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Additive Manufacturing Post Process

Background of 3D Printing

In the additive manufacturing industry, 3D printers themselves vary not only in the material they use for printing, whether they print resin, filament, or even cement, but also in how things get printed. The 3D printing world is changing every single day and new things are constantly coming out for this industry. 3D printers are categorized into 4 different types: SLA, DLP, LCD, and FDM. FDM are filament based printers, which mean that they use a heated nozzle to melt the thermoplastic filament building layers on a build platform.

SLA, DLP, and LCD printers use a process called Vat Polymerization to cure the resin into layers by using a resin tank and a certain type of light source. This allows for ultra detailed pieces compared to the detailed abilities of FDM printers.

Stereolithography (SLA) started being commercialized in the mid 1980's, and uses a laser beam to selectively cure layers of resin on the bottom of the resin tank that then adhere to a print platform (Types of 3d Printers: SLA vs DLP vs LCD vs FDM, 2022). The laser works by using galvanometers, which are little mirrors under the resin tank, to guide the laser to the precise position that needs to be cured.

In 1987, Digital Light Processing (DLP) was introduced but not for 3D printing, it was originally used for movie projection (Types of 3d Printers: SLA vs DLP vs LCD vs FDM, 2022). In DLP 3D printing, they use a digital light projector to cure the layer of resin simultaneously.

The last type of Vat printers are the Liquid Crystal Display (LCD) printers, which use LCD panels with LED lights to cure layers of resin in the resin tank. They are similar to DLP printers in that they flash the entire layer at once, but LCD uses the LED lights to shine light through to cure the model while the LCD panel blocks off the portions of resin that do not need to be cured.

One thing that SLA, DLP, and LCD all have in common is that after the model is done printing, the model needs to go through a process called the post print process. This process helps clean the excess resin off the model and finish curing portions that may not have been fully cured in the printing process. This post print process is vital for the success of the 3D printed models. Without the post print process, the model may not have the highest quality in both dimensions and physical properties.

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Post Print Process Overview

After 3D models are printed, it is important to follow a post printing process that is optimized for the specific material being printed. The post printing process includes a wash process, the curing process and the final preparation of the model for its use. It's important to follow the post process to get the best quality models, both in physical appearance and physical properties. Variation of any stage in the post process will affect both physical aspects of the models.

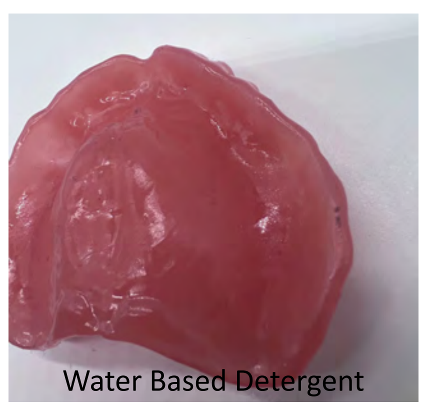
The post wash process cleans the models of excess resin that may be still on the surface, as well as cleaning out resin stuck in ridges or holes of models. Cleaning is done using a wash bath unit and solvent. This cleaning process is typically done using isopropyl alcohol (IPA), ethanol or other cleaners as a solvent. It is also common practice to use ultrasonic agitation cleaners as the equipment used to wash 3D printed models.

After the wash process is complete, the next step is to use a curing unit to finish curing the model. There are many different curing units on the market, and most brands of 3D printers have their own curing equipment that they recommend for the models printed on their printers. This process helps any partially cured resin become fully cured and improve the overall strength of the model. After the curing process is complete, the model is ready for any finalization that needs to be done to prepare for commercialization.

Gloss vs. Matte Observations

One observation we started to notice while postcuring models in different solutions is the significant difference in gloss between the different wash solutions. Keeping the material, 3D model, DLP printer, and post curing the same, we observed that different wash solutions caused different final surface properties.

IPA



Water Based Detergent

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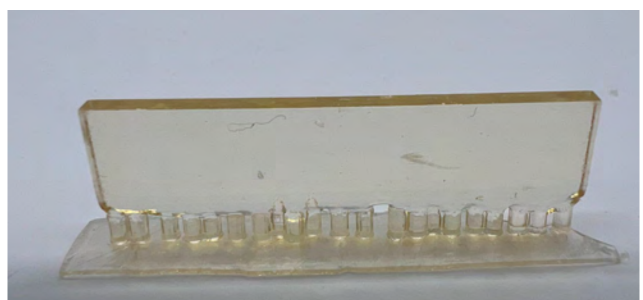
The more aggressive solutions created a matte surface, while the less aggressive solutions created a glossy surface on our models. We performed some preliminary gloss testing using a gloss meter on some of the different solutions:

Wash Solution Type	**Gloss Measurement**
IPA	2.6 ø
Water Based Detergent	15.5ø
Food oil	18.1ø
Commercial Wash	18.3ø

Another observation as we were using different wash solutions, was how different solutions were more aggressive to materials and affecting their surface, as shown in the imagery below. At times it seemed as if some materials were being attacked by harsher solutions, making the models more brittle in the process.

Material washed in IPA



Material washed in water based detergent

Theory

Different solvents affect materials differently, whether that be physical or chemical properties. We are going to investigate nine different materials as "solvents", mainly looking at physical properties of the printed materials. The nine solvents that we will be testing are: no wash, IPA, commercial wash (glycol based), food oil, water based detergent, water based detergent in ultrasonic cleaner, PEA, HDDA, and TMPTA. We want to understand how well they cleaned the part and how they impact certain properties, including preventing decay of the model.

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Our initial observations of the surface gloss, led us to develop a theory for what could be happening during the post print wash process. After printing a model, you have a model made out of gel polymer that is a mixture of mostly cured, partially cured and uncured resin. The entire post print process is to help the model finish curing and clean away the remaining uncured resin.

We theorized that washing in different solvents will show some significant differences in physical properties. For an analogy, imagine a stucco wall with cinder block and mortar being the foundation underneath. The cinder blocks represent the cured material matrix, the mortar represents the partially cured material, stucco represents an uncured layer of material coating the surface of the model.

Now a printed model straight off the printer is this stucco wall covered in dirt. The dirt represents excess material that needs to be removed. The goal of the wash process is to remove the dirt without removing the materials below it. The more aggressive wash solutions remove the dirt but also remove the stucco, mortar and maybe even some of the cinder blocks (leaving a low gloss surface). The gentler wash solutions remove the dirt but leave the stucco in place over the mortar and cinder blocks.

We also theorized that there could be wash solutions that would also not only remove the dirt, but place more stucco and blocks to make up for any standard deformities that may occur during the printing process. Therefore, our theory is that some of these wash solutions have the potential to increase the physical properties of this material.

Method of Testing

For this experiment, we used ASTM-D790 and 3D printed specimen bars per the ASTM specifications and ran a study using different solutions as the post printing wash. The configurations per the ASTM standard are listed below.

Flexural Test Configurations for Test standard: ASTM-D790

1. Test speed/crosshead speed- 0.05-0.1 in/min (or 1.27-2.54 mm/min)
2. Fixture- 3-point flex fixture with 4mm diameter anvils
3. Specimen type and dimensions:
    a. Type: Bars
    b. Dimensions: 38.4mm x 8mm x 2mm (length x width x depth)
    c. Span length to Depth = 16:1
    d. Length = span length + twice the 10% overhang

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e. Width = 25% of span length

4. Number of test specimens: 5

When washing the specimens, some were washed in the solution then wiped down by hand. Touching the models with your hands is not recommended when post processing 3D printed models, however to control variables and due to the models printed being test specimen bars, we did touch the models to wash them. The solutions used for this experiment were all unused previously, and therefore clean from any excess resin or any other uses. After being washed, the test specimens were then cured in the material specified curebox and for the appropriate timing. After being cured, the test specimens were left to sit for 24 hours before being tested on the Instron for flexural properties per ASTM-D790.

Flexural Properties

After our theorizing, we ran the experiment layout out above in our testing method. The results are posted below:

	Flex Strain (Extension)%	**Flex Modulus (MPa)**	**Maximum Stress (MPa)**
Bulk Cured	7	4100	183
Compressed Air & Wipe (Control)	7	4200	181
IPA	7	3570	170
Glycol based commercial wash	11	3509	172
Food Oil	8	3757	178
Water-Based Detergent	9	4100	179
Water-Based Ultrasonic	8	3550	170
PEA	13	2904	227
HDDA	7	4031	166
TMPTA	5	4177	160

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1173	9	3781	175

The control specimen was done with bars that were washed using compress air and hand wiping. While this is not feasible as a commercial process with more complicated parts; the data does match the bulk cured properties of this formula.

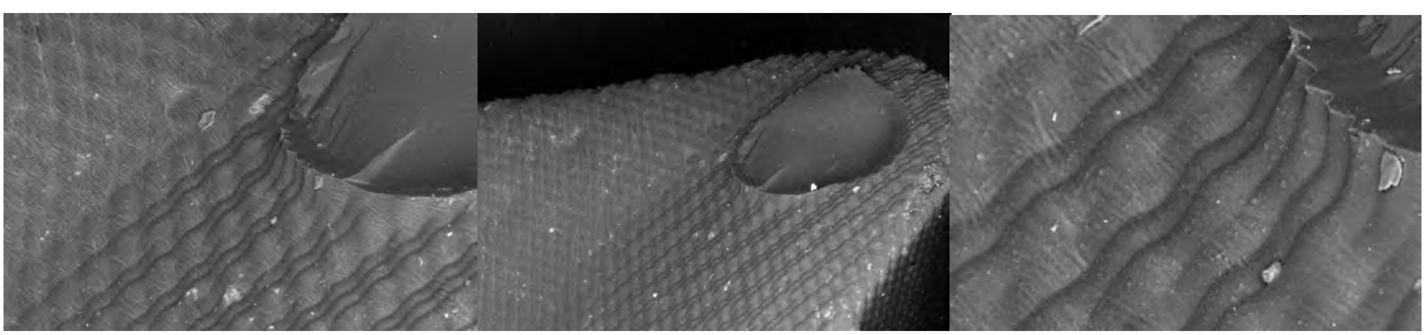
IPA and the glycol based washes give a significant drop in modulus and stress, while the food oil does show some improvement. Interestingly this aligns with the glossy surface. The waterbased washed specimens wash solution most closely matches the control until it is used in combination with the ultrasonic cleaner. Our theory is that the ultrasonic bath vibration shakes too much of the uncured structure off the model. The UV monomers gave interesting results. The PEA must have left residual material on the part and plasticized the bar to increase flexibility. We are not sure why the same effect could not be seen with the HDDA and TMPTA. We expect the TMPTA is too high in viscosity to penetrate the bar, but HDDA should have. We expect it has to do with the aromatic nature of the PEA helping the material.

This will be followed up on with future studies and creates the interesting possibility of post modifying the surface of the part. The 1173 results in reasonable physical properties with possibly an increase in flexibility.

SEMs

SEMs were performed on some of the solutions we used in our wash study. We wanted to get a closer look at what some of the wash solutions were doing to the surface of the models, and observe if your theory was correct.

These first SEMs featured below are of an IPA washed model. We observed that the surface of the model has many exposed ridges, making the surface seem quite textured and rough.



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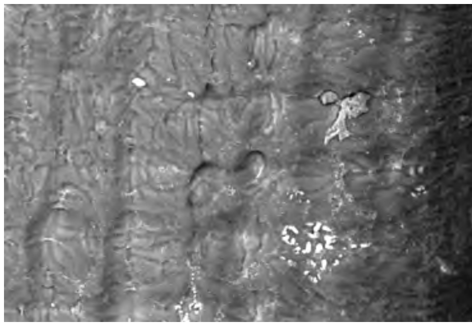
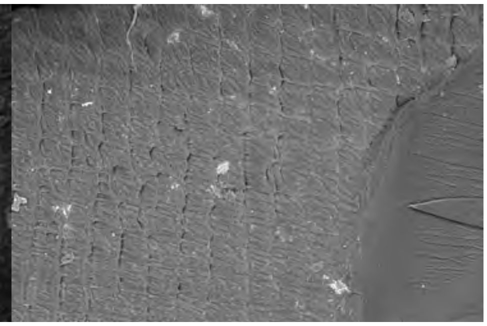
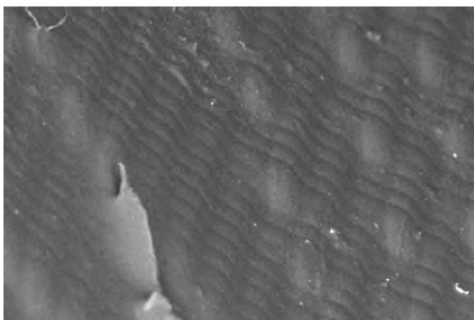
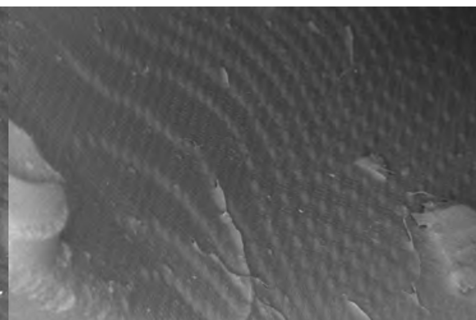
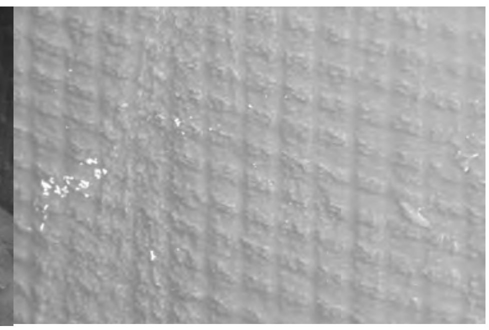
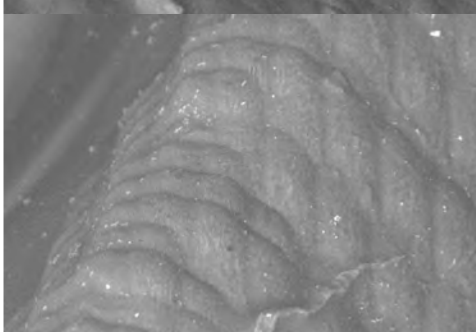
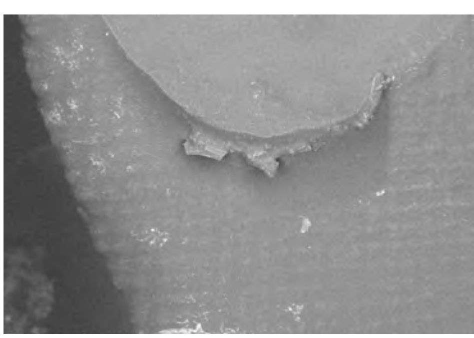
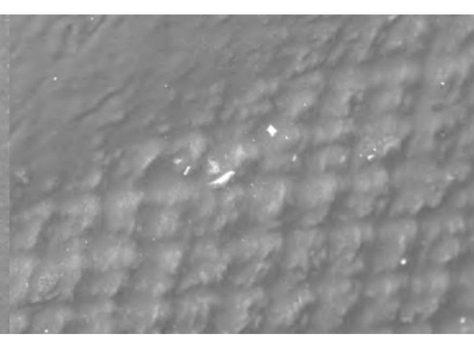
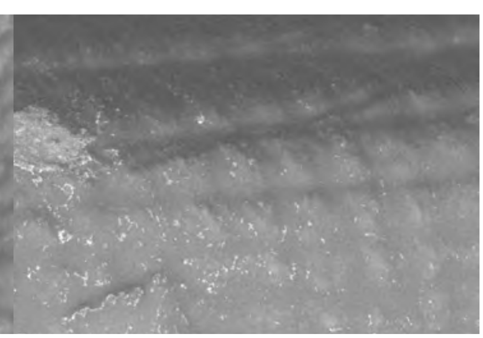






These SEMs were from a sample that had been washed using the food oil solution. The ridges in these images were observed to be less pronounced and intense than the IPA sample, however still plainly visible.

The images featured below, are SEMs taken of a model washed using the PEA wash solution. The ridges in these SEMs are fairly similar to what was observed in the SEMs of the food oil. Less pronounced ridges compared to the IPA model. However, there is still visible texture on the surface of the model.



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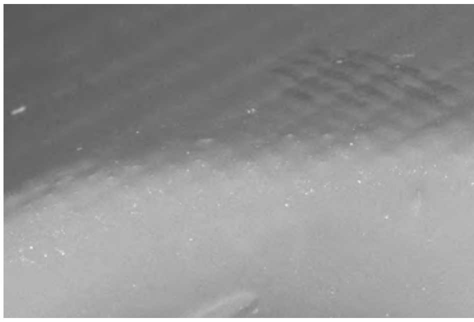

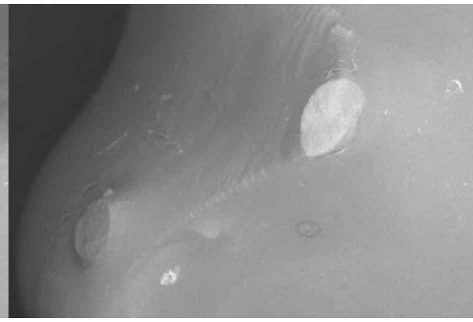

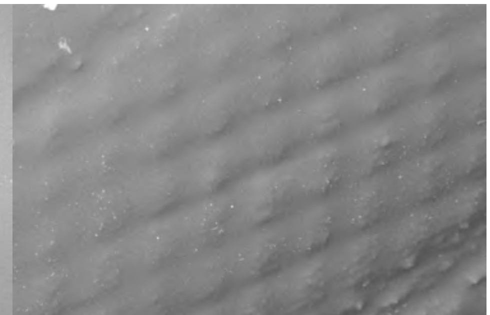

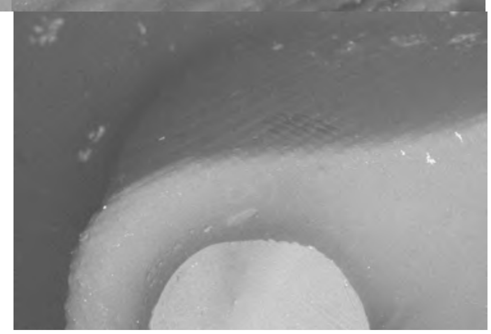

The final SEM images were taken of the water-based detergent solution. The observations from these images tell us that this wash was quite gentle. Only minimal texture is shown in these images compared to the ones taken of the IPA, food oil, and PEA solutions. The surface of the model is smooth, with minimal texture visible.

Analysis of the Study

When relating to our analogy about the stucco wall with a mortar and cinder block wall, the results of our control sample washed without any wash solution but air and hand wiping, shows how not enough of the dirt was removed from the model, but the model does remain intact. However, not washing models is not a practical process.

The results of the IPA solution, as one of the aggressive washes, shows with both the data and SEM images how aggressive it is as a wash solution. Based on the analogy, not only was the dirt removed, but also stucco, some mortar and occasionally a cinder block or two.

Reviewing the results of the oil wash showed that it was much like our control sample. The oil wash somewhat cleaned the test specimens, however it didn’t completely clean the poly polymer. Back to the analogy, the stucco wall still had some dirt on it even if it was still intact.

The water-based detergent solution showed good results. The test specimens had good physical properties, much better than the harsher IPA solution and close to the control specimens. On top of good physical results, the water-based detergent washed specimens were clean after going through the wash. This system is gentle enough when removing the dirt from the stucco and leaves behind mostly intact stucco with the blocks and mortar underneath.

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Analysis of the Monomer Wash

In analysis of the three different monomer washes, PEA, HDDA, and TMPTA, our results show that our original theory about how there is potential for some of the wash solutions to increase the physical properties of materials, is valid. By changing the properties of the wash solutions used in the post printing process, we are able to change the surface of an uncured model. Essentially, imbuing the stucco with a different monomer can give different results.

Our results also show that PEA is more impactful than both HDDA and TMPTA. There are a couple of possible explanations. One, the PEA is aromatic and maybe more able to embed itself in the model. Two, the TMPTA is higher in viscosity then PEA and HDDA and the HDDA is most like the formula we are using, so it's possible the HDDA and PEA penetrated and embedded but the PEA is the only real effect due to being different then the formula. More studies are underway in this area.

Analysis of Industrial Viability

When looking at the industrial viability of the different solutions we used in this study, not all the different washes used would be able to become commercially viable. We did an analysis of how viable each wash would be commercially, along with how clean the test specimens were for testing, and how well detailed models would be cleaned using the solutions.

We used a rating system in recording the data below, with a “1” signifying the least viable, a “3” being moderately viable, and “9” meaning highly viable.

Wash Solutions	Process Commercially Viable (1,3,9)	Test Specimens Clean (1,3,9)	Detailed Models Clean (1, 3, 9)
Compressed Air & Wipe (Control)	1	9	3
IPA	9	9	9
Commercial Wash	9	9	9
Food Oil	9	9	3

Water-Based Detergent	9	9	9
Water-Based Ultrasonic	9	9	9
1173	3	3	3
PEA	3	9	3
HDDA	3	9	3
TMPTA	3	3	1

From our analysis, the least commercially viable would be using compressed air and hand wiping the model. This process doesn't remove all uncured resin, which would be potentially harmful to users and might impact quality of detailed models if unable to completely remove excess resin. However, for control test specimens, it is a good method for comparison.

Across the board, IPA does a good job for cleaning test specimens and detailed models, and is already a commercially viable solution for washing.

The commercial wash, food oil, and the water-based detergent both with and without using the ultrasonic, as solutions all were highly viable in each category, with only the food oil scoring moderately in cleaning detailed models.

The UV raw materials are an interesting approach. The low viscosity monomers cleaned ok, but these would raise safety concerns with eye and skin irritation. Also, disposal could be a challenge creating a large amount of industrial waste. This interesting approach is on the ability to surface modify the part. The bars are only 2mm so the surface is a large percentage of the overall mass. Will this surface treatment have enough impact on larger parts? What kinds of modifications can be done with the surface treatment? We will be following up on these and other questions in future studies.

Special Thanks

We would like to extend a special thanks to Tactile Material Solutions for the SEMs they provided for this study.

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TACTILE MATERIALS SOLUTIONS

Works Cited

ELEGOO Official. 2022. *Types of 3d Printers: SLA vs DLP vs LCD vs FDM*. [online] Available at: <https://www.elegoo.com/blogs/learn/types-of-3d-printers> [Accessed 24 March 2022].