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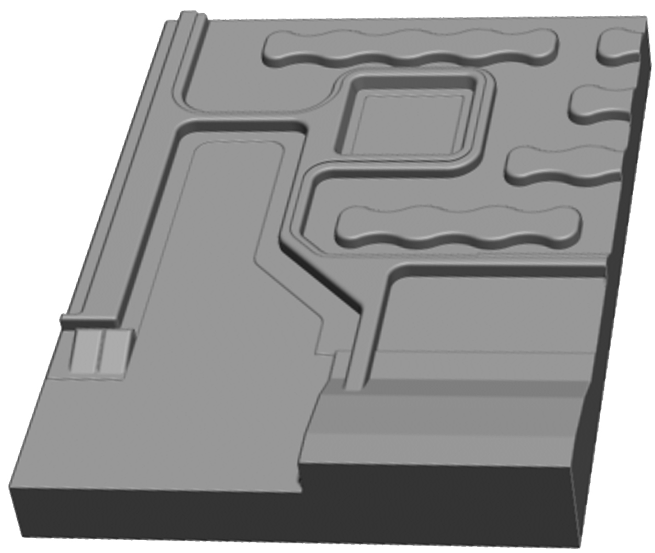
Massivit Thermoforming Tool "Proof of Concept"



MASSIVit 3D

3DComposites

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Massivit Thermoforming Tool “Proof of Concept”

ACS Hybrid Inc., Massivit 3D and 3D Composites came together to collaborate on developing and testing a additive manufactured thermoforming tool.

Each company provided their expertise and resources with the intent of proving the feasibility of an additive manufactured thermoforming tooling printed on the Massivit 1800 Pro Large Format 3D printer.

- **Massivit 3D** provided their R&D Facility, (located in Israel), their engineering & technical expertise, the Massivit 1800 Pro 3D Printer and the 3D-printed tooling—print to finish.
- **3D Composites** provided their Additive Manufacturing Industry expertise, their facility located in Arlington WA, metrology equipment, thermoforming equipment and ovens along with the end use aerospace thermoforming part / application.
- **ACS Hybrid Inc.** provided the sales / service arm of this 3 team collaboration along with the project management that facilitated and coordinated the proof of concept project.

Thermoforming Tool

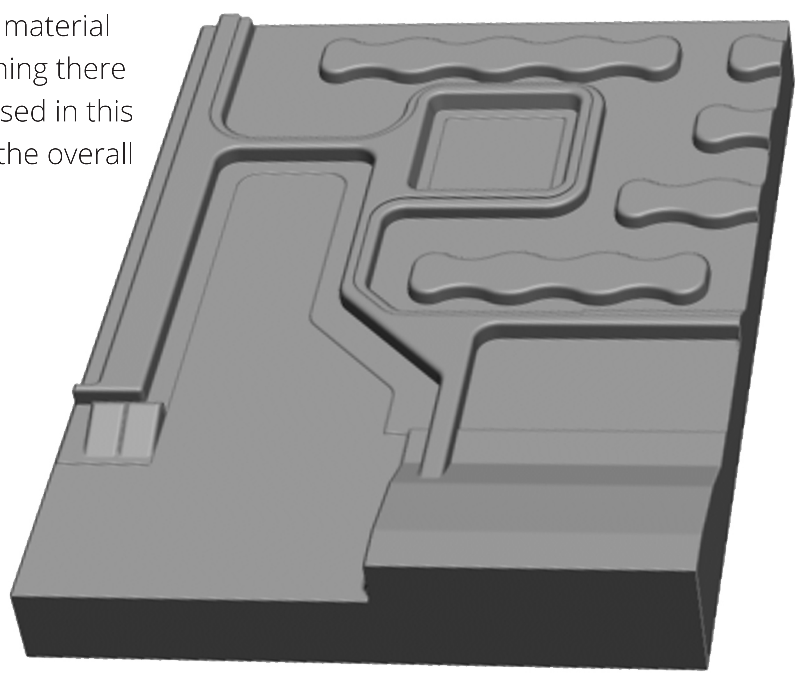
The part selected by 3D Composites was a large-scale aerospace production part requiring multiple tooling processes, bonding, and finishing applications that would have to be implemented with high precision in order to produce the final tool. For the purpose of this proof of concept we produced only a small section of the tool, *(see caption 1 & 2 - section of 3D Printed Mold and finished tool)*. Originally, using conventional subtractive methods, it would have required 12 pieces to build this tool. When printed with the Massivit 1800 Pro 3D printer, **it could be built with just two pieces.**

To minimize post 3D printing finishing time, this section was printed on the highest resolution, which took 16 hours to print and used 2.75 kg of Dimengel 90—**a Massivit 3D proprietary photo polymeric acrylic gel.**

Traditional tooling processes start with a large billet of material typically aluminum or high-density foam, then a subtractive process is used to shape the final part, creating large amounts of waste.

Additive manufacturing (3D Printing) only uses material necessary tp produce the part geometry, meaning there is much less waste. The total cost of material used in this process was $220.00 of Dimengel 90 bringing the overall cost of tool production down.

Caption #2: *Massivit provided - Finished parts and samples demonstrating different variations of the tool making processes*



Section of Printed Mold

Caption 1#:
The 3D model of the thermoforming tool section that withstands approximately 50 pulls of 0.063" Kydex (ABS) sheets without showing any major signs of deterioration

Cast Epoxy

The first step of reinforcing the 3D-printed mold for production was to drill a hole in the back side of the mold, mix a two-part epoxy resin together and pour it into the mold, (see Caption #3 -layer of epoxy inside tool). The mold was then manually rotated around in order to spread between 1/8"-3/16" layer of resin throughout the entire interior of the mold. The thin layer of epoxy gave the finished tool more heat resistance while reinforcing the tool's surface. This method was used as the material cost was considerably less compared to having the full mold cast out of epoxy. Additionally, an epoxy mold would have likely warped the 3D-printed tool due to the exothermic reaction during curing.

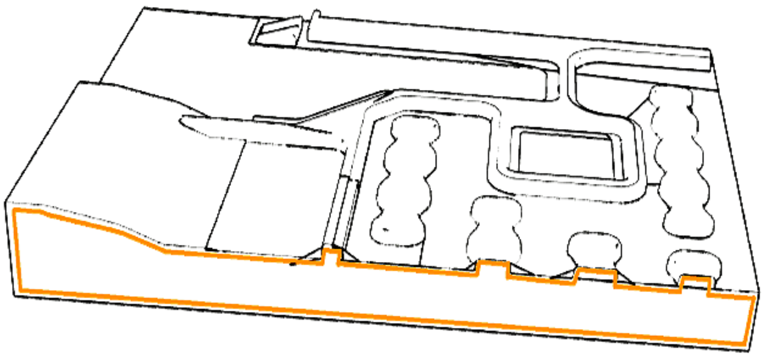
Mold Filling

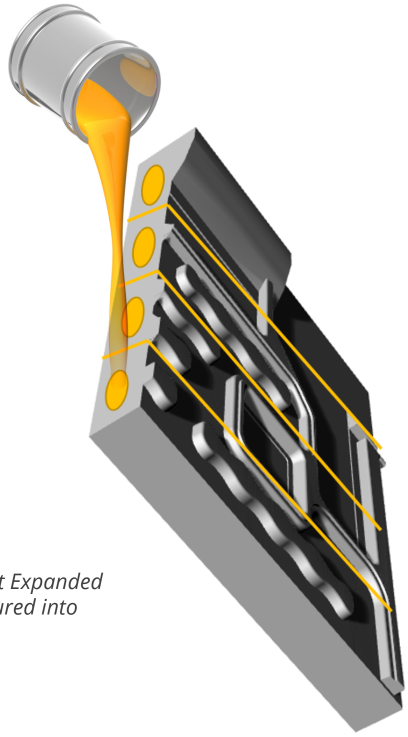
The second step, after the epoxy had fully cured, was to drill additional holes into the side of the mold. A two-part expanded polystyrene foam was poured into each section, allowing it to expand and fill the entire interior, *(see Caption #4 – Two Part Expanded Polystyrene being poured into the tool).* This gave the thermoforming tool greater rigidity and dissipated heat from the surface. Expanded polystyrene foam is relatively low cost and simple to use, adding the strength necessary for a viable production tool.

The third step, after the foam had finished curing, was to sand the surface of the tool, reducing any potential high and low points between the printed layers.

The fourth and final step was to CNC drill small holes throughout the tool's surface to allow air flow through the tool during the forming process, and finally, to mount the tool on a vacuum box.

Caption #3: *Layer of Epoxy inside tool. Illustrated Example*

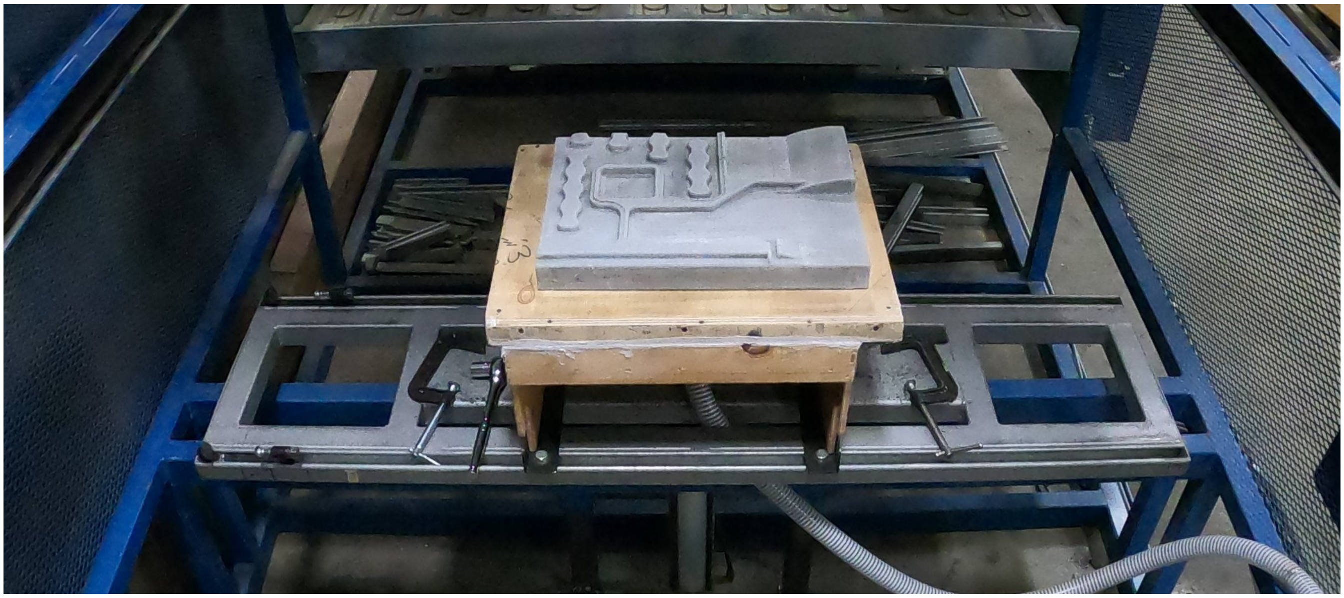




Caption #4: *Two Part Expanded Polystyrene being poured into the tool*

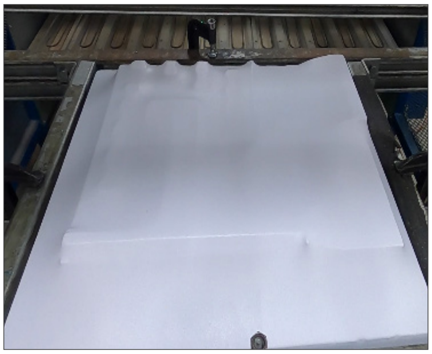
Pre-Production Inspection

Prior to starting production, the tool was visually inspected to ensure that the surface was smooth and free of defects and voids. A portable Creaform Handyscan 3D scanner was then used to scan the tool and record baseline dimensions. The baseline 3D scan would reveal any unacceptable anomalies, such as tool warpage or expansions that would void this tool's usage in any crucial aerospace or other high tolerance applications. These baseline dimensions would also be used in the final inspection of tool and the post-production inspection to prove the tool's viability. The final step for the pre-production inspection was running a test sheet to ensure that the oven heat and cycle time were sufficient to heat the plastic and produce the detailed features of the final formed part.



Production Process

The 0.063" ABS plastic sheet was heated anywhere between 85 and 120 seconds after which it was pulled out of the oven and the tool was pushed up into the sheet. A seal was formed around the vacuum box, at which time suction was then pulled on the tool. After approximately 20 to 25 seconds later the tool was lowered away from the sheet and the finished part was removed from the thermoforming machine, *(see Caption #5 - Thermoforming Process).* This process was repeated for all 45 sheets with minimal cooling periods in between parts.

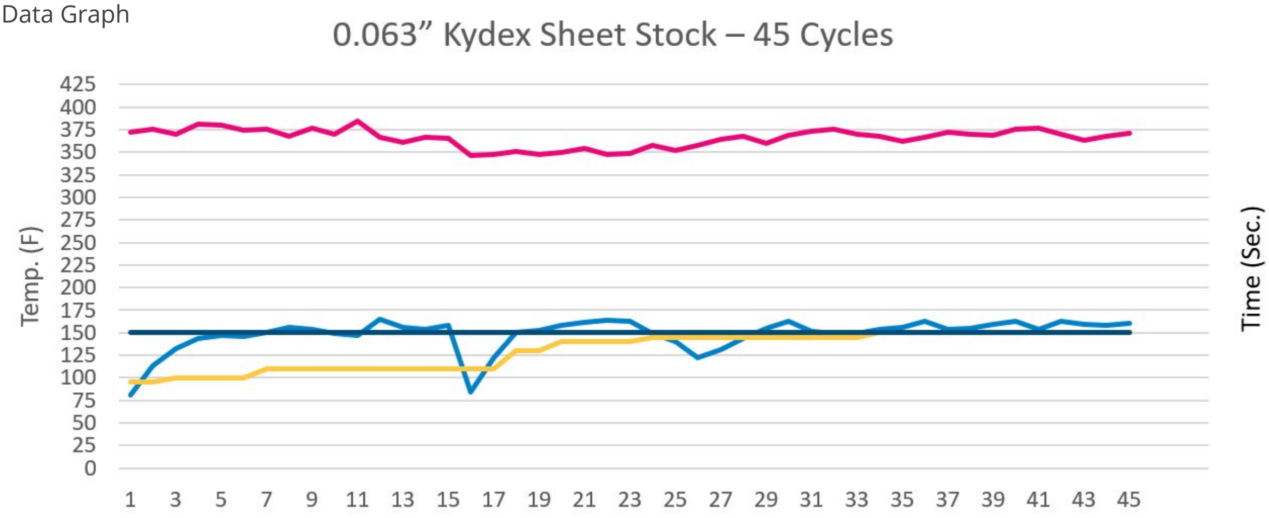


Caption #5: *Thermoforming Process*

Production Run Data

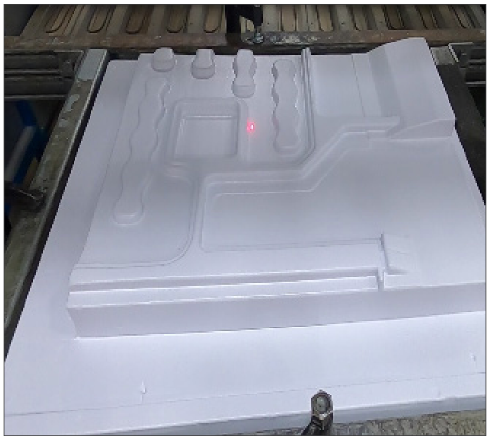
This graph (shown below) shows the production run temperature data that was recorded during the thermoforming process of the 45 sheets of 0.063" ABS. Tool temperature, sheet temperature, and cycle time (in seconds) were recorded.

Data Graph



The observed glass transition temperature (160 degrees Fahrenheit) of the Dimengel 90 was used as the baseline temperature to be avoided for any long periods of time. The tool temperature line, after the first 4 to 5 thermoformed parts, started to level off at approximately 154 Degrees Fahrenheit. This is important as the tool temperature averaged below 160 degrees Fahrenheit during the entire production period, proving its integrity.

As cycle time gradually increased due to the temperature outside decreasing, the heating period was incrementally increased to keep the sheet temperature stable. The sheet temperature was recorded in order to ensure that the cycle times were sufficient, and that the sheet temperature was stable throughout the process. The conclusion from the recorded data shows that the tool plateaued at or below the observed glass transition temperature, meaning that the materials and process used were sufficient for the production of the thermoforming tool.



Post-Production Inspection

After the production run was completed, a visual inspection of the tool was done looking for any signs of wear and/or defects on the tool surface. None were observed.

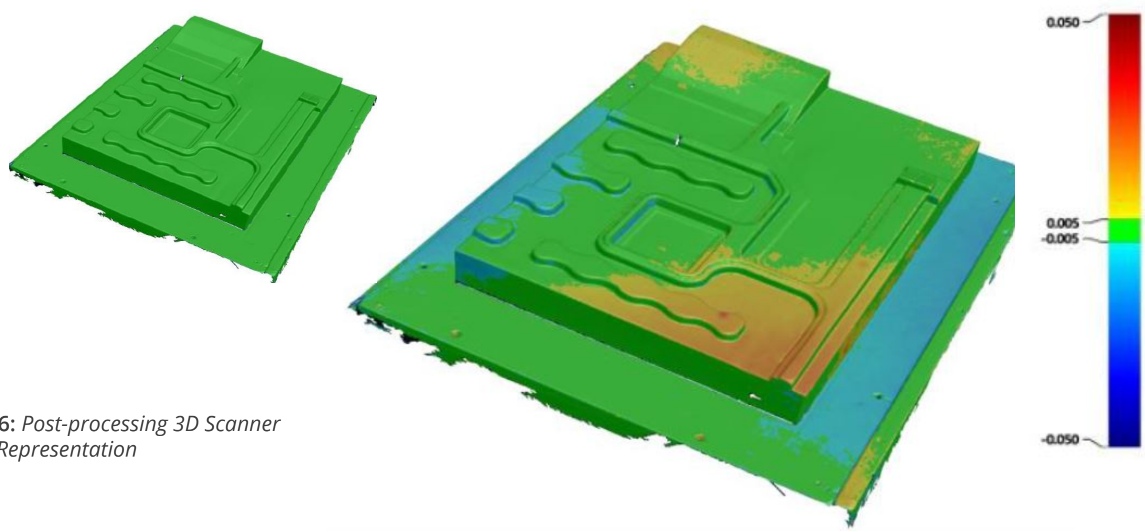
A second scan of the tool was completed using the portable Creaform Handyscan 3D scanner to compare the tools dimension after being used in the thermoforming process to the dimensional baseline results, *(see Caption #6 - Post-processing 3D Scanner Graphical Representation)*

Post-production Inspection of the tool showed that the surfaced warped a total of +0.025" on the front left and back right corners. It is calculated that heat from the thermoforming process likely caused these sections of the tool to expand.

Thermo Forming Euipment Operator Quote:

> ***"This tool is good to go. I wouldn't even put a number on how many pulls it will last."***

The data showed that the tool withstood the production run of parts with little to no signs of degradation. In the operator's own words, "This tool is good to go. I wouldn't even put a number on how many pulls it will last."



Caption #6: *Post-processing 3D Scanner Graphical Representation*

Benefits of Additive Manufactured Tooling

The key benefits of additive manufactured tooling are to reduce cost, reduce manufacturing steps, and reduce lead times.

The traditional steps used in the subtractive manufacturing methods to build this specific tool:

- CAD – Digitally designing of the tool
- CAM – Programming the subtractive toolpaths of 3 or 5 axis milling machine
- Milling – the actual loading of the material into the machine, indexing and beginning the subtractive cutting process
- Drilling holes – Lots of small holes needed to be drilled throughout the tool allowing vacuum pull down over the entire surface area of the tool
- Post processing – Finishing the tool (grinding, sanding, surface prep, etc.)

The steps used in the additive manufacturing methods used to build this mold/tool were:

- CAD – as is the case in traditional methods, CAD designing of the tool is still required.
- 3D-print tool – The 3D-printing process is generally an automated process that can take minutes, hours or days and can be run overnight and unattended.
- Post processing – Once the print was completed the part was removed, prepped, and sanded to be ready for forming

In conclusion: The steps required to produce this tool using traditional subtractive methods were reduced from 5 steps to 3 steps when using additive methods.

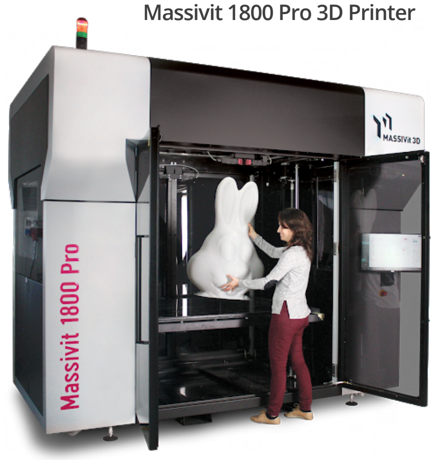
Massivit 1800 Pro Specifications

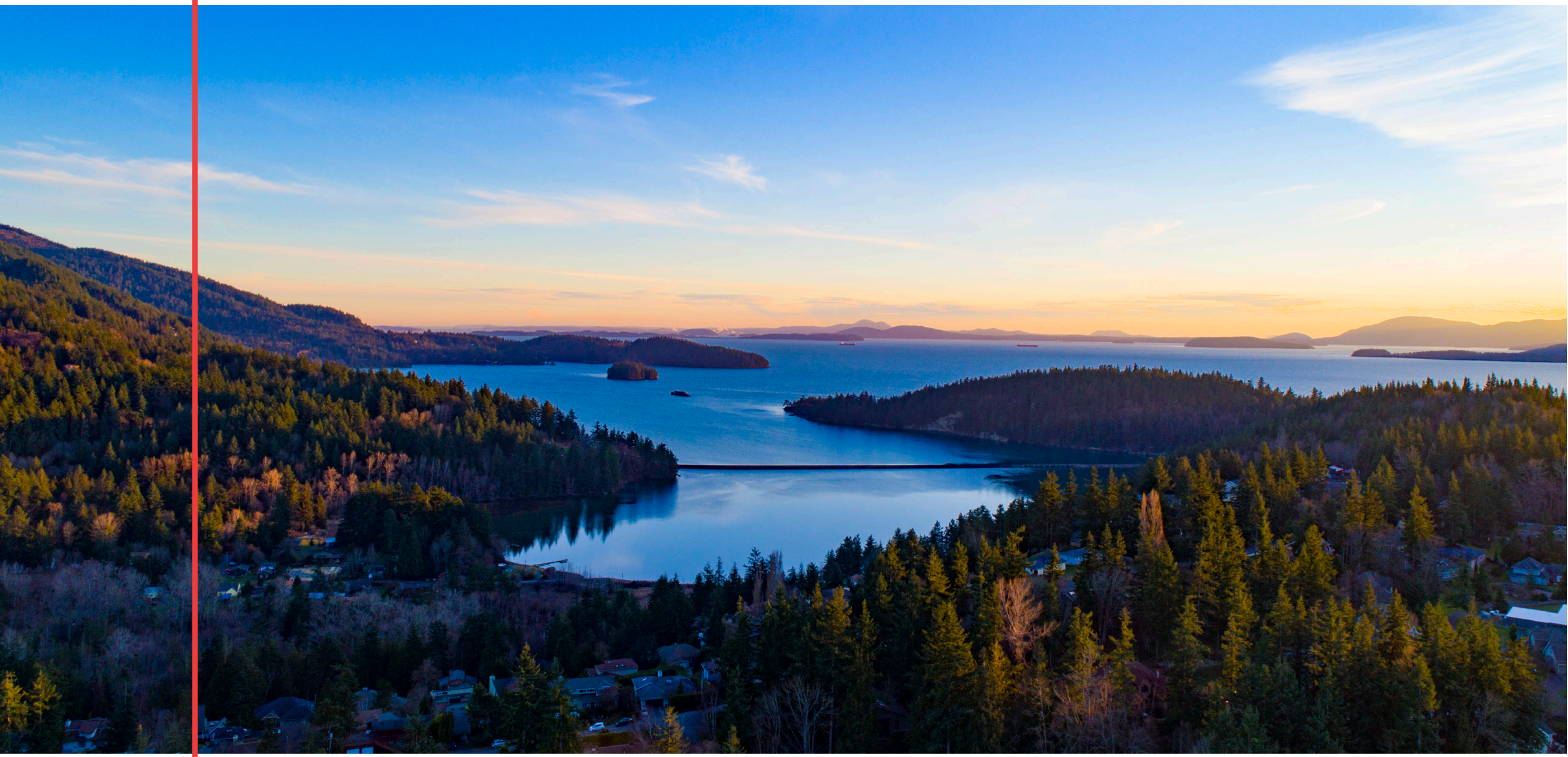
The Massivit 1800 Pro was the 3D printer used to manufacture this thermoforming tool. The Massivit 1800 Pro is a one of a kind, large-format 3D printer with a build volume of 5′ x 4′ x 6′, configurable with single or dual print heads, adjustable printing resolutions, and lights out, remote-control operation. It is the build volume and print speeds that make this platform an ideal choice for medium to large scale tooling projects such as the application presented in this proof of concept.

No. of printing heads	2
Unprecedented printing speed	300 mm/sec linear speed 35cm /13.7″ on Z axis per hour*
Printing quality	Normal/ Quality/ High Resolution/
Maximum printing volume	145cm x 111cm x 180cm or 57″ x 44″ x 70″
Supported materials	Proprietary Dimengel 100
Integrated software	Massivit Smart Pro (complimentary)
Remote control via tablet	Yes

**Printing speed for 1-meter diameter cylinder*

Massivit 1800 Pro 3D Printer





ACS Hybrid

ACS is a select team of applications & consultative sales and service specialists, with an exclusive network that spans over 40 years of accumulated and collective experience.

ACS's primary focus is to provide the vertical markets we serve with the latest technologies (both new and distributive).We offer the broadest range of Automated Workflow Solutions for Hybrid & Additive Manufacturing & Fabrication, CNC Mechanized / Automated Cutting & Finishing Systems, Material Bending Forming and Processing Solutions, 3D Printing Platforms.

WA 360.318.7534 / OR 503.585.8741
info@acshybrid
1355 Pacific Place. Unit #117
Ferndale, WA 98248