WHITEPAPER

DYE MANSION

POLYSHOT SURFACING (PSS) OF HP MJF PARTS FOR END-USE APPLICATIONS

EXECUTIVE SUMMARY

Surfaces from parts produced by power-bed fusion technologies, like HP's Mulit Jet Fusion, usually require further surface smoothing to meet the requirements of high-quality end-use parts. In addition, the gray shading of raw parts, printed by HP's MJF 4200 series, is not sufficient for certain end-use applications. The present whitepaper presents, how the automated PolyShot Surfacing (PSS) process developed by DyeMansion helps to achieve improved material properties and a matte glossy look on MJF parts. The PSS technology refines the surface and produces long lasting, high quality, finished products. This enables 3D printed parts for end-use applications, which require a uniform color and a high-value finish. Especially in combination with dyeing, PSS achieves parts with an outstanding quality in terms of appearance and feel and provides additional value for demanding end-use applications.

POLYSHOT SURFACING: AN AUTOMATED SURFACE HOMOGENIZATION FOR IMPROVED PART PROPERTIES AND DYEING RESULTS

During the PSS process, the surface of polymer parts, produced by powder-bed fusion technologies, is homogenized with plastic beads shot through blasting nozzles. By doing so, the unevenness of the surface is reduced as surface variations are leveled out. The obtained, smooth surface offers better haptics and provides perfect conditions for uniform dyeing. Depending on the desired color and finish, the PSS can be applied before the dyeing for an improved color uniformity and after the dyeing for additional gloss and resistance. Although PSS leads to significantly better results especially in combination with dyeing, it is also useful in combination with other after-treatments, e.g. coating, metal plating and painting. The proprietary PSS process achieves unmatched part properties. The improved look and feel of the parts can be noticed by means of the following attributes:

- Matte, glossy look
- Scratch- and dirt resistant surface

Apart from the improved surface properties, the PSS is characterized by an outstanding process performance. Other surface treatments, such as manual blasting or tumbling cannot compete here.

- Fast cycle time (roughly 10 min)
- Cost-effective
- Automated
- Non abrasive

Both, the part properties and the process performance allow the use of PSS treated MJF parts in a variety of applications. End-use applications that require color are particularly noteworthy.

- **CONSUMER AND LIFESTYLE APPLICATIONS,** e.g. eyewear or wearables
- **MEDICAL APPLICATIONS,** e.g. insoles, orthoses or protheses
- **INDUSTRIAL APPLICATIONS,** e.g. automotive spare parts or housings

SURFACING WITH THE POWERSHOT S: HOW DOES IT WORK?

During the PolyShot Surfacing process, round plastic beads are shot with high pressure onto the surface of the raw MJF printed polymer parts. The impact force of the blasting material compresses the surface of the polymer and reduces the roughness by plastic deformation on a micorscopic level.

MACHINE INFORMATION

NAME	DyeMansion Powershot S
DIMENSIONS	1300 x 1665 x 2030 mm^3 | 51.2 x 65.6 x 79.9 $inch^3$
AIR CONSUMPTION	Recommended: 1.8 m^3/min at 5 bar | 64 cfm at 73 psi Maximum: 2.5 m^3/min at 7 bar | 88 cfm at 101 psi
SPACE REQUIREMENTS	2915 x 2465 x 2300 mm^3 | 114.8 x 97.0 x 90.6 $inch^3$
BLASTING MEDIA RECOMMENDED	DyeMansion PolyShot PS6 beads
POWER	Connection: 400 V; 50 Hz; CEE 16 A Consumption: 1 kW
CAPACITY	Up to one complete HP Jet Fusion 4200 build job
MAXIMUM PART SIZE	Highly geometry dependent (Automatic-program up to 300 x 300 x 300 mm^3 | 11.8 x 11.8 x 11.8 $inch^3$)

SETTINGS POWERSHOT S

MINIMUM DISTANCE BLASTING NOZZLE TO PART	200 mm | 7.9 inch
PRESSURE RECOMMENDED	5 bar | 73 psi
BLASTING TIME	10–20 min (depending on material and finish)

Compared to other blasting processes, the automated PSS process in the Powershot S offers some advantages. These advantages arise from the fact that all components and functions in the Powershot S are specifically matched to each other. During the blasting process, the basket filled with the parts constantly rotates. Its special geometry and the well-adjusted rotation allow that each part is machined equally. In addition, the Powershot S uses a combination of blasting and ionizing nozzles. Both are installed in the system and the alternate use of them is perfectly designed for the powder-free PSS process. Meanwhile, the high-performance cyclone recycles the blasting material after each pass and allows the reuse of it.

In the following, the individual operating steps of the Powershot S are explained in more detail.

INSERT PARTS	PROGRAM TIMER	START AUTOMATIC PROGRAM	AUTOMATED BLASTING PROCESS	END OF PROCESS
			– 10–20 min blasting process – 4 min cleaning	– Remove finished parts – Machine is ready for next batch

Although the fully automated PSS process in the Powershot S is suitable for the great variety of parts, there might be the need of manual blasting in seldom cases. Especially for large and fragile parts, the manual blasting, which is also possible in the Powershot S, might be helpful. Therefore, blasting gloves and a foot pedal are installed in the Powershot S. The recommended settings for the automated process should not be exceeded even during manual operation.

TESTED TO THE CORE

In order to demonstrate the possibilities of the PSS process and its advantages over other post-processing methods (e.g. tumbling), various tests were carried out. Therefore, different part geometries were printed on a HP 4200 using a balanced print mode, a natural cooling and a recycle ratio of 20/80 PA12 powder. The obtained, depowdered parts were pre-characterized using a Measurement Macroscope.

TECHNOLOGY	PRINTER	MATERIAL	MATERIAL NAME	PRINTHEAD RESOLUTION	LAYER THICKNESS
HP Multi Jet Fusion	HP Jet Fusion 3D 4200	Polyamide 12	HP 3D HR PA 12	1200 dpi	0.08 mm | 0.003 inch

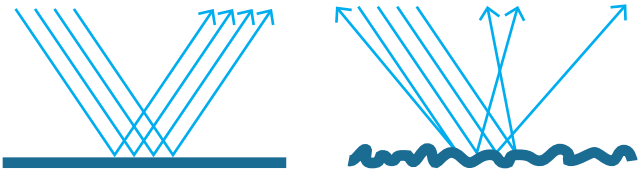
In addition, the weight was controlled. The parts are post-processed as followed: tumbling with a tumbler or PolyShot Surfacing (PSS) with the Powershot S.

SYSTEM	PROCESS	MEDIA	SETTING	CYCLE TIME
ROTARY VIBRATOR MMTV-5321	Tumbling	RMB/D110/20 Z ceramic media	1500 rpm	6 h
POWERSHOT S	PolyShot Surfacing (PSS)	PolyShot PS6 plastic beads	3–5 bar	10–60 min

SURFACE ROUGHNESS

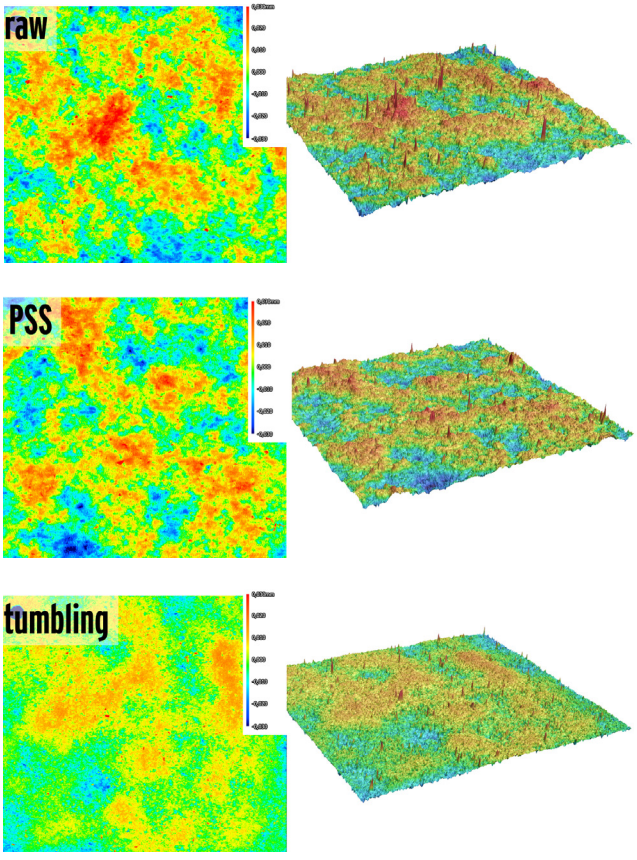
The quality of a surface can be described by the surface roughness. In the past, the surface roughness was mainly characterized by the 2D parameters Ra (arithmetic mean height of a line) and Rz (maximum profile height of a line), as the first available roughness measurement devices were tactile systems, which only allowed to measure these 2D values.

However, usually a surface is much more complex and can be more accurately described by 3D roughness parameters. Analogous to the 2D values Ra and Rz, the corresponding 3D roughness values Sa and Sz exist. But still, these surface parameters do not contain all the information needed to adequately characterize a surface with respect to look and feel. Therefore, additional surface texture parameters are defined in the ISO 25178. Among them, there are the so-called hybrid parameters, which include both the peaks and their distances from each other. These parameters are well suited to make gloss and smoothness measurable. Therefore, we used the following parameters: Sdq (developed interfacial ratio) and Sdr (root mean square gradient).



Sdq describes the slope of the surface. Therefore, it is an indirect measure of the optical behavior of the surface. The closer the Sdq is to one, the higher is the amount of surface sub-parts which are not parallel to the macroscopic surface but inclined with an angle up to 45°. As parallel surfaces reflect light in a defined angle, parts with small Sdq values appear glossy. At the same time, the light is diffusely scattered on irregular surfaces and thus surfaces with high Sdq values appear matt and dull.

Sdr calculates the ratio of the true surface to the measured surface. It is a measure of the roughness of the surface and can be directly linked to the smoothness. The higher the Sdr value, the smaller the contact area between a finger and the surface of a material. Thus, surfaces with high Sdr feel rough.



In order to get statistically sophisticated results, roughness measurements were performed on flat chips. Several representative areas around 1 mm^2 were analyzed and averaged.Comparing the Sdr and Sdq values of raw parts with parts which are either treated by the PSS process or tumbled shows that both surface treatments improve the properties of the material with respect to look and feel. Especially the Sdq value is drastically decreased for the PSS treated parts, which is in good accordance with the glossier look of the PSS post-treated parts.

PROCESS	Sdq*	Sdq IMPROVEMENT TO RAW PART	Sdr*	Sdr IMPROVEMENT TO RAW PART
RAW	0.355	0 %	0.0596	0 %
PSS 10 MIN @5 BAR | 73 PSI	0.288	19 %	0.0404	32 %
TUMBLED 6 H @1500 RPM	0.326	8 %	0.0496	17 %

*measured on up-skin surface

Systematic tests with varying process times and blasting pressure show that 10 min of PSS with a blasting pressure of 5 bar is enough to obtain high valuable surfaces. Therefore, DyeMansion recommends a PolyShot Surfacing process time of 10 to 15 minutes with a blasting pressure of 5 bar. Increasing the pressure or process time will not result in any further improvement of the surface quality. Instead, it can even harm fragile parts. Applying less than 5 bar could be recommended for fragile parts, but in this case longer cycle times should be taken into account. The flat chips were measured on the naturally rougher up-skin surface. The effect of a rougher up-skin and smoother down-skin can be observed on any powder bed fusion technology. In the case of the flat chips down-skin surface roughness values reaches as low as 0.228 Sdq and 0.0255 Sdr.

TIME	PRESSURE	Sdq*	Sdq IMPROVEMENT TO RAW PART	Sdr*	Sdr IMPROVEMENT TO RAW PART
raw		0.355	0 %	0.0596	0 %
10 min	5 bar | 73 psi	0.288	19 %	0.0404	32 %
20 min	5 bar | 73 psi	0.291	18 %	0.0410	31 %
40 min	5 bar | 73 psi	0.285	20 %	0.0395	34 %
60 min	5 bar | 73 psi	0.293	17 %	0.0412	31 %

*measured on up-skin surface

PRESSURE	TIME	Sdq*	Sdq IMPROVEMENT TO RAW PART	Sdr*	Sdr IMPROVEMENT TO RAW PART
raw		0.355	0 %	0.0596	0 %
3 bar | 44 psi	10 min	0.297	16 %	0.0428	28 %
5 bar | 73 psi	10 min	0.288	19 %	0.0404	32 %
6 bar | 87 psi	10 min	0.298	16 %	0.0431	28 %

*measured on up-skin surface

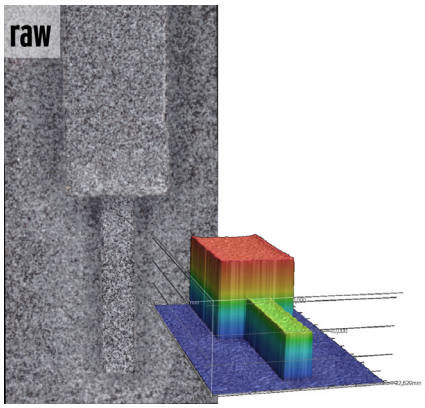
DIMENSIONAL VARIATION

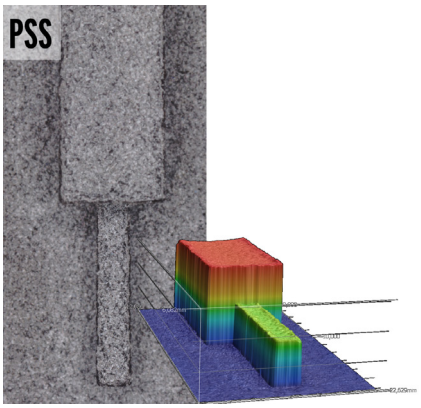
Additively manufactured parts often offer the advantage of complex geometries, which cannot be obtained by other production methods. Therefore, it is even more important that the geometry of the parts remains intact.

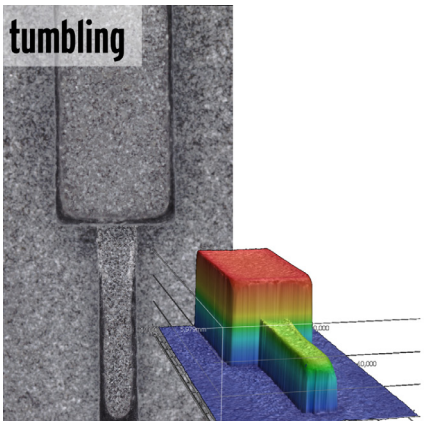
To understand the abrasive influence of PSS and tumbling on the preservation of the geometry more accurately, the mass of the parts was measured before and after post-processing. It indicates, how much of the raw part is erased. While the mass loss during the PSS treatment is negligible, tumbling removes a certain portion of the material (almost 1 %). In this context it is worthwhile to mention, that the mass loss for tumbled parts is highly dependend on the part design as well as tumbling time, setting and media used and will vary for different applications.

PROCESS	MASS LOSS
PSS	0.02 %
TUMBLING	0.93 %

Besides the over-all mass loss of a part, geometrical changes of fragile and exposed locations play an important role. To evaluate the dimensional variation, which comes along with post-processing, different geometries offering sharp edges and fragile pins are treated by the PSS process and tumbling.



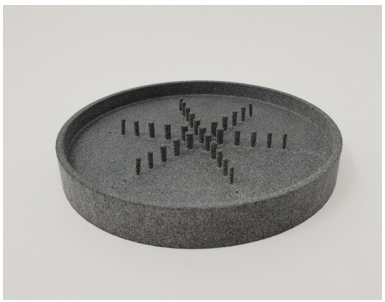




CORNER RADIUS	0.085 mm	0.126 mm	0.208 mm

After the post-processing, changes are clearly visible. While the raw part offers sharp 90° edges, the post-treated parts show a rounding of the edges. This fillet is already visible to the naked eye for tumbled samples. Looking at the corner radius of the raw part, the tumbled and the PSS processed part, it is clearly visible that sharp edges are less affected during the PSS process.

The same applies for fragile parts e.g. the tested parts with pins as thin as 1.5 mm. No matter which post-processing method is applied, it is obvious that not only the diameter of the pin but also its aspect ratio is crucial for its stability. High aspect ratio pins (6 mm length) fail more frequently than small aspect ratio pins (3 mm length). However, it can also be seen that most pins survive the PSS process, but more than 50 % of the pins are destroyed during tumbling.



PROCESS	BROKEN PINS ON UP-SKIN 6 MM | 0.24 INCH LENGTH	BROKEN PINS ON DOWN-SKIN 3 MM | 0.12 INCH LENGTH	SMALLEST SURVIVING PIN 6 MM | 0.24 INCH LENGHT	SMALLEST SURVIVING PIN 3 MM | 0.12 INCH LENGHT
PSS	12 %	4 %	1.5 mm	1.5 mm
TUMBLING	70 %	47 %	2.0 mm	2.0 mm

FROM HIGH-QUALITY SURFACES TO HIGH VALUE PRODUCTS WITH POLYSHOT SURFACING

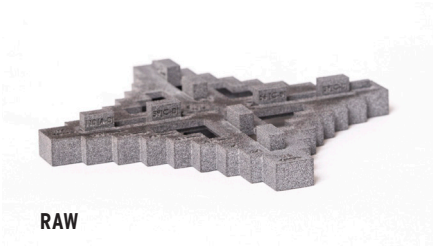
DyeMansion's sophisticated surfacing technology delivers a homogeneous surface quality, transforming porous, powder-based plastics into long-lasting, finished products. Although the surface is structurally homogenized, MJF parts still offer an inhomogeneous gray-shaded look after the PSS process. For high value products not only the surface structure, but also the part color should be homogeneous. Therefore, an additional post-processing step e.g. dyeing is indispensable.

DYEING

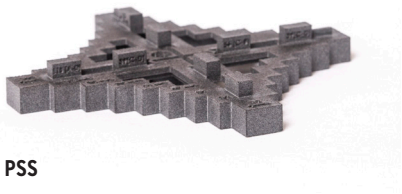
The combination of PSS with dyeing is the most used solution to achieve a high-quality look and feel in an economical way. This combination enables many applications that require an end-use part finish at low costs like eyewear frames. For high quality results, parts can be treated with the Powershot S before and/or after dyeing. To increase the homogeneity of the dyeing, a PSS treatment prior to the dyeing is essential, as PSS treated surfaces offer the best surface quality for a consistent distribution of the color. Surfacing after the dyeing increase glossiness and resistance. In addition, the reduced Sdq increases the glossiness of the surface and thus of the colored part as-well. To obtain the best results for powder-bed fusion based AM parts, DyeMansion has developed a Print-to-Product workflow. This automated process consists of the following steps:

STEP	SYSTEM	PROCESS	CYCLE TIME
1	**POWERSHOT C**	Damage-preventive, automated part cleaning	15 min
2	**POWERSHOT S**	PolyShot Surfacing (PSS) for improved properties	15 min
3	**DM60**	Coloring under pressure and heat	2.5 h
4	**POWERSHOT S**	PolyShot Surfacing (PSS) PSS for brilliant finish	15 min

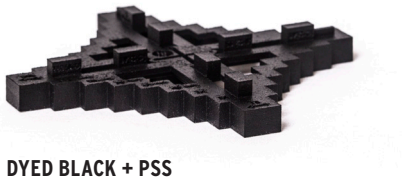
Due to the nature of black color, surfacing only after the dyeing process is enough for deep black dyeing.



RAW



PSS



DYED BLACK + PSS

OTHER COMPATIBLE POST-PROCESSING TECHNOLOGIES

COATINGS

Compared to dyeing alone, additional coatings can deliver more shine. Meanwhile, more sophisticated coatings can improve surface properties, which are needed for certain applications. Using the well established PSS process, dense and glossy surfaces can also be achieved by dyeing. However, there are still some applications that require beneficial properties obtained by coating:

- Water repellence
- UV-resistance

Although PSS does not limit the use of coatings at all, coatings are only recommended, when the standard process does not meet the requirements. Coatings add cost to the process and offer certain geometry restrictions to the part due to the drying process. DyeMansion can help with the selection of the right coatings for each of the different applications and has many in its portfolio.

METAL PLATING

This process is often used to make parts conductive and improve mechanical properties and visual appearance. However, as the metal layer, applied to the material is very thin, it might mimic the variations on the surface of MJF parts. Combining the PSS process with metal plating improves the visual appearance by reducing the surface roughness.

GLUEING

Although additive manufacturing offers a lot of geometrical freedom, there might be circumstances, which still require to bond two different parts with each other. Although the surface roughness is reduced during the PSS process, glueing can still be used to bond two parts together without additional preparation steps.

PAINTING

While the most common way of applying color to a part is dyeing, some applications might need spray painting (e.g. metallic colors). As PSS compresses the surface of the printed parts, less paint is absorbed during spray painting. This reduces the required amount of paint, as well as the number of steps. Consequently, cost and time needed for spray painting of the parts are reduced.

TUMBLING

For some applications, especially those with skin contact, an even smoother surface than obtained by PSS alone, is necessary. This is where tumbling comes into play. Long tumbling times in combination with PSS can reduce the surface roughness further, but as shown in this whitepaper, it also has some negative effects on the part geometry. In addition, the process itself may cause damage on the part, e.g. scratches. If tumbling cannot be avoided, it is recommended to use the PSS process after tumbling. After the PSS the scratches are negligible, and the part offers a high-quality glossy and homogenous surface. In general, most applications that require a smooth finish also are in need of a nice look and feel. So, combining the two processes will lead to sophisticated results, while tumbling alone usually doesn't deliver the required quality.

COST-EFFICIENT HIGH-QUALITY SURFACE FINISH FOR HIGH-VALUE PARTS

The process is automated and time-efficient. Therefore, the personnel requirement is reduced to a minimum. In addition, the Powershot S is optimized in such a way that the running costs are very low. On one hand, the blasting basket is designed, so that a complete HP Jet Fusion 3D 4200 built job can be finished in a single pass. On the other hand, the blasting material consumption is very low, with a high recycling rate due to the high-performance cyclone incorporated in the Powershot S. Using a hypothetical calculation, which takes the fixed and the variable costs into account, the cost-efficiency of the PSS technology can be demonstrated. Therefore, a depreciation period of 5 years is estimated. According to industrial standards, the Powershot S is roughly operated 3 times per day and 250 days per year with an average run time of 15 minutes. Taking all this into account, the cost per part varies only due to the batch size.

As discussed previously, the PSS finish on its own is not sufficient for high-value parts. Therefore, it is recommended to treat the parts with the entire DyeMansion Print-to-Product workflow. Since all processing steps meet the high demands of DyeMansion and are therefore automated and cost-efficient, the costs for the high-value finish are also kept within limits. Please note that all calculations made here cover all costs (including maintenance, electricity, water supply, consumables) and might vary, depending on the local prices for electricity, water supply and effluent disposal.

EXAMPLE	# PARTS	BASKET FILLING	PSS FINISH	COMPLETE PRINT TO-PRODUCT
Eyewear	150	100 %	0.09 €	1.00 €
Eyewear	75	50 %	0.18 €	1.61 €
Automotive spare parts	25	100 %	0.55 €	5.98 €
Ortheses	15	100 %	0.92 €	9.58 €

Photo: Freshfiber
Design: Matthijs Kok

CONCLUSION

DyeMansion's surfacing technology – the PolyShot Surfacing – delivers a homogeneous surface quality, transforming rough, powder-based plastics into long-lasting, finished products, especially in combination with dyeing. PSS is an automated process, which achieves a homogeneous surface quality at a cycle time as short as 10 minutes. The special blasting process reaches almost all areas of the part without any material removal. The obtained shiny surfaces and pleasant haptics enable an improved look & feel for powder-bed fusion produced plastics. This is the key to high-value 3D-printed products.

The influencing factors, which make a high-quality product possible, but also ruin it, are manifold. To minimize these factors and get reproducible results, an automated process is recommended. DyeMansion offers its customers an automated, well established Print-to-Product workflow. This workflow combines the essential steps to obtain high-value AM parts: Cleaning (Powershot C), PolyShot Surfacing (Powershot S) and Dyeing (DM60). With this in mind, the production of high-quality powder-bed printed parts is no longer an obstacle.

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