Sharp edges and the relatively weaker adhesion between layers also increase the opportunity for fracture. To restore full mechanical properties to the parts produced, an additional post-production process is needed. Metal plating and vapor smoothing are two possible remedies.

Metal adds strength and weight, changes dimension:

METAL PLATING

Parts that have a requirement of greater strength can be plated, usually with nickel, to increase their strength. Typically, this could be done as an alternative to prototyping a metal part.

The plating process presents some challenges that prevent it from being a universally acceptable solution.

Metal plating is an expensive process, increasing cost, and because the process adds a layer of metal to the part, not only can the dimensional accuracy change but the weight of the part is increased.

Improving strength, reducing fractures, retaining dimensionality:

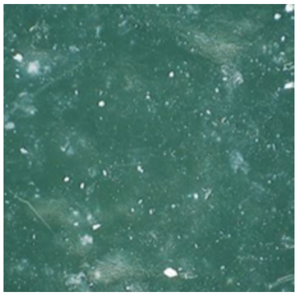
VAPOR SMOOTHING

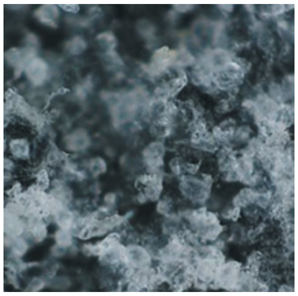
As vapor smoothing transforms the surface from rough and porous to smooth and sealed, the number of places where a crack could be initiated are reduced. The layers also are smoothed together, eliminating layer lines that could potentially become a point of failure or a place where a small surface fracture could start. The result is increased tensile strength, and a reduction in fatigue and surface fractures. In addition, the weight and dimensions of the part are unchanged by the vapor smoothing process.

PERFORMANCE TESTING: TENSILE STRENGTH

AMT tested mechanical properties on MJF PA12 before and after vapor smoothing that show the following results:

> *"Ultimate tensile strength, elongation at break and Young's modulus were measured for the processed and un-processed PA 12 samples. Samples were prepared to ASTM D638 Type 1 dimensions. The gauge length of the tensile testing machine was 50mm and tested at a speed of 5mm/min.*
>
> *The results show no loss in Ultimate Tensile Strength in processed samples. Elongation at Break (EAB) of the tested samples has significantly increased, whereas the Young's Modulus decreased."* [5]





Source: Additive Manufacturing Technologies Limited (2015-2020)

Microscopy images show the change in surface porosity—granular, with sharp edges, on the left, to smooth and even on the right. According to AMT test results, the increase in EAB can be attributed to the reduction in the number of potential sites where a crack could be initiated. [6]

SUMMARY OF RESULTS

SAMPLES	YOUNG'S MODULUS, MPA	ULTIMATE TENSILE STRENGTH, MPA	ELONGATION AT BREAK, %
MJF PA12 AS PRINTED UNPROCESSED	1800	48	20
MJF PA12 VAPOR SMOOTHED	1572	49	26

Source: Additive Manufacturing Technologies Limited (2015-2020)

MECHANICAL PROPERTIES: SOLUTION COMPARISON

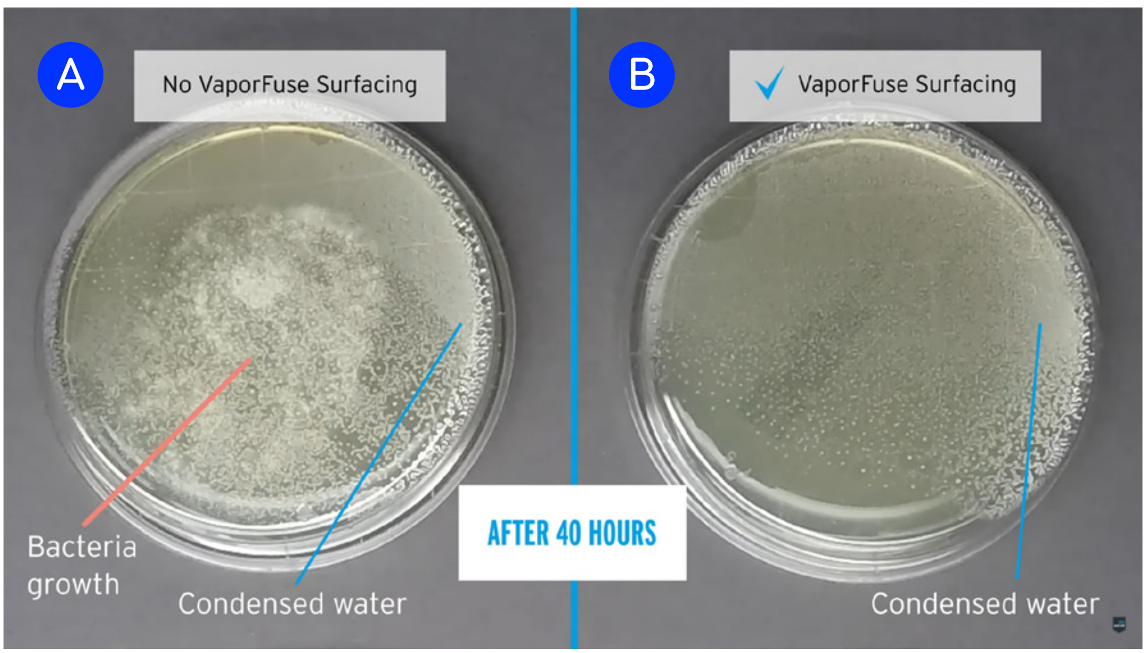
While both metal plating and vapor smoothing produce surfaces that are strong and that smooth the imperfections that would allow cracking, metal plating sharply increases costs, adds weight to the individual parts, and alters their dimensions. Vapor smoothing accomplishes similar improvements in mechanical properties without changing the weight or part dimensions, or a high material cost.

HEALTHCARE:
INHIBITING BACTERIA GROWTH

Since vapor smoothing seals the surface of the parts processed, the resulting finish reduces the amount of bacteria growth on the surface or penetrate the material. Components sealed with the vapor smoothing process can easily withstand repeated disinfection, making them suitable for a wide variety of health, medical, and cleaning applications.

PERFORMANCE TESTING:
INHIBITING BACTERIA GROWTH

DyeMansion performed a test by wiping a non-vapor fused part and a vapor fused part across contact plates which were allowed to sit for 40 hours. Photos here show the growth of bacteria on the surface without vapor smoothing. [7]



Source: DyeMansion

A. Bacteria growth on a surface with no vapor smoothing.
B. Surface with vapor smoothing.

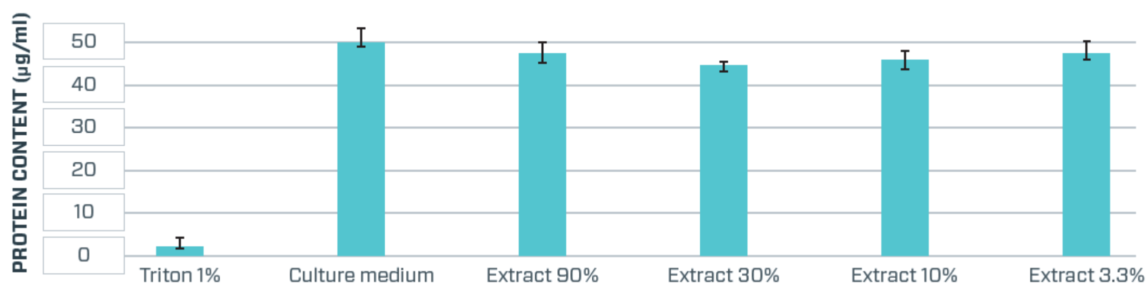
PERFORMANCE TESTING: **CYTOTOXICITY**

Going a step further into medical applications, AMT also submitted samples for cytotoxicity testing at a nationally recognized European laboratory to Normative References: ISO 10993-5 (2009); ISO 10993-1 (2010); ISO 10993-12 (2012).

AMT provides the following results and explanation of the testing process:

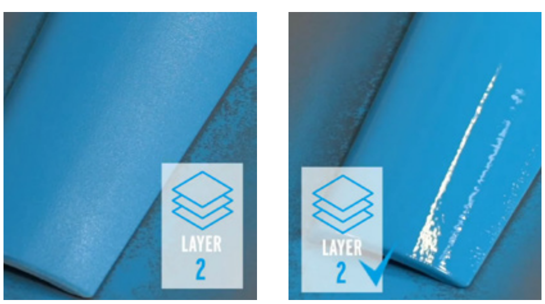
> *"The cytotoxicity test is one of the biological evaluations and screening tests that use tissue cells in vitro to observe the cell growth, reproduction and morphological effects by medical devices. Cytotoxicity is an important indicator for toxicity evaluation of medical devices as it is simple, fast and has a high sensitivity.*
>
> *The results 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."* [8]

CYTOTOXICITY PROTEIN COMPARISON



Source: Additive Manufacturing Technologies Limited (2015-2020)

SECONDARY PROCESSING: **IMPROVED FINISHING QUALITY AND SPEED**



Source: DyeMansion

A. The results of 2 coats of paint applied to an untreated surface.
B. The gloss level achieved when the same number of coats were applied to a vapor smoothed surface

Painting and other secondary finishes may still be required for parts even after a smooth, sealed surface has been achieved.

DyeMansion reports that painting a part following sealing of the surface requires fewer coats of paint if the part has first been treated with their vapor surfacing system, and offers an illustration:

CLEARING THE HURDLES OF ADDITIVE MANUFACTURING

Vapor Smoothing technology is resolving the challenges that have prevented manufacturers from taking full advantage of the benefits of additive manufacturing.

Processing speed has largely been addressed in recent years with improvements in 3D printing technology. Challenges have remained in other areas, particularly in relation to surface characteristics and strength, but also in relation to the automation and repeatability of the processes and their ability to retain dimensional accuracy.

Vapor smoothing checks all the boxes. Through an automated, repeatable process, it creates a surface that is smooth, strong, and sealed while not changing the dimensions of the parts. Because the process is highly controlled, it can be adjusted for various materials and specific surface finishes and textures, creating a finish that is substantially improved and acceptable for use in production or end-use parts.

Additive manufacturing has always offered the benefit of facilitating rapid and cost-effective design changes. With a high-quality, rapidly repeatable and automated finishing process, the door is open to increased short-run production and preliminary product runs.

Moving forward, vapor smoothing is a significant step toward the acceptance of additive manufacturing, helping it to take its place in production, not necessarily replacing other methods but enhancing the ability to provide new and improved solutions.

ABOUT THE AUTHOR

Doug Campbell is CEO of Sicam Corporation where he has been applying additive manufacturing and subtractive manufacturing for the last 31 years. An early adopter of solid modeling, since 1986 Doug has implemented 3D CAD/CAM systems.

Prior to founding Sicam, Doug worked in manufacturing for 15 years designing tooling and process for all conventional manufacturing.

He has extensive experience in designing tooling and defining processes in injection molding, die castings, extrusions, CNC machining, conventional turning and milling, investment casting, sand casting, stampings, urethane castings, finishes, plating, painting, heat treating, CAD systems, and consultation for design for manufacturing.

Contact Doug at 908-271-8595 or dougc@sicam.com for consultation for design for manufacturing and more information on vapor smoothing solutions.

ENDNOTES

1. Additive Manufacturing Technologies Limited. (2015-2020). AMT PostPro®. [White paper] Retrieved from https://amtechnologies.com/whitepapers/automated-finishing-technology-for-post-processing-mjf-parts/
2. Ibid
3. Ibid
4. DyeMansion source
5. Additive Manufacturing Technologies Limited. (2015-2020). AMT PostPro®. [White paper] Retrieved from https://amtechnologies.com/whitepapers/automated-finishing-technology-for-post-processing-mjf-parts/
6. Ibid
7. DyeMansion
8. Additive Manufacturing Technologies Limited. (2015-2020). AMT PostPro®. [White paper] Retrieved from https://amtechnologies.com/whitepapers/automated-finishing-technology-for-post-processing-mjf-parts/