POSTPROCESS
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WHITE PAPER:
Multi Jet Fusion
Post-Processing

Automated Powder Removal and Surface Finishing for MJF

This paper explores a new technology that automates the post-printing processes for Multi Jet Fusion (MJF) for excess powder removal and surface finishing. This automated post-printing enables higher quality with greater consistency, faster throughput, lower operator attendance time, and preservation of fine feature details, ultimately expanding the opportunity and application of MJF.

Multi Jet Fusion Print Technology Background

HP Multi Jet Fusion technology uses scalable HP thermal inkjet technology to make printbars of different widths by stacking printheads across the width of the scan. Just as this capability allows HP to scale its 2D printing solutions from the desktop to more than 100-inches wide, HP can create a range of HP Jet Fusion 3D printing solutions with working areas of different sizes. HP printheads can also be stacked along the scan direction to add more nozzles for speed, functionality, and nozzle redundancy for dependable printing quality.

The build begins by laying down a thin layer of powdered material across the working area. Next, the printing and fusing carriage with an HP thermal inkjet (printhead) array and energy sources scans from right-to-left across the working area. The leading energy source preheats the working area immediately before printing to provide consistent and accurate temperature control of each layer as it is printed. The printheads now print functional agents in precise locations onto the material to define the part's geometry and its properties. The printing and fusing carriage now returns left-to-right to fuse the areas that were just printed.

At the ends of the scans, supply bins refill the recoater with fresh material and service stations can test, clean, and service the printheads on the printing and fusing carriage as needed to ensure reliable operation. After finishing each layer, the surface of the work area retracts about the thickness of a sheet of office paper, and the material recoater carriage scans in the reverse direction for optimum productivity. The process continues layer-by-layer until a complete part, or set of parts, is formed in the build unit.

A key innovation in HP Multi Jet Fusion technology is a high-speed, synchronous architecture that builds parts layer-by-layer. As shown schematically in Figure 1, dual carriages scan across the Working area in perpendicular directions: one carriage recoats the working area with fresh material, and the other prints HP functional agents and fuses the printed areas. This separates the processes of recoating and printing/fusing so that each process can be separately optimized for performance, reliability, and productivity.

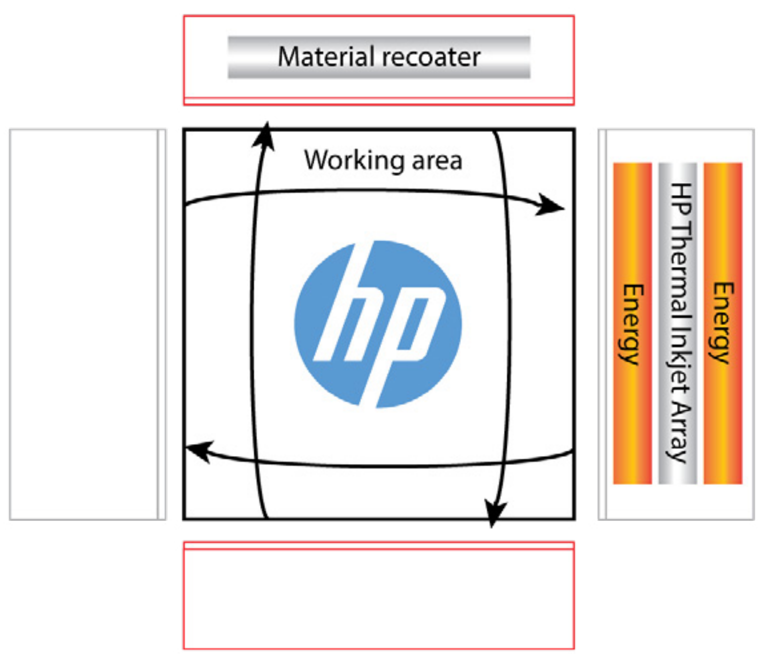


Figure 1

In the past, removing excess powder from MJF parts typically involved a high-pressure system combined with an abrasive component. A common technique for excess powder removal in production facilities is manual air or bead blasting. The first limitation of bead blasting is relying primarily on manual labor. This process requires an operator to stick their hands through thick and clumsy rubber gloves and peer through a limited window while they try to 'hose off' the part with high-pressure grit. With complex and fragile part geometries, handling and blasting parts this way can lead to wide inconsistencies and breakage. Beyond being labor intensive, the dry nature of bead blasting struggles to fully remove powder from fine cavities and increases downtime with issues such as hose clogging.

Another method is a traditional vibratory system. The concept is to aggressively shake and scrape off this final powder layer. However, this process runs into the same issues as dry bead blasting; you will not be able to remove the powder from smaller crevices. This uncontrolled approach, designed for subtractive manufacturing, also runs a high risk of damaging parts, or at minimum wearing down fine features before the powder layer is fully removed.

An automated approach designed specifically for additive manufacturing and capable of precision performance mitigates all of these challenges by freeing up labor, providing fast, repeatable results in batches, preserving fine feature details, and dampening airborne particulates.

Executive Summary

Utilizing the PostProcess DECI Duo Solution, automated powder removal times ranged from 20 to 30 minutes for the geometries tested, without the need for an operator. In addition, less than 5 minutes of technician time was needed to set up and remove the parts from the fixture. With a software-enabled solution, post-processing is accomplished with **significantly reduced touch time** and **increased consistency** to a level required for production volumes. In addition to speed and ease of use, the DECI Duo's *Thermal Atomized Fusillade (TAF)* process **prevents any dust generation** during excess powder removal and/or surface finish.

Designed for dual post-printing steps in one compact footprint, the DECI Duo performs surface finishing in the same envelope as powder removal with the same fixturing, utilizing different agitation parameters within the software. Parts in the following tests were left in the printed containers for excess powder removal and removed for the surface finishing steps. If the parts were printed without containers, the operator would not have to touch the parts in between the powder removal and surface finishing steps. Average roughness across all parts was reduced 3.58 μm on the bottom surface in just 5 minutes, while the top surface was reduced 1.40 μm in the same period of time.

Thermal Atomized Fusillade (TAF)

Thermal: Leveraging heat when necessary to operate in temperature ranges required for optimal Chemical Rate of Removal (cRoR).

Atomized: Balancing and varying both liquid and air pressures to reduce our chemistry to exact particles for precise accuracy while protecting fine feature detail.

Fusillade: A sequence of controlled jetting, either simultaneously or in rapid succession, to support a variety of geometries and throughput requirements.

Overall Conclusions

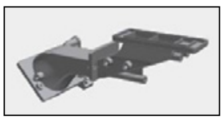
* The DECI Duo successfully removes powder in <30 minutes in an automated fashion, significantly **reducing technician touch time.**
* Surface roughness can be reduced up to 50% with minimal additional time in the DECI Duo.
  - On the chips, R_a was reduced 2.76 µm in 5 minutes. Reduction in roughness was achieved using RSF/2 10/10 ZS media in a traditional vibratory system in 60 minutes.
  - The DECI Duo was **~12x faster** to achieve the same reduction.

PostProcess DECI Duo
Powder Removal & Surface Finish Solution

Excess Powder Removal: ROI Calculation

Low Volume / Large Part

Parts per Day: 30
Labor $ per Hour*: $60



129.81 x 255.48 x 120.15 mm

Current Method
Manual Air / Bead Blasting

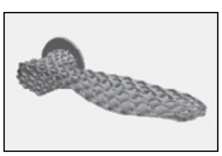
Parts per Cycle	1
Technician Time per Part (min)	15
Total Cycle Time per Part (min)	15
Total Cost per Part	**$15.03**

PostProcess Method
DECI Duo Solution

Parts per Cycle	5
Technician Time per Cycle (min)	2
Technician Time per Part (min)	.4
Automated Operating Time (min)	25
Total Cycle Time per Cycle (min)	27
Total Cycle Time per Part (min)	5.4
Total Cost per Part	**$0.76**
Savings per Part	**$14.27**
Savings per Day	**$428.00**
Return on Investment	**56 wks****

High Volume / Small Part

Parts per Day: 500
Labor $ per Hour*: $60



55.64 x 132.37 x 34.71 mm

Current Method
Manual Air / Bead Blasting

Parts per Cycle	1
Technician Time per Part (min)	1
Total Cycle Time per Part	1
Total Cost per Part	**$1.00**

PostProcess Method
DECI Duo Solution

Parts per Cycle	30
Technician Time per Cycle (min)	2
Technician Time per Part (min)	.06
Automated Operating Time (min)	25
Total Cycle Time per Cycle (min)	27
Total Cycle Time per Part (min)	.9
Total Cost per Part	**$0.09**
Savings per Part	**$0.91**
Savings per Day	**$456.00**
Return on Investment	**52 wks****

**Fully burdened labor rate*
***Investment includes DECI Duo Solution and estimated daily consumables cost.*

Test Overview

Three types of geometries were evaluated, with tensile bars accounting for a fourth. On each geometry, surface roughness was evaluated throughout two scenarios (Table 1).

- The first scenario is excess powder removal only, performed in the DECI Duo.
- The second scenario is excess powder removal and surface finish, both performed in the DECI Duo.

Table 1 - Cycle times (min)

Part	Scenario 1	Scenario 2
Pins	25	25+5
Chips	20	20+5
Features	30	30+5
Tensile bars	25	25+5

Table 1

Parts and Method

Chips

Evaluated on surface finish values alone, taken in 2 perpendicular directions.

Pins

Evaluated on both surface finish and number of pins broken during the process.

Features

Evaluated on surface finish.

Tensile Bars

These were/will be evaluated on tensile strength.

The method utilized was the automated DECI Duo Solution with *Thermal Atomized Fusillade (TAF)* technology (seen at right), precisely controlled by PostProcess' proprietary *AUTOMAT3D* software (Figure 2 next page).

The DECI Duo Solution integrates proprietary software, hardware, and chemistry. Abrasive fluid is jetted in a preprogrammed configuration from two nozzles which each move on a single axis. The spray jetted from the nozzles is a specially formulated detergent and suspended solid.

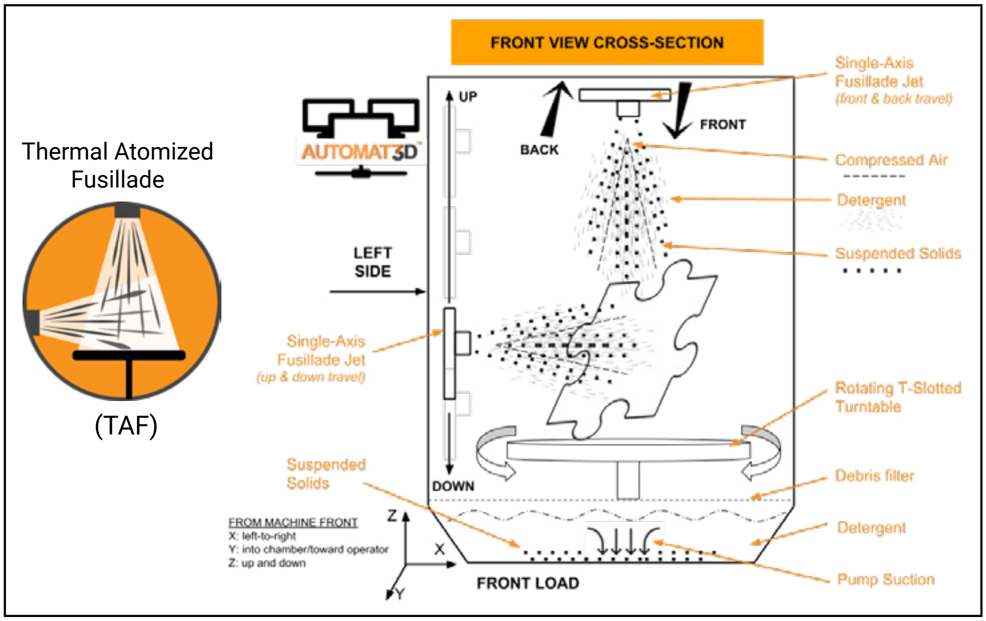


Figure 2

The spray is accelerated at the nozzle manifold using compressed air, providing precise force where required. Depending on the part material and geometry, parameters such as liquid pressure, air pressure, nozzle and rotary table speed, and valve configuration can be changed to create a specific part *Agitation Algorithm (AGA)* within the software program.

Agitation Algorithm (AGA) is a combination of predictive cycle parameters and logic optimizing both chemical and mechanical rates of removal. These settings are adjusted to address custom applications when required.

For optimum results with MJF excess powder removal, a zirconium dioxide (ZrO_2) based media suspended in PG5 detergent is used in the DECI Duo. The zirconia-based bead provides consistent results, even as powder collects in the system. For efficient excess powder removal of MJF parts, pump flow rates of 90.8 - 113.6 L/min and air pressures of 0 - 207 kPa are recommended. These values are geometry dependent and can vary slightly from application to application. The process of developing recipes is simple and reviewed thoroughly during training. The goal of recipe development is to “bucketize” parts so that a single recipe can be used across multiple parts that have similar attributes. Deeper cavities, fine channels, and slots could all require higher air and liquid pressures. When programming nozzle movement, it helps to set nozzle bounds just slightly past the edge of the part(s) for total coverage. Here is a summary of “as tested” settings showing a glimpse of the DECI Duo’s control and versatility -

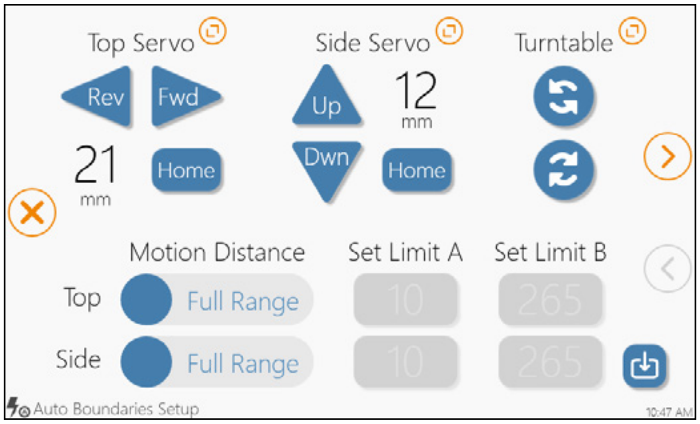
Settings

Media:	ZB-CBM
Liquid flow rate:	113.6 L/min
Air Pressure:	138 kPa
Top Nozzle travel bounds:	10-15mm beyond part ends
Side Nozzle travel bounds:	10-15mm beyond part ends

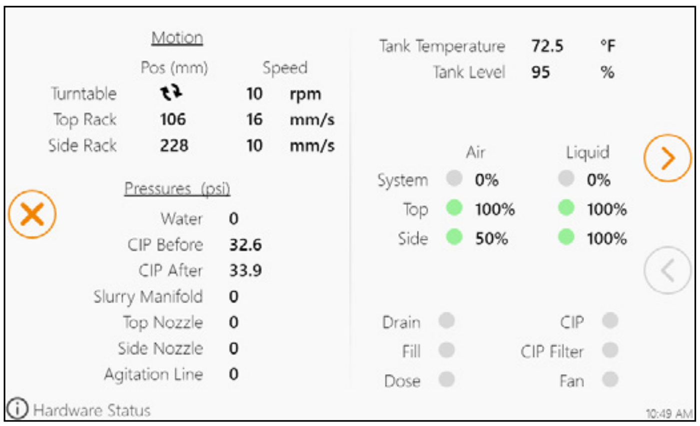
AUTOMAT3D is PostProcess’ proprietary HMI-enabled machine control software. It was developed from benchmarking over 500,000 geometries of various print technologies and geometries.

AUTOMAT3D controls all process variables based on selections made by the user such as cycle time, temperature, and agitation level.

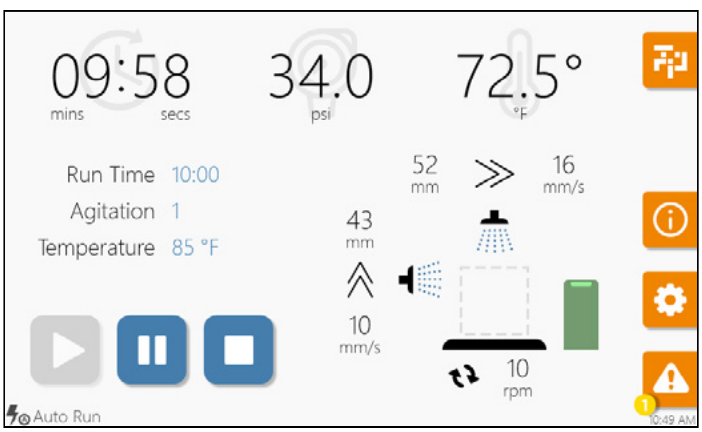
Shown below are screenshots of the *AUTOMAT3D* software HMI, including motion boundary set up, the info page showing current hardware status and a back-end screen used to customize the AGA.



Motion bounds are "taught" to the DECI Duo, based on the geometries being run.



Parameters being monitored by the industrial PC which are directly related to the AGA.



Real-time AGA and hardware outputs along with simple user functionality to Play, Pause, or End the cycle.

Air and liquid pressures were chosen based on the fine feature details needing to remain intact. Nozzle travel and speeds were chosen to achieve optimal coverage during the excess powder removal step and to preserve part features in the surface finish step. Parameters were verified through initial testing on each part type.

WASTE MANAGEMENT

Once saturated with powder, the DECI Duo detergent/media mixture is treated using a built-in software program. The automated cycle allows the solids to be separated out, creating two, more manageable waste streams. Disposal of waste streams need to follow local/state regulations as procedures will vary with location. Please consult your municipality or an independent waste disposal company in your area for details.

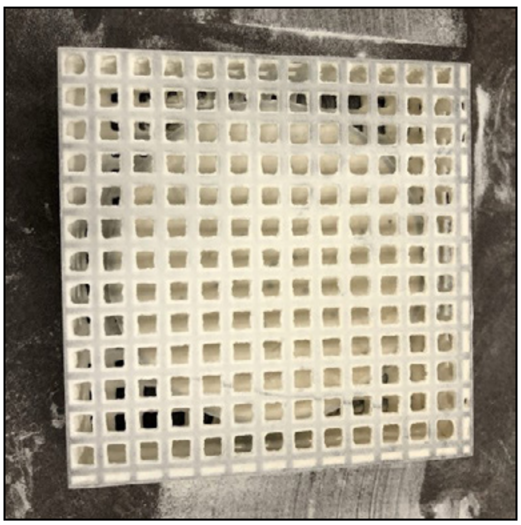
Scenario 1: Powder Removal Only

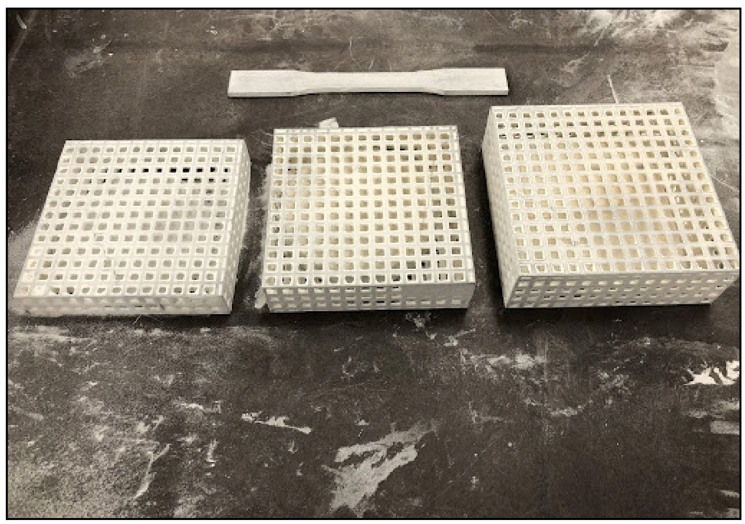
THROUGHPUT
Utilizing a proven standard PostProcess fixturing option, **throughput was greatly enhanced**, giving manufacturing the ability to perform excess powder removal on multiple geometries in a single, automated media separation cycle. Another advancement is the ability to process up to 4.5 kg of powder before needing to use the automated cycle, a short 30 minute process. Assuming 1 gram of powder per part, up to 4500 parts could go through the excess powder removal process prior to the detergent becoming saturated.

CONSISTENCY
Powder removal was consistent following a visual inspection of all 6 parts in each batch, with even coverage ensured by the AGA settings.

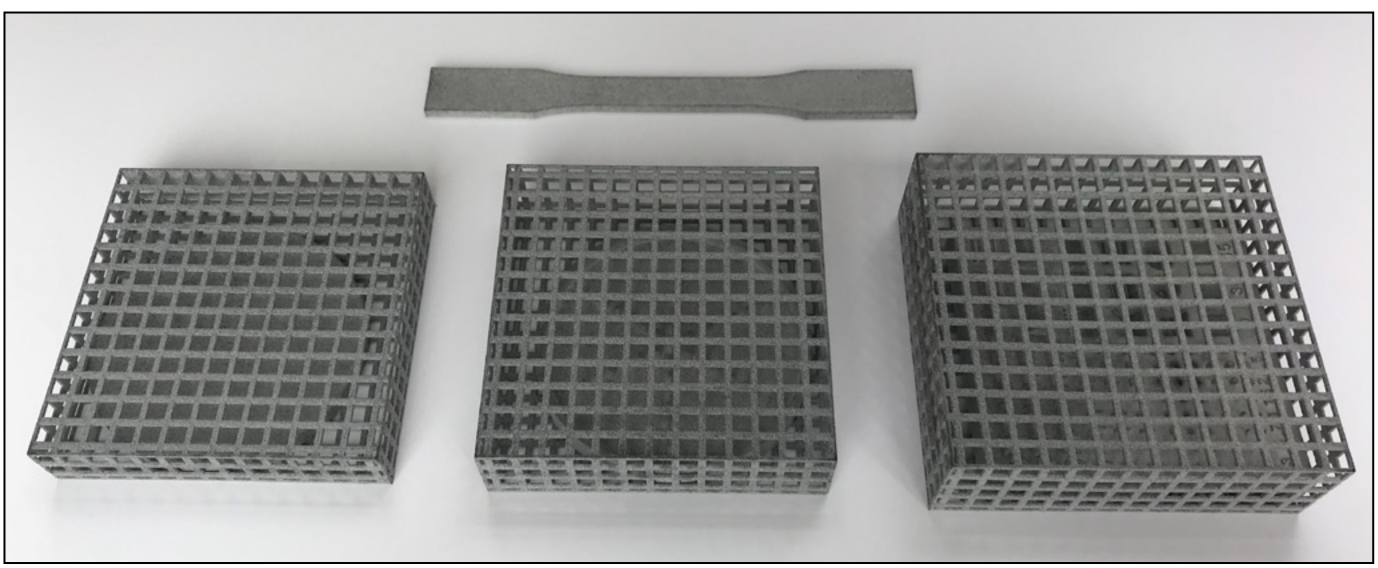
SAFETY
Dust issues are non-existent due to the TAF process, which utilizes solids suspended in a liquid detergent.

Before Images:





After Images:



SCENARIO 1 CONCLUSIONS

Powder was successfully removed from each part in 30 minutes or less. After confirming the process parameters by processing a single part at a time, remaining parts were done in sets of six, within the printed containers. Varying geometries will factor into overall cycle time.

Fixture used for testing, showing a batch operation of 6 parts. Utilizing both the top and side nozzle, parts had excess powder removed in 25 minutes.

Scenario 2: Powder Removal with Surface Finish

All results obtained in Scenario 2 went through 2 processes;
- Excess powder removal (as performed in Scenario 1).
- Surface finishing in the DECI Duo for 5 minutes, shown in Figure 3 below.

Between these two steps, parts were removed from the printed containers to ensure full coverage of surfaces.

SCENARIO 2 CONCLUSIONS

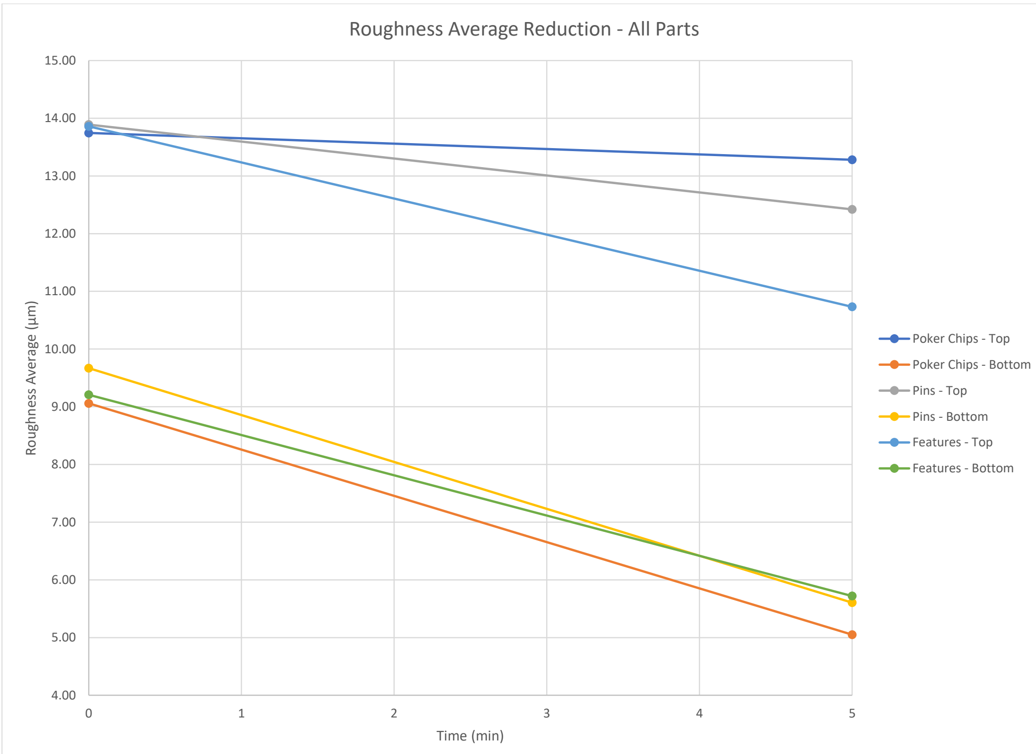


Figure 3

INITIAL INSIGHTS

As printed, there are clear differences in the results from bottom surfaces to top surfaces. The bottom surfaces begin with a smoother surface and have generally consistent finishing results, whereas the top surfaces start with rougher surfaces and have more variability in finishing results. Top surfaces experience improvement, although more moderate than for bottom surfaces. HP recommends giving an angle to the parts with cosmetic requirements of at least 30º to avoid large surfaces on the top face and get a uniform surface roughness across the part.

CONSISTENCY

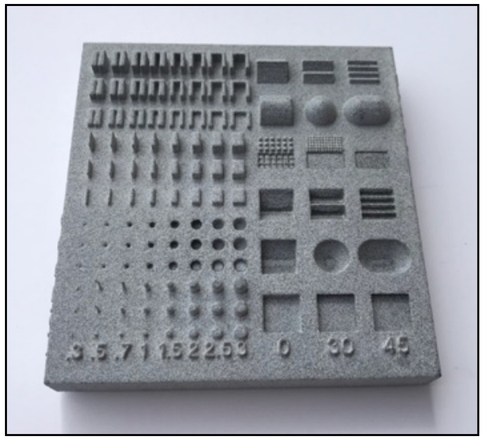
An important data point to note is that the top surfaces achieved consistent ending roughness averages (R_a) despite having inconsistent deltas. Key findings include:
- The average reduction in R_a across all parts regarding top surfaces was 1.40 µm over 5 minutes.
- The bottom surfaces saw an average reduction of 3.58 µm over 5 minutes.
- Initial testing was performed to find optimal cycle time, diminishing returns were seen after 5 minutes.

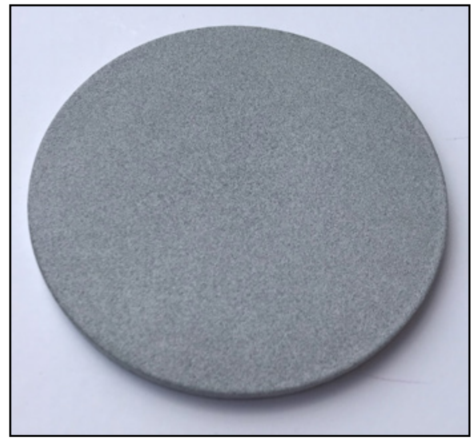
PRESERVING FINE FEATURE DETAILS

Pins Part:

Of the 6 parts processed in this Step, 5 parts had three or fewer of the twelve 0.5 mm pins broken. None had any of the 0.75 mm pins broken. All remaining pins were left intact.

Scenario 2 - After Images:





Conclusions

Automated post-printing techniques for excess powder removal and surface finishing deliver superior results and open up new use cases and improved efficiencies for MJF.

Powder Removal Only:

Powder was successfully removed from each geometry in **30 minutes or less**. Varying geometries will factor into overall cycle time. This is a proven application that has been tested and confirmed on multiple geometries.

Powder Removal with Surface Finish:

As printed, there are clear differences in the results from bottom surfaces to top surfaces. The bottom surfaces begin with a smoother surface and have generally consistent finishing results, whereas the top surfaces start with rougher surfaces and have more variability in finishing results. Top surfaces experience improvement, although more moderate than for bottom surfaces.

An important data point to note is that although the top surfaces had generally inconsistent delta's, the ending roughness averages (R_a) were consistent. Overall, the **average reduction in R_a across all geometries** regarding top surfaces was 1.40 µm over 5 minutes. The bottom surfaces saw an average reduction of 3.58 µm over 5 minutes. Initial testing was performed to find optimal cycle time, diminishing returns were seen after 5 minutes.

Fine feature details were kept intact, showing the ability to remove excess powder from complex or delicate geometries. Of the 6 'pins' geometries processed in this scenario, 5 had three or fewer of the twelve 0.5 mm pins broken. None had any of the 0.75 mm pins broken. All remaining pins were left intact.

Appendix A - Benchmark Process Overview

PostProcess' Benchmark process allows customers to see the transformative results possible from our automated and intelligent post-printing solutions. Using customer-provided samples, our expert team runs the parts through the FINISH3D™ lab to each customer's specific needs.

To initiate the benchmark process, contact PostProcess directly. After a PostProcess representative gathers initial information via email or phone call, the customer will send the following to PostProcess HQ:
(1) 5-10 samples of the same part,
(2) a "gold standard" example of the same part finished with current post-processing methods, and
(3) any specifications such as final R_a value.
While (2) and (3) are not required, they help to facilitate the most successful outcome.

Upon receipt, PostProcess will complete the benchmark in approximately 7-14 days in our FINISH3D™ lab.

When the benchmark is completed, the parts are returned with a comprehensive Performance Evaluation report for each unique geometry that includes machine operation time, technician attendance time, approximate batch size, and final R_a value.

To initiate a benchmark, please contact:

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