DYE MANSION

# STATE-OF-THE-ART SURFACING

## WHAT CURRENT TECHNOLOGIES CAN ACHIEVE ON POWDER BED FUSION PARTS

# EXECUTIVE SUMMARY

With the constant growth of Additive Manufacturing and its fields of application, the demands for 3D-printed parts are also increasing. Today market-ready products manufactured with Powder Bed Fusion technologies such as Selective Laser Sintering (SLS) or Multi Jet Fusion (MJF) must meet not only aesthetic but also functional requirements. These requirements can vary depending on the product, industry and application. Since Powder Bed Fusion technologies work layer by layer the outcome are parts with rather rough surfaces compared to conventional manufacturing methods. In addition, the untreated surface is predisposed to dirt. The right post-processing helps to change these part properties. While, for example, tumbling as an abrasive method for 3D-printed parts is usually counterproductive because material is removed, there are now real alternatives that are compatible with almost any geometry and do not add changes to it. Especially with parts that are to be colored, a previous homogenization of the surface is  necessary as this is the only way to guarantee consistent results.

This paper shows how current surfacing solutions for 3D-printed parts can enhance surface quality. As a leading supplier of industrial post-processing systems,  DyeMansion offers two different proprietary processes that differentiate between mechanical and chemical solutions. Based on concrete tests of different materials (PA12 & TPU) the advantages, differences and limitations of the two processes PolyShot Surfacing (mechanical) and VaporFuse Surfacing (chemical) are shown.

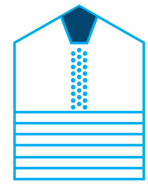
No surface treatment

PolyShot Surfacing +
DeepDye Coloring

VaporFuse Surfacing +
DeepDye Coloring

# POLYSHOT SURFACING (PSS)

## The most efficient technology to achieve an end-use part finish


### FUNCTIONALITY

During the PolyShot Surfacing (PSS) process, beads accelerated by compressed air are shot at the surface of the parts. Depending on the speed and mass of the beads, energy is transferred to the surface by impulse transmission. The alignment of peaks and valleys reduces the roughness and homogenizes the surface. In contrast to tumbling, where material is removed, PSS is dominated by plastic deformation in the microscopic range. In this process no material is removed and the original geometry of the part is retained. In the DyeMansion Powershot S, 3/4 of an EOS P396 or a full HP Jet Fusion 4200/5200 build job can be processed with a cycle time of 10 minutes per batch.

### PROPERTIES

#### Matt-glossy surfaces with pleasant haptics and improved properties

PolyShot Surfacing (PSS) achieves matt-glossy surfaces with a homogeneous surface quality for hard polymers such as PA11 and PA12. The process not only increases scratch resistance, but also achieves a dirt-resistant surface.

#### Homogenization of the surface as key for maximum coloring results

The homogenized surface achieved by PolyShot surfacing ensures that the color is absorbed more evenly and better by the part during coloring. This is advan-tageous when further processing steps such as gluing or painting are to be carried out.

## LIMITATIONS

With thin tubes or labyrinth structures, the degree of homogenization achieved by PSS can vary. The reason is that the energy input to internal geometries outside the line of sight is lower after previous deflection of the beads. This effect can be partially compensated by longer process duration. Heavy parts with fragile geometries such as antennas or pins can be damaged during PSS. While PSS is perfectly designed for processing hard polymers such as PA11 or PA12, it is not suitable for flexible materials such as TPU, since the high proportion of elastic deformation makes homogenization virtually impossible.

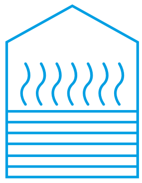
## FIELDS OF APPLICATION

PSS has established itself very strongly on the 3D-printing market since 2016 and has set a completely new surface quality standard. In particular, the processing of parts produced with Powder Bed Fusion technologies is more efficient and simpler than ever. The process is suitable for all applications that require a scratch-resistant, matt-glossy and above all colored surface. From orthotics like protheses and orthoses  to eyewear in the lifestyle sector to automotive interior parts, the process is already being used in a wide range of industries.

Leg protheses by Gottinger, eyewear by Götti
Finish: PolyShot Surfacing

# VAPORFUSE SURFACING (VFS)

**The Clean Vapor Technology for parts challenging injection molding**




### FUNCTIONALITY

Thermoplastic polymers consist of long polymer chains connected by hydrogen bonds and Van-der-Waals forces. During the VaporFuse Surfacing (VFS) the polar solvent vapor condenses on the surface of the parts and dissolves these connections. By striving to minimize the total surface area and thus the surface energy, the molecular chains rearrange themselves. This process results in a smoothing of the surface. By removing the solvent from the parts by vacuum drying, the surface solidifies in its new, smoother form.

### PROPERTIES

**Sealed injection molding like surfaces across all geometries**

VaporFuse Surfacing (VFS) provides sealed and washable parts with washable injection molded like surfaces. The surface roughness of the parts is reduced to Ra less than 2 by the process, even with complex or internal structures.

**For parts fulfilling all industrial health & safety standards**

The VaporFuse Eco Fluid solvent is approved for the processing of parts with food contact according to regulation (EU) 10/2011. This enables a sustainable contact-free process without chemical waste.

## LIMITATIONS

Since the surface of the entire part is dissolved, places remain after the process where the part had contact with a part receptacle. If a VFS treatment is planned, this should be taken into account in the design process and the creation of the CAD fi les. For example, a hook can be added to position the part in the process chamber. In addition, the functionality of moving parts may be limited after VFS handling. Before the treatment it must be ensured that the parts are suffi ciently cleaned, since residual powder is also dissolved and melts with the part's surface. If further processing steps such as gluing or coating are to be carried out, a smooth surface can have a positive or negative effect in some cases.

## FIELDS OF APPLICATION

VFS opens up completely new applications through its ability to create washable surfaces on porous, flexible materials. The process offers great potential especially in the sports and lifestyle sector for 3D-printed shoe soles or in the medical sector, where washable surfaces are often required. A glossy surface can also be advantageous for aesthetic reasons, for example if spare parts originally manufactured by injection molding are to be produced using Additive Manufacturing. The smooth surface is advantageous for air- or fluid-carrying parts as it reduces flow resistance and turbulence. Parts treated with VFS can be used in an environment under clean conditions without any problems. The water-repellent surface is also easier to clean, which is advantageous for applications in contact with food.

Industrial grip, automotive interior cover I Finish: VaporFuse Surfacing

## EXAMINED SURFACE PARAMETERS

The quality of a surface can not only be assessed subjectively but can also be characterized more precisely by various measurements. For 3D-printed applications, roughness and gloss as well as water-repellent properties are particularly important.

### ROUGHNESS

In the past, surface roughness was mainly characterized by the 2D-parameters Ra (arithmetic mean height of a line) and Rz (maximum profile height of a line), since the first available roughness measuring instruments were tactile systems that could only determine these 2D-values.

However, a surface is much more complex and can be described by 3D-roughness parameters in more detail and with higher statistical weight. For 3D-roughness measurements, tactile measuring instruments cannot be used. Instead, strip light measuring instruments are used. Analogous to the 2D-values Ra and Rz, the corresponding 3D-roughness values are Sa and Sz. Even though these surface parameters provide more accurate values, they do not contain all the information required to adequately characterize the optics and haptics of a surface. ISO 25178 defines additional surface structure parameters. Among them are the so-called hybrid parameters, which consider both the peaks and valleys of a surface as well as their number and distance to each other. These parameters are well suited to evaluate gloss and smoothness. In addition to the Sa and Sz values, the following parameters are used to describe the influence of surface refinements (PSS and VFS): Sdq (square mean slope) and Sdr (developed interface ratio).

Since Sdq describes the inclination of microscopic surfaces relative to the macroscopic surface, it is an indirect measurement of the optical impression of a surface. The smaller the Sdq value, the more surfaces are parallel to the macroscopic surface. This is why objects with a small Sdq value appear glossy. Parts with a large Sdq value, on the other hand, have many surface geometries in other spatial directions. Due to this irregular surface, the light is scattered diffusely and the object appears matt and dull. The following applies: the smaller the Sdq value, the glossier the finished part appears. Sdr calculates the ratio of the actual surface to the projected surface. It is an indication of the number, height and steepness of peaks and valleys. It can directly be related to the haptics of a part. The higher the Sdr value, the more steep peaks exist on the surface. Therefore, the contact area between e.g. a finger and the surface of a material is small. This makes the surface feel rough. The smaller the Sdr value, the smoother a part feels.

### GLOSS

Although gloss correlates directly with surface roughness, it can also be measured directly using incident and reflected light beams. The ratio of light reflected at a certain angle varies depending on the surface. The gloss of a surface can thus be determined by measuring the reflected light. In order to enable a comparative measurement, it is essential that the angle is kept constant. The shinier the surface, the smaller the measuring angle can be. To be able to use the matt surface of a non-surface-finished part as a comparison, it is necessary tomeasure the degree of gloss at an angle of 85° relative to the perpendicular of the surface. The higher the measured value, the shinier the surface.

### WATER-REPELLENT PROPERTIES

For many applications it is crucial that they have a water-repellent surface. This means they are very easy to clean and do not form a breeding ground for bacteria and germs. These water-repellent properties can be determined by wettability. The contact angle of a water droplet, which corresponds to diameter of a droplet with a defined volume, or the spread of such a water droplet over time can be used. The larger a drop and the faster it runs, the less water-repellent a surface.

## TEST SETUP

The basis for the comparison between PSS & VFS finish and no surface treatment are PA12 and TPU parts produced with SLS and MJF technology. Prior to surface finishing, all parts were treated with the DyeMansion Powershot C and then either with PolyShot Surfacing in the Powershot S or VaporFuse Surfacing in the Powerfuse S. Details of the production parameters and subsequent machining of the parts can be found in Tables 1 and 2.

| TECHNOLOGY | SYSTEM | MATERIAL | MATERIAL DECLARATION | LAYER THICKNESS |
|---|---|---|---|---|
| SLS | EOS P396 | PA12 | EOS PA 2200 | 120μm |
| MJF | HP Jet Fusion 3D 4200 | PA12 | HP 3D HR PA 12 | 80μm |
| SLS | EOS P396 | TPU | L&V LUVOSINT TPU 92A | 120μm |

**Table 1:** Parameters of the production process.

| PROCESS | SYSTEM | MEDIA | PROCESS SETTING | PROZESSDAUER |
|---|---|---|---|---|
| Cleaning | Powershot C | Powershot C Glass Beads (200-300 μm) | 3bar | 5min |
| PSS | Powershot S | Powershot S PS6 PolyBeads | 5bar | 10min |
| VFS | Powerfuse S | Vaporfuse VF47 Eco Fluid | | 45-57min (depending on material) |

**Table 2:** Parameters of the surfacing steps (Cleaning, PSS and VFS).

## ROUGHNESS

| SURFACE TREATMENT (EOS PA 2200) | RA [µm] | RZ [µm] | SA [µm] | SZ [µm] | SDQ | SDR |
|---|---|---|---|---|---|---|
| NO TREATMENT | 7,67 | 42,2 | 8,45 | 146,0 | 0,225 | 0,0245 |
| PSS | 6,86<br>-12 % | 34,2<br>-9 % | 7,61<br>-10 % | 121,6<br>-17 % | 0,168<br>-25 % | 0,0138<br>-44 % |
| VFS | 1,89<br>-75 % | 11,60<br>-73 % | 2,34<br>-72 % | 27,8<br>-81 % | 0,095<br>-67 % | 0,00447<br>-82 % |

**Table 3:** Average surface values for SLS parts with and without surface finishing (PSS and VFS).

The measured values (see Tables 3 and 4) underline the feeling one has with and without DyeMansion finishing. Parts that have only been cleaned are characterized by a rough and matt surface. This can be seen by the relatively high Sdq and Sdr values.

| SURFACE TREATMENT (HP 3D HR PA 12) | RA [µm] | RZ [µm] | SA [µm] | SZ [µm] | SDQ | SDR |
|---|---|---|---|---|---|---|
| NO TREATMENT | 9,79 | 50,1 | 10,8 | 130,1 | 0,270 | 0,0354 |
| PSS | 8,99<br>-8 % | 47,6<br>-5 % | 10,3<br>-5 % | 117,7<br>-10 % | 0,193<br>-29 % | 0,0184<br>-47 % |
| VFS | 1,60<br>-83 % | 10,2<br>-80 % | 1,79<br>-82 % | 21,8<br>-83 % | 0,098<br>-64 % | 0,00479<br>-86 % |

**Table 4:** Average surface roughness values for MJF parts (HP 3D HR PA 12) with and without surface finishing (PSS and VFS).

Both Sdq and Sdr values are significantly reduced by the surface refinement, which affects the feel and appearance of the parts. The parts feel smoother and have a much shinier surface. The effects for PA12 SLS and MJF parts are similar. The PSS process primarily results in plastic deformations on the surface, flattening sharp peaks and valleys. As a result, the finished part feels significantly smoother and has a matt gloss, which is also confirmed by the reduced Sz, Sdq and Sdr values. In comparison, the VFS process changes the surface to a greater extent. By dissolving the surface, reorienting the polymer chain and then hardening the surface again, an even smoother surface is created. As a result, all relevant roughness parameters (Sa, Sz, Sdq and Sdr) are reduced by more than 60 percent. This makes the part feel even smoother after the VFS process and gives it a shiny surface. The change in the surfaces due to the surfacing processes is shown in Figures 1 and 2.

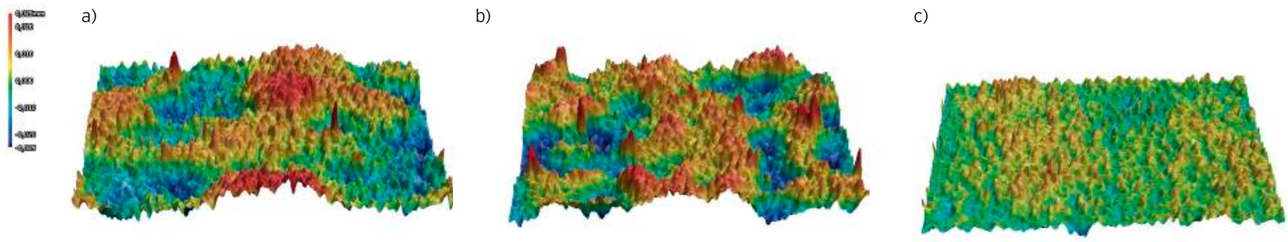



**Figure 1:** Surface profiles of SLS parts made of EOS PA 2200: a) without surface treatment, b) with PSS and c) with VFS surface treatment. All images are stretched by factor 5 in the z-direction to better illustrate the differences in roughness.

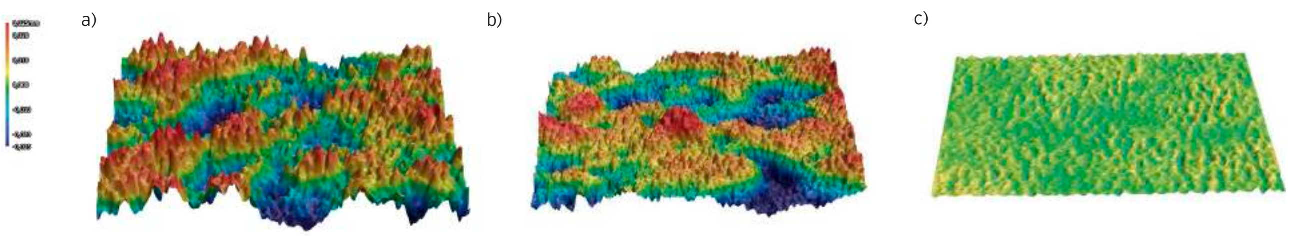



**Figure 2:** Surface profiles of MJF parts made of HP 3D HR PA 12: a) without surface treatment, b) with PSS and c) with VFS surface treatment. All images are stretched by factor 5 in the z-direction to better illustrate the differences in roughness.

| SURFACE TREATMENT (L&V LUVOSINT TPU 92A) | RA [µm] | RZ [µm] | SA [µm] | SZ [µm] | SDQ | SDR |
|---|---|---|---|---|---|---|
| NO TREATMENT | 18,9 | 105,8 | 20,7 | 267,5 | 0,588 | 0,158 |
| VFS | 3,34<br>-82 % | 17,1<br>-84 % | 5,47<br>-74 % | 73,6<br>-72 % | 0,087<br>-85 % | 0,00374<br>-98 % |

**Table 5:** Average surface roughness values for SLS parts made of L&V LUVOSINT TPU 92A with and without VFS surface treatment.

Figure 3 also shows that for SLS parts made of TPU, the VFS surface treatment results in a smoother, shinier surface. Since the starting material, the cleaned TPU part, is considerably rougher than a PA12 part due to the printing process and material, the effects are even more visible here. The surface parameters, summarized in Table 5, are reduced by at least 72  percent.

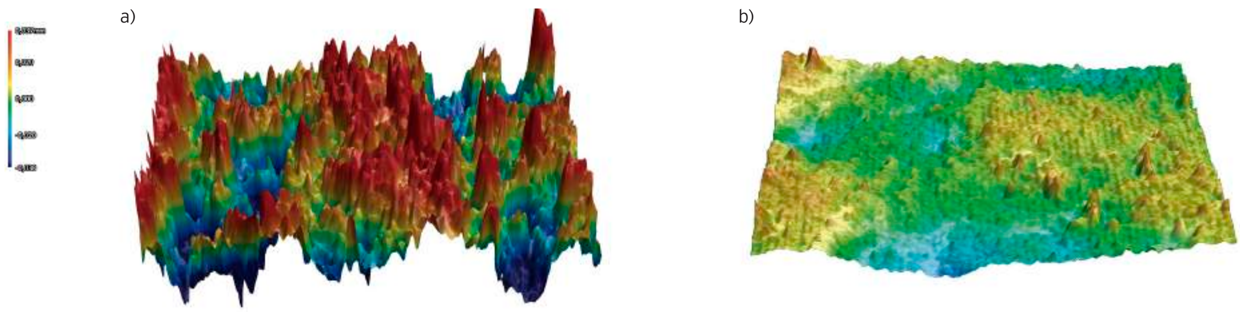


**Figure 3:** Surface profiles of SLS parts made of L&V LUVOSINT TPU 92A: a) without surface treatment, **b**) with VFS surface treatment. All images are stretched by factor 5 in the z-direction to better illustrate the differences in roughness.

## GLOSS

In order to determine the influence of the surface finishes on the gloss of the parts more precisely, gloss measurements were carried out at an angle of 85° (micro-TRI-gloss, BYK-Gardner GmbH) on untreated parts as well as on parts treated with PSS and VFS. The results for EOS PA 2200 parts are summarized in Table 6.

| SURFACE TREATMENT (EOS PA 2200) | GLOSS [GE] |
|---|---|
| NO TREATMENT | 0,6 |
| PSS | 3,9<br>+550 % |
| VFS | 24,5<br>+3983 % |

**Table 6:** Comparison of the gloss values for an unfinished part and parts finished with PSS and VFS.

These results confirm the results of the roughness measurements. As already determined by the Sdq values, the gloss increases in the series: raw - PSS - VFS.

## WETTABILITY

In order to determine the wettability of the raw and refined surfaces more precisely, a drop of water with a volume of 20µL was applied to the surface. The radius of the water droplet allows conclusions to be drawn about the contact angle of the water droplet and thus the wettability of the surface immediately after contact with water. Figure 4 shows the size of the water droplet immediately after contact with the surface. It can be seen that the water droplet on the surfaces treated with PSS (r= 3,8mm) and VFS (r= 2,7mm) is smaller than on the raw part (r= 4,5mm), which indicates hydrophobic properties.

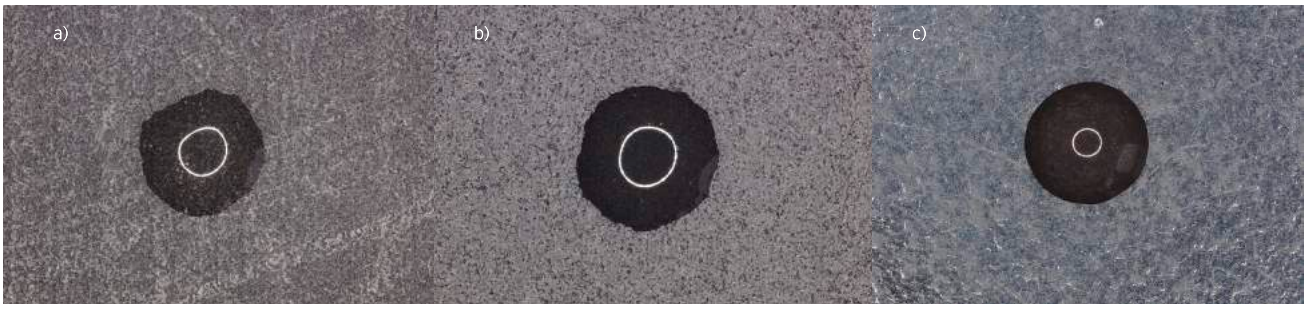



**Figure 4:** EOS PA 2200 parts with a water drop of 20µL volume on differently treated surfaces. a) Water drop on colored EOS PA 2200 (r=4,5mm), b) on PSS treated and colored EOS PA 2200 (r=3,8mm), c) on VFS treated and colored EOS PA 2200 (r=2,7mm).

**Figure 5:** Dispersion of a water droplet on EOS PA2200 parts which have been treated differently.
a) and d) colored (DDC) only, b) and e) PSS+DDC, c) and f) VFS + DDC.

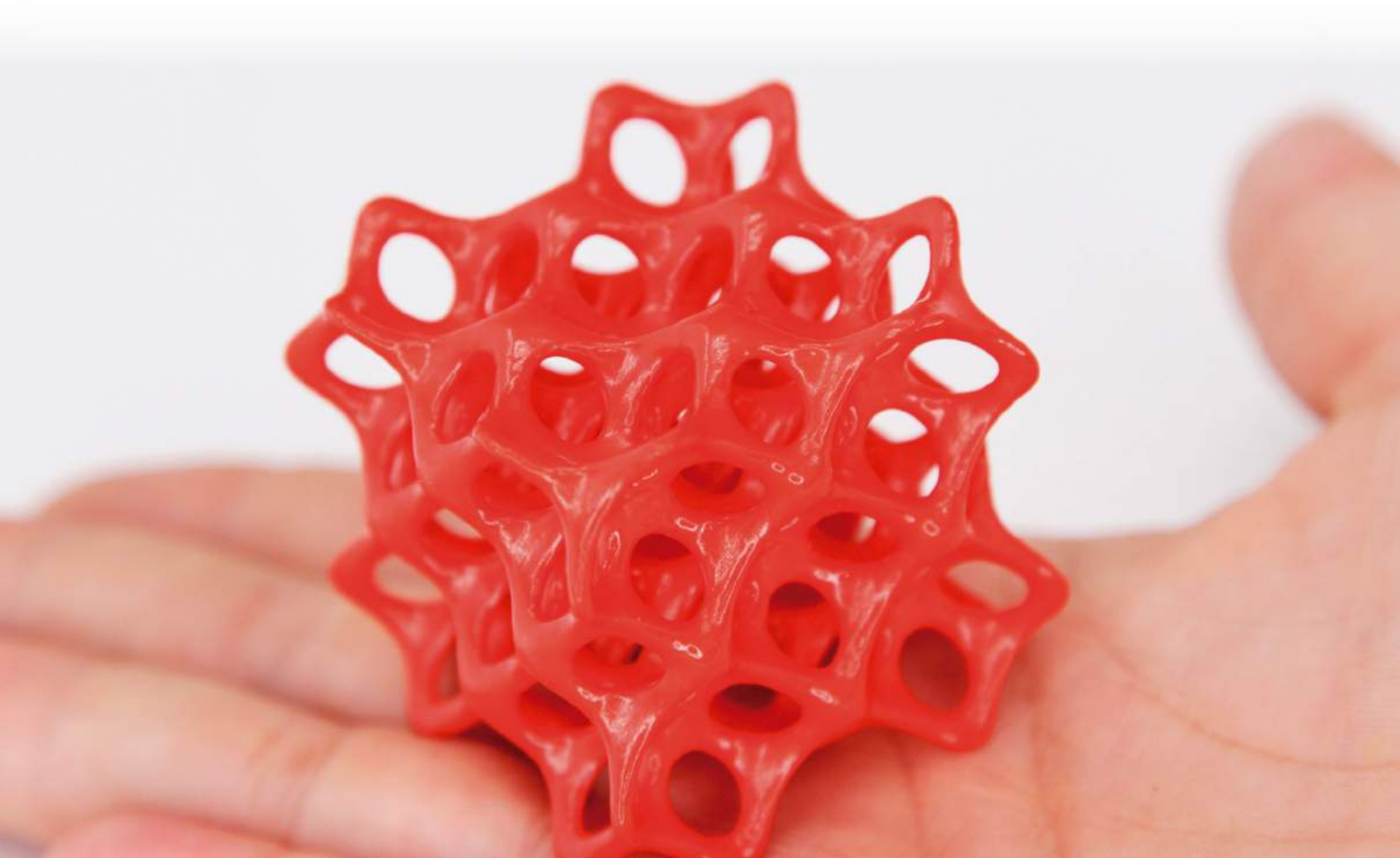

a)-c) shows the water droplet directly after dropping.


d)-f) was recorded 1 minute later.

If you look at the change of the water droplet over time, you can see in Figure 5 that the front of the water droplet changes within the first minute after it has dripped on. The front on the untreated surface has proceeded 300µm, while the droplets on the treated surfaces were much smaller. On the PSS treated surface, the front has progressed about 50µm, while on the VFS treated surface, no increase in droplet size could be detected.

These results show that surface finishing makes 3D-printed parts much more water-repellent. This is especially true for parts treated with the VFS process. Wetting these parts with water is significantly more difficult, which in turn makes it easier to clean the surfaces.

The fact that VFS treated parts are water-repellent has no influence on the colorability of the parts with DeepDye Coloring. Polyamides and thermoplastic polyurethanes absorb a certain amount of water and can therefore still be colored after using the VFS process. In addition, DeepDye coloring takes place under pressure, which improves the penetration of the dye solution.



## CONCLUSION

This whitepaper shows that with PolyShot Surfacing and VaporFuse Surfacing significantly different surfaces can be achieved. Depending on the requirements for the part's properties, the appropriate process with its individual advantages can be selected. The effects of the processes described in the whitepaper for PA12 parts are comparable: PolyShot Surfacing makes the treated parts feel smoother and delivers a matt-gloss, which is also confirmed by the reduced surface roughness of Sz, Sdq and Sdr.

In comparison, VaporFuse Surfacing produces an even more uniform surface by dissolving the surface. As a result, the part feels even smoother after the VFS process and has a glossy and sealed surface, even for TPU parts. The gloss level also increases in both processes, with the VFS treated parts having a higher gloss than the PSS treated parts.

**PolyShot Surfacing (PSS)**
**POWERSHOT S**

- Mechanical process
- Matt-glossy surfaces
- Improved scratch-resistance
- Pleasant haptics
- Suitable for hard polymers such as PA11 or PA12

**VaporFuse Surfacing (VFS)**
**POWERFUSE S**

- Chemical process
- Injection molding like surfaces
- Delivers sealed and washable surfaces
- Solvent approved for food contac
- Works for all common hard and flexible polymers such as PA11, PA12 & TPU

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