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WHITE PAPER
SAF

Optimizing SAF PP for Watertight Applications:

Pressure Testing, Sealing Surfaces & Hole Filter Design

Introduction

Polypropylene is a versatile and widely utilized material, lending itself to a multitude of industries, from packaging to automotive and sporting goods. Polypropylene exhibits excellent resistance to the absorption of gases and liquids. This coupled with its exceptional chemical resistance makes it an ideal material choice for chemical storage tanks, vessels, piping systems, manifolds and laboratory equipment, where exposure to corrosive substances is common.

SAF PP, processed on the Stratasys H350 takes full advantage of the material properties provided by Polypropylene. The powder-based material is consolidated using HAF (a high absorption fluid) and infrared radiation providing layer to layer fusion, which results in parts with isotropic strength and fluid tightness. Parts also exhibit great durability and impact resistance, which can absorb movement in assemblies without losing their mechanical integrity.

Water Tightness Testing

In order to test the material water tightness of the printed material a simple cylinder (Figure 1) was created, with a ½" BSP printed thread to allow connection to a water pressure testing hand pump. The part was designed with openings at both ends to aid with powder removal.

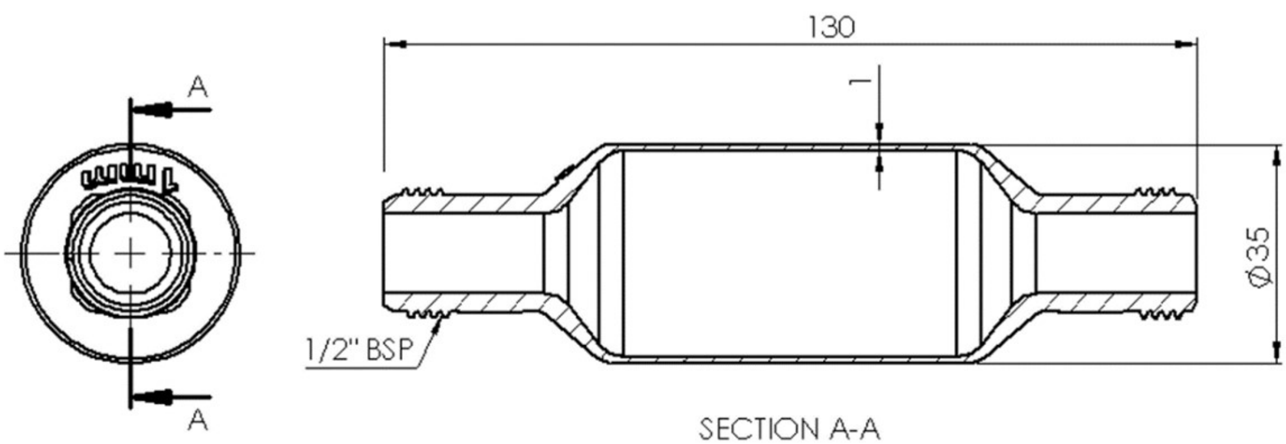

Figure 1: Cylinder Test Part

25 Test cylinders were printed (with their lengths along the Z axis) in a single build using standard printing parameters. After printing, parts followed a standard depowdering process, involving a 24 hour cool down, manual break out and a 15 minute cycle in a Dyemansion Powershot C. Further manual depowdering was undertaken in a Guyson shot blasting cabinet to remove the final powder residue.

For pressure testing, an end cap was screwed onto one end and the cylinders were prefilled with water before being attached to the pump hose with a spanner. They were then lowered into a 12mm thick Polycarbonate box (Figure 2) and pressurized with water.

Figure 2: Cylinder being lowered into test chamber

The theoretical bursting pressure of the cylinders is given by Barlow's Formula, Equation 1:

$$P = \frac{2St}{D}$$

Equation 1
P = Internal pressure,
S = Material Strength (UTS),
t = Wall thickness, D = Outside diameter.

Given a material strength of 26MPa and the dimensions above this gives:

$$P = \frac{2 \times 26Mpa \times 1mm}{3.5mm}$$

Therefore:

$$P = 1.486MPa \text{ (14.9 bar)}$$

The maximum theoretical pressure the cylinders can withstand is 1.486MPa (14.9 bar, 215.5 Psi). All 25 cylinders were pressurized to failure and the maximum pressure was recorded. The results are plotted below (Figure 3):

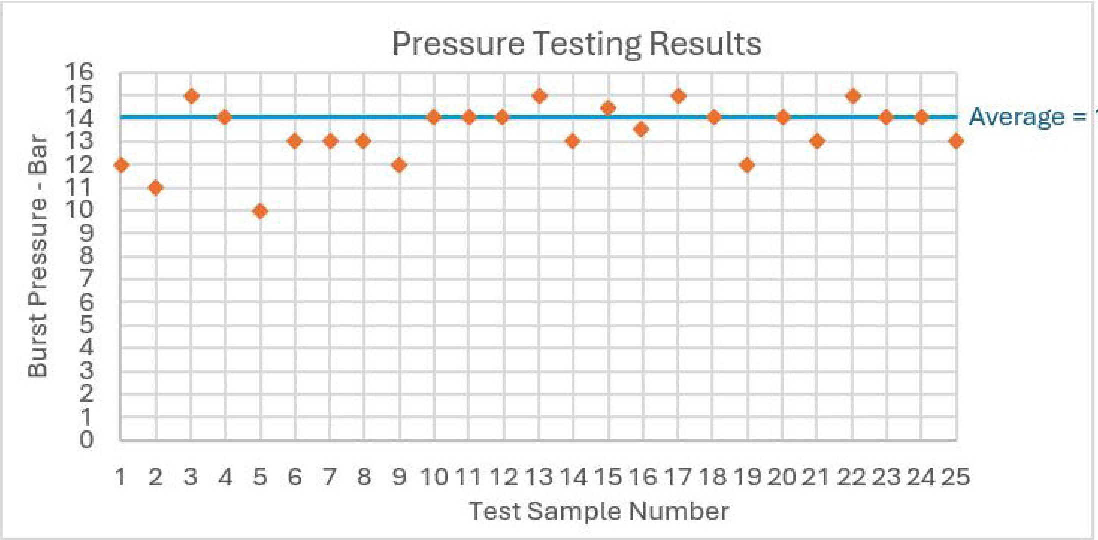

Figure 3: Pressure Testing Results

The average maximum pressure observed was 14.1 bar, with a minimum of 10 bar and maximum of 15 bar, very close to the theoretical maximum. This demonstrates excellent material strength and consistency. During testing it was observed that the parts all fractured in a similar manner, which wasn't across layer lines (a common failure mode in AM). Burst pressure was found to be sensitive to the rate of pressure increase. The manual nature of the test likely contributed to some of the lower values and variation in results.

Example Part: Pump Filter

The pump filter below (Figure 4) is an example application for SAF PP. The part has printed, functional threads, a barbed outlet for hose attachment and a mounting feature. The three-part assembly comes together, along with a tapered silicone seal, to create a component that is used to filter solid contaminants from a fluid prior to exposing it to a pump.

Figure 4: Pump Filter Example Part

Utilizing SAF technology on the H350, 25 complete assemblies can be manufactured (see Figure 5) and be ready for use within 35 hours (~11 hours printing, and 24 hours cooldown).

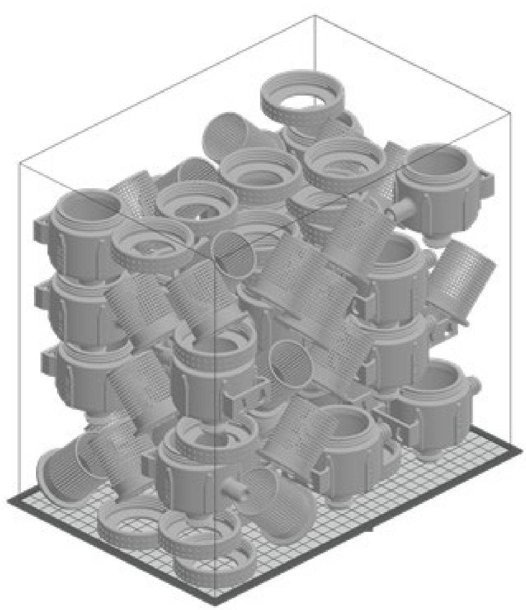

Figure 5: Full nest of pump filters

Pump Filter Leak Testing

In preparation for testing, pump filters were built with a blocked outlet and the same ½" male thread as the cylinders. They were then filled with water before being slowly pressurized. Upon application of any pressure the filter leaked where the lid meets the body. This highlighted an issue between the sealing surfaces of the mating parts.

Sealing Surfaces

The effectiveness of a sealing surface is determined by how much deviation is inherent in the components. Deformation can be due to manufacturing tolerances (such as warp), load-based distortions, dents, thermal expansion discrepancies or surface roughness. The intent of a gasket is to deflect into these deviations and create a consistent seal line. An equal and sufficient load needs to be applied to the sealing surface in order to deflect the seal around the entire seal line. When comparing the pump filter to the simple cylinder part, there is an increased sealing surface area which reduces the amount of pressure being applied (as pressure = force ÷ area). This, in addition to the fact the pump filter is hand-tightened rather than with a spanner, reduces the deflection of the gasket and its ability to accommodate the deviations.

Finishing Methods

To reduce the amount of deviation the gasket has to account for, additional post processes were applied to improve the surface finish of the parts. Three different finishes were applied (see Figure 6) to the parts and compared with the raw finish. These were **shot peened** (in-house in the DyeMansion PowerShot S), **tumbled** in ceramic media (at ActOn Finishing Ltd) and **vapour smoothed** (via the DyeMansion OnDemand service using the Powerfuse S). Three measurements were taken from the same areas of all three parts using a profilometer.

The three finishes provided a good range of surface finishes to test, with vapour smoothing being the most effective, which improved the raw surface finish by 6x, down to an Ra of 1.8μm.

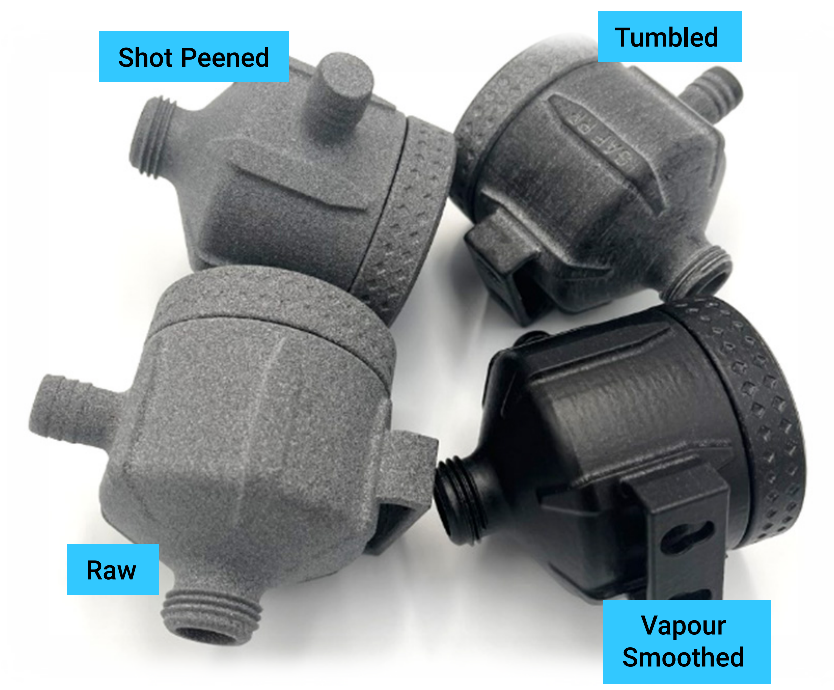

Figure 6: Post-process finishing

Finished Pump Filter Leak Testing

The same water tightness testing was conducted on the finished parts. They were prefilled with water before very slowly increasing the pressure until water leakage was observed. The pressure at which this occurred was recorded and the results are plotted below, along with the corresponding leakage pressure (Figure 7).

The finished parts all performed much better than the raw part, having no visible signs of leakage at atmospheric pressure. The test demonstrated a relationship between the surface roughness and the pressure at which there was an onset of leakage. As the internal pressure inside the filter increased this counteracted the clamping force achieved by the thread pushing down on the gasket, reducing the net clamping force. The smoother the surface finish, the lower the clamping force required to deflect the gasket sufficiently.

Further improvements could be made by:

- Further reducing the surface roughness
- Reducing the contact area of the sealing surfaces
- Using a softer gasket
- Increasing the clamping force

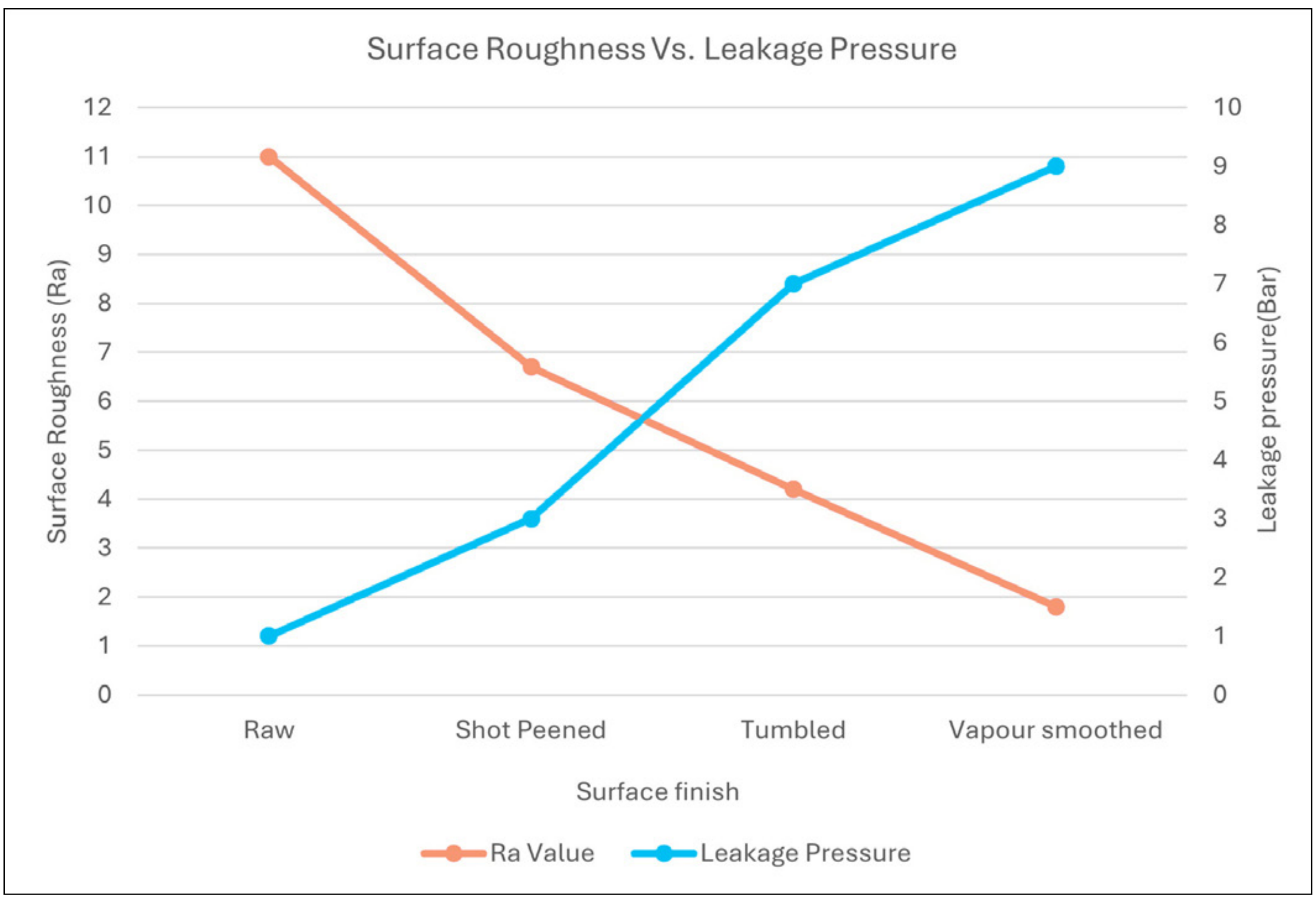

Figure 7: Surface Roughness vs. Leakage Pressure

Filter Hole Sizes

SAF PP allows fine features to be printed, support free and with excellent depowderability. This provides a great deal of freedom for designers when considering filter design. To test the limits of minimum printable hole size a number of plates were printed (Figure 8). These plates had varying hole sizes (2mm, 1.5mm, 1mm, 0.75mm & 0.3mm) and shapes (triangles, squares, circles). A variety of plate thicknesses (6mm, 3mm, 1.5mm, 0.75mm & 0.5mm) and print orientations (flat and on edge) were tested. The parts were processed as standard with a 15 minute cycle in the Dyemansion Powershot C following initial powder removal.

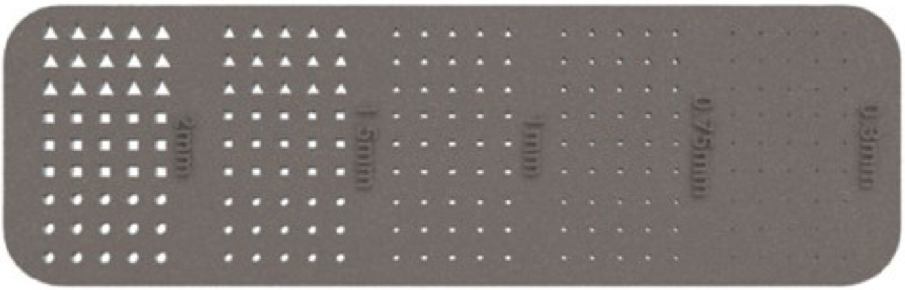

Figure 8: Hole size test part

The tables below (Figure 9 and Figure 10) show the results of the test. Holes marked as 'Translucent' can be seen when held up to light, but aren't effective through holes. It was found that hole shape didn't have any influence on the ability to remove powder, so the results shown apply to all shapes tested.

The holes printed in plates which were stood on edge in the build depowdered better than those printed flat in XY (a finding which is in keeping with recommendations provided in the SAF Design Guide). Holes down to 0.75mm width can successfully be printed, although some additional depowdering would be necessary for depths greater than 0.5mm. When printing holes flat in the XY plane the minimum hole size is 1.5mm width (with some additional powder removal).

Key	
0	No hole
1	Translucent
2	Acceptable (may need additional manual removal)
3	Fully clear

On Edge

Thickness (mm)	Hole Size (mm) 0.3	0.75	1	1.5	2
0.5	1	3	3	3	3
0.75	1	2	3	3	3
1.5	1	2	3	3	3
3	0	2	3	3	3
6	0	2	2	3	3

Figure 9: Depowdering results - On Edge

Flat

Thickness (mm)	Hole Size (mm) 0.3	0.75	1	1.5	2
0.5	1	1	2	2	3
0.75	1	1	1	2	3
1.5	1	1	1	2	3
3	1	1	1	2	3
6	0	1	1	2	3

Figure 10: Depowdering results - Flat

Summary

SAF PP combines the material property benefits of Polypropylene (chemical resistance, impact resistance, low density) with the advantages of powder bed additive manufacturing (quick time to part, complex geometries, part-assembly consolidation). Parts have also proven to have great functionality, being weldable, machinable and, as demonstrated in this report, watertight. With a wall thickness of just 1mm, parts can hold liquids up to high pressures, up to mechanical failure, regardless of print orientation.

It was found that, for surfaces that interact with a gasket (at the interface between components), surface finish is a critical factor for a successful seal. Several post processes were applied to improve the surface finish, all of which improved the sealing capability.

The last section investigated minimum printable hole sizes at different wall thicknesses. Holes printed with their profiles laying flat in the build depowdered less effectively than in the perpendicular orientation. Holes under 1mm width were successfully built and depowdered without manual intervention.

References

https://www.simplexitypd.com/blog/successful-sealing-strategies-how-to-design-a-sealed-system/#:~:text=Key%20Concept%201%3A%20Envision%20a%20Line&text=Usually%2C%20several%20rigid%20components%20come,the%20seal%20won't%20seal.

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