APPLICATION NOTE

Chemistry Advancements for Automated Resin Removal: PLM-403-SUB

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CONTENTS

I. SUMMARY

This paper examines PostProcess Technologies' newly released resin removal chemistry, PLM-403-SUB (referred to as 403 from here on), as part of its comprehensive Automated Resin Removal Solution. It will review the effectiveness across a range of materials, safe operations, and process optimizations as compared to traditional alternatives isopropyl alcohol (IPA) and tripropylene glycol monomethyl ether (TPM).

The goal of the new 403 chemistry is to, in concert with the software and hardware components of the resin removal solution, ease the multiple burdens that typically arise when removing uncured resin following various Vat Photopolymerization processes. With this solution, users can dramatically reduce cycle times, process steps, and the typical operational risk factors that come with legacy resin removing solvents.

II. TESTING & VALIDATION

The PostProcess 403 chemistry is a new formulation that improves upon the performance of the previously released PLM-402-SUB (referred to as 402 from here on). The primary benefits of the solution are the same as those identified previously with the 402 detergent, including industry-leading cycle times and reduction of required process steps. Unlike previous methods which may have required both TPM and dirty IPA baths followed by various rinse steps, cycle times with 403 in PostProcess's patented hardware technology are frequently less than 10 minutes. Additionally, the process takes place within just one piece of equipment. This effectively cuts down on both attended and unattended process time. The user can simply load and unload from the system, and perform a quick rinse before moving to the post-cure step. This is compared to cycle times of 20+ minutes in multiple TPM/IPA baths which involve operator intervention throughout the cycle to move from one step to the next.

The 403 chemistry has been successfully used to remove uncured resin from the model materials listed in Table 1 (as of publication date noted in the footer). Ongoing validation tests

for additional resins are being conducted with the intention of covering the vast majority of resins available, and will be updated periodically in this document available on the PostProcess website.

TABLE 1 - RESINS SUCCESSFULLY REMOVED BY 403	
3D Systems SLA	Accura ClearVue, Accura Xtreme White, Accura 60 Clear, Accura 5530, Accura Xtreme Grey, Accura 48 HTR, and Visijet SL Clear
3D Systems Figure 4	HI TEMP 300-AMB PRO-BLK 10 TOUGH-BLK 20
Carbon 3D	CE 221 EPX 82 DPR 10
Henkel	3955 High Temp FST
Prodways	PLASTICure Model 300
SOMOS	White Next, XL Black

One of the most important factors for users, after ability to clean parts, is the detergent life, or longevity. This typically determines the frequency of labor-intensive equipment cleaning efforts. Longevity for resin removal detergent is typically defined as the amount by weight that the chemical solution can hold and still effectively remove resin. As most users look to remove resin as quickly as possible, the longevity of various solvents are compared while holding 10 minute cycle times. From the data depicted in Figure 1 and in Table 2, 403 has significantly better longevity (capacity by weight of resin in solution at 10 minutes) than all other typical solvents (i.e., IPA, DPM, TPM) used to remove uncured resin from printed parts. Likewise, 403 has 6% improved longevity versus PostProcess's previously released industry-leading chemistry, 402.

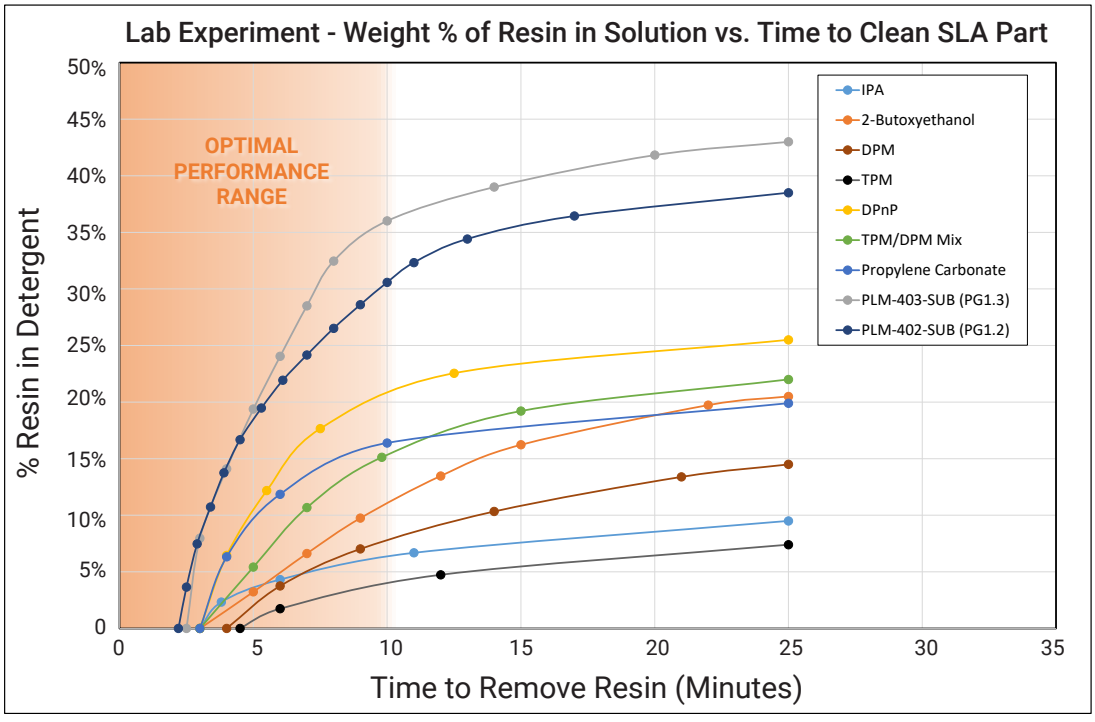

Figure 1: Saturation of various chemical solvents for resin removal

TABLE 2 - Weight % Resin Removal Saturation While Maintaining 10 Minute Cycle	
Cleaning Solution	**% Resin in Solution by Weight**
TPM	4.00%
IPA	6.50%
DPM	7.50%
EB (2-Butoxyethanol)	12.00%
Propylene Carbonate	16.50%
DPnP	21.50%
PLM-402-SUB (PG1.2)	30.50%
PLM-403-SUB (PG1.3)	36.50%

The saturation of the 403 chemistry with removed resin can be measured using the hydrometer (see Figure 2 and Table 3 below), which is provided with every PostProcess Automated Resin Removal Solution.

FIGURE 2: Hydrometer

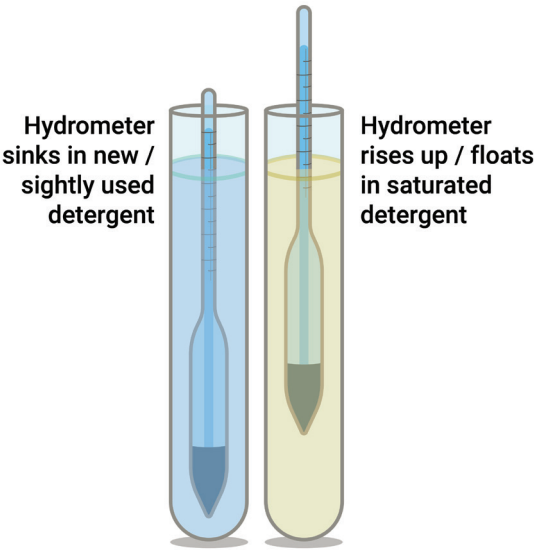

TABLE 3 - Saturation Levels		
Resin by Weight in solution +/-2%	**Specific Gravity 403**	**% Saturation +/-2%**
0% Resin	0.890 g / mL	0.00%
10% Resin	0.905 g / mL	25.00%
20% Resin	0.924 g / mL	50.00%
30% Resin	0.943 g / mL	75.00%
40% Resin	0.962 g / mL	92.00%
42% Resin	0.980 g / mL	100.00%

WASTE CONSIDERATIONS

Due to its increased longevity, 403 offers a significant reduction in waste generation compared to other solvents. Subsequently, the lower frequency of chemistry changeouts reduces the required maintenance labor hours in the process.

The detergents used in the resin removal process will also contain the uncured resins in solution. These resins do not become less hazardous after removal, and are all considered hazardous materials in the chemicals used to remove them. The frequency and volume of waste disposal will be a factor in the total cost to dispose of the exhausted chemicals.

MECHANICAL PROPERTIES OF SLA PARTS AFTER RESIN REMOVAL

An initial set of tensile testing has been conducted to show mechanical property integrity compared to existing solvent cleaning methods. Accura ClearVue, Accura 60, and Accura Extreme Grey were all subjected to a resin removal process using 403 and IPA, along with a control group in which the uncured resin was carefully wiped off. Following these procedures, all tensile bars underwent a curing step according to manufacturer recommendations. Key properties have been compared below.

TABLE 4 - Mechanical Properties Effects

Model Material	Solvent	Tensile Strength @ Yield (MPa)	Tensile Strength @ Break (MPa)	Elongation @ Break (%)
Accura ClearVue	403	50.2	37.7	8.78
	IPA	51.4	39.9	6.97
	None	50.9	48.5	4.38
Accura 60	403	65.2	60.6	5.27
	IPA	66.2	60.3	5.42
	None	68.2	64.5	4.43
Accura Extreme Grey	403	40	37.9	17
	IPA	39.7	37.3	14.4
	None	42.1	39.1	10.2

As shown above, tensile strength at yield is within 5% of the control group for both 403 and IPA processed parts. Values for tensile at break are also nearly identical for 403 and IPA. While elongation varies slightly, it still lies within the manufacturer specifications (3-15% for ClearVue, 5-13% for 60, and 14-22% for Extreme Grey) for both 403 and IPA. In summary, when moving from an IPA cleaning process to the PostProcess solution utilizing the 403 chemistry, mechanical properties will not be significantly affected.

SAFETY CONSIDERATIONS

Inhalation and combustion risks during the resin removal process are a widespread concern for all resin removal users. Additionally, regulations can significantly limit the amount of combustible resin removal liquids that can be stored on site in a facility. The 403 chemistry has improved safety and environmental characteristics that address these issues, as seen in Table 5 below.

TABLE 5 - FLAMMABILITY CHARACTERISTICS - FLASHPOINT and LEL

	OSHA Flammable Liquid Class	Vapor Pressure @ 20°C (mm Hg)	Flash Point (Closed Cup) ASTM D93	Boiling Point ASTM D2879	LEL (vol.% in air) UEL (vol.% in air) APL 024	Autoignition ASTM E659
PLM-403-SUB	Non Flammable Liquid	0.2	220˚F 104.4˚C	407˚F 208.3˚C	1.80% 11.40%	500°F 260˚C
PLM-402-SUB	Flammable Liquid, Category 3	0.7	131˚F 55˚C	347˚F 175˚C	5.00% 29.00%	464˚F 240˚C
IPA	Flammable Liquid, Category 2	33.1	53˚F 11.7˚C	180˚F 82.2˚C	2.00% 12.70%	750˚F 398.9˚C

The high flash point of 403 (220°F, 104.4°C) means far less vapor will end up in the air near the machine, especially when compared to a volatile solvent like IPA. With typical process temperatures ranging from ambient temperatures (75 - 85°F, 23.9 - 29.4°C) up to 120 - 130°F (48.9 - 54.4°C) for the PostProcess Resin Removal Solution, there is still a very large gap before reaching the ¼ LEL temperature of 163°F (72.8°C).

STORAGE

For higher volume resin removal, where large volumes of chemical are required to remove the resin, 403 addresses storage limitation issues with flammable liquids.

The amount of flammable/combustible resin removal liquids that can be kept on-site is limited by various regulations. Liquids with a flashpoint below 200°F (93.3°C) are usually limited to 120 gallons (454 L). Conversely, liquids with a flashpoint greater than 200°F (93.3°C) can usually be stored in quantities up to 13,200 gallons (5000 dekaliters). Because 403 has a flashpoint of 220°F (104.4°C), it can operate and be stored in much larger quantities than other resin removal chemistries, as summarized in Table 6. Table 6 is specific to the United States. Please refer to your local regulations when outside of the US.

TABLE 6 - Storage

SLA RESIN REMOVAL CHEMISTRY	29 CFR 1910 OSHA Category MAQ -Maximum Quantity		NFPA-497 and NFPA-30 Class MAQ (Maximum Allowable Quantity) Per Control Area	
ACETONE	Category 2	120 gal (2) 454 L	Flammable Liquid Class IB	120 gal (3)(4) 454 L
IPA	Category 2	120 gal (2) 454 L	Flammable Liquid Class IB	120 gal (3)(4) 454 L
PLM-402-SUB	Category 3	120 gal (2) 454 L	Combustible Liquid Class II	120 gal (3)(4) 454 L
PLM-403-SUB	Non-Flammable	Not Limited	Combustible Liquid Class IIIB	13,200 gal (3)(4) 5000 dal

1. Maximum quantity of liquid located outside of a storage room or storage cabinet in a building or fire area
2. Up to 660 gallons (2498 L) is allowed in a single portable tank
3. Amount can be increased by 100% (doubled) with a flammability safety cabinet
4. Amount can be increased by 100% (doubled) with the installation of automatic sprinkler systems

ENVIRONMENTAL & SUSTAINABILITY

The new 403 chemistry is an environmentally-friendly alternative. It has a much lower vapor pressure than other solvents, and a 220°F (104.4°C) flashpoint that makes it much safer to use. In 402, D-limonene was used to help with resin removal. Although generally safe to use, it has been replaced in 403 with a more environmentally-friendly option that reduces risks following the waste removal step.

Once saturated with resin, 403 can be recovered for reuse by distillation. Under a typical vacuum distillation, up to 90%+ of 403 by saturation weight (amount of resin in solution) can be recovered for reuse of the detergent. This makes 403 a particularly sustainable option.

With **reduced waste generation, lower vapor pressure, and higher flashpoint** than any other option on the market, the 403 chemistry is the **most sustainability-friendly** solution available.

III. CONCLUSION

PostProcess Technologies' new 403 chemistry as a part of its comprehensive Automated Resin Removal Solution is a definitive improvement over current mechanical and chemical technologies used to remove resin in Vat Photopolymerization 3D post-printing. Through a combination of breakthrough chemistry, patented hardware technology, and proprietary soft-ware, uncured resin removal can be accomplished in 10 minutes or less for simultaneous trays of printed parts. This newest formulation offers a much higher resin capacity, yielding a longer useful life compared to other chemical methods. With intuitive software controls and process monitoring, the speed and ease of use of the solution results in increased consisten-cy at levels required for production volumes. Ultimately, the attended operator time is greatly reduced and the 403 chemistry is inherently safer to use and store.