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Demonstrating High-Performance, Energy-Efficient Additive Manufacturing

Final Report

April 2016

Report Number 16-09

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Demonstrating High-Performance, Energy-Efficient Additive Manufacturing

Final Report

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Keywords

Biomimicry, Conformal Cooling

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1 Introduction

HARBEC's core philosophy is to be a sustainable manufacturing company that continuously looks for ways to reduce energy usage. HARBEC's management saw a need within their industry of plastic parts manufacturing to improve upon the current design standards of conformally cooled plastic injection mold cavities. HARBEC wanted to look at the viability of using biomimicry to see if cooling systems in nature can improve upon the current conformal cooling designs used in additively manufactured plastic injection mold cavities.

Nature offers many designs and strategies that can be applied to meet technology challenges. Abstracting these ideas can open the way to technological breakthroughs and profitable innovation that are often unattainable using conventional product design and development. Biomimicry is the abstraction and translation of the designs and strategies seen in nature. Through biomimicry, companies can discover design ideas and emulate nature by embedding sustainability into the development of new products and processes.

Biomimicry allowed HARBEC to design molds with unique geometries that mimic efficient processes in nature, particularly the dissipation of thermal energy. Many organisms have developed replicable, low-energy heat dissipation strategies to maintain constant temperatures despite temperature fluctuations in their environment. These strategies suggest ways of tailoring the heat transfer step in HARBEC's manufacturing process. The resulting molds are a new generation of manufacturing tools for HARBEC's customers that incorporate principles of biomimicry, sustainability, and conformal cooling, thereby reducing cycle times and energy input per plastic part.

Conformal cooling is a method of creating cooling lines inside a mold that follow the contours of the mold's cavity surfaces. This design allows faster cooling and more consistency among molded parts. The theory behind conformal cooling is that when a part is molded, the plastic is injected into the mold in a molten form. To obtain consistent and acceptable molded parts this molten material must be cooled (or cured) before the molded part can be ejected from the mold. If the molded part is ejected from the mold before cooling enough, the part will show excessive and non-uniform shrink after it has ejected from the mold. Conformal cooling lines increase the cooling surface area as well as provide even cooling to the entire mold.

HARBEC has demonstrated conformal cooling in cavities in the past to reduce cycle time for plastic injection molded parts. This reduced the cooling time versus a part made with conventional cooling channels. In completing a study done in 2008 for NYSERDA, HARBEC tested conformally cooled cavities grown in an M270 additive manufacturing machine from EOS, a leading manufacturer of laser-sintering systems, and showed a definite improvement on cooling time over traditionally machined cooling lines.[1]

1.1 Laser-Sintering Techniques

Conformal mold cavities can currently only be produced by two methods: additive manufacturing with direct metal laser sintering (DMLS) and vacuum brazing. Vacuum brazing involves slicing a mold core horizontally and machining the cooling line into the slice plane. The core is then fused back together through a vacuum brazing process and conventional cooling lines are cut to reach the conformal cooling lines. Vacuum brazing is typically used for simple, cylindrical cores. DMLS technology can be used to print any mold cavity, making it a more desirable method for HARBEC to pursue.

HARBEC has been producing plastic and metal selective laser sintered items since 2000, after putting a lot of resources into researching the DMLS process. The DMLS process uses a laser to melt metal powder at cross-sections to “grow” an item. When the technology was first introduced, the lasers used were only capable of melting low-melt point metals such as bronze. Blends of metal powders were used to increase the overall strength of a part, however the higher melt-point metals would simply float in the matrix of melted bronze. This incompatibility resulted in a porous structure that needed to be infiltrated with a bronze-based metal in a post-production process using a kiln. At more advanced iterations of the technology, higher power lasers became capable of fully melting metals such as steel and aluminum while maintaining the desirable material properties similar to those of their cast ingot counterparts.

Of note, this technique is effectively laser welding on a larger scale, rendering the DMLS name inaccurate. This development is relatively new, so “DMLS” will be used to describe the process until a new name becomes commonplace in industry. Selective laser melting (SLM) is the preferred name among industry professionals, but it is not yet known if it will replace DMLS in the manufacturing industry’s lexicon.

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[1] NYSERDA,2008, Direct Metal Laser-Sintering Process Capabilities, Agreement#9093, Prepared by Harbec, Inc.

When EOS introduced their DMLS machines to the American market, HARBEC took interest immediately and purchased one of the first M270 machines sold in the United States. Unfortunately, the M270 machine is not capable of building with newly developed DMLS materials, specifically aluminum and titanium. Subsequently, after researching the newest DMLS machines currently available, HARBEC decided to pursue the purchase of an EOS M290 DMLS machine to stay ahead in the additive manufacturing industry. The M290 has a more powerful 400-Watt (W) laser compared to the M270’s 200-W laser. Therefore, HARBEC prints in new materials, and reduces the building time of parts with materials currently run in the M270 such as maraging steel. According to EOS, maraging steel builds 30% faster in the M290 compared to the M270. HARBEC’s tests have proven this claim. The majority of conformally cooled mold cavities are built in maraging steel and build time drives a large portion of the cost to produce an additively manufactured part, which justified HARBEC’s decision to pursue the new machine.

2 HARBEC'S Implementation

2.1 Preparation

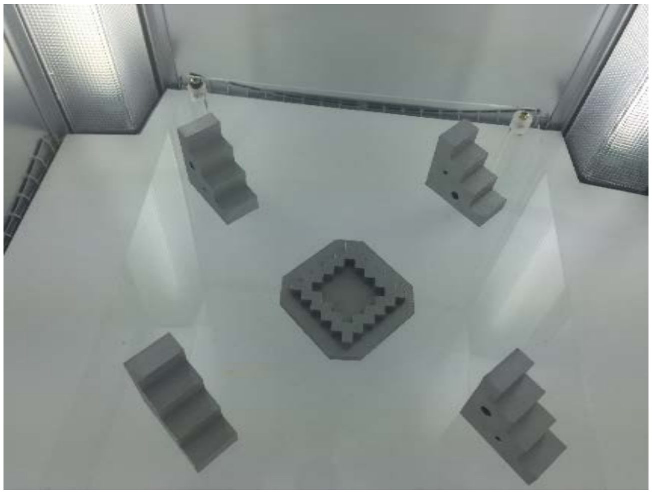
To fully utilize DMLS technology, HARBEC consulted with the vendor to determine the space and facility requirements necessary for an effective work environment for the M290 machine. Considerations included:

- Raw material storage space
- Machine accessibility for:
    - Operation
    - Trouble shooting
    - Maintenance
    - Mold-in-out handling
    - Power requirements

The DMLS equipment vendor provided training for the M290 machine, including, documentation of procedures, forms, hands-on instruction in programming, machine operation, and troubleshooting and maintenance schedules.

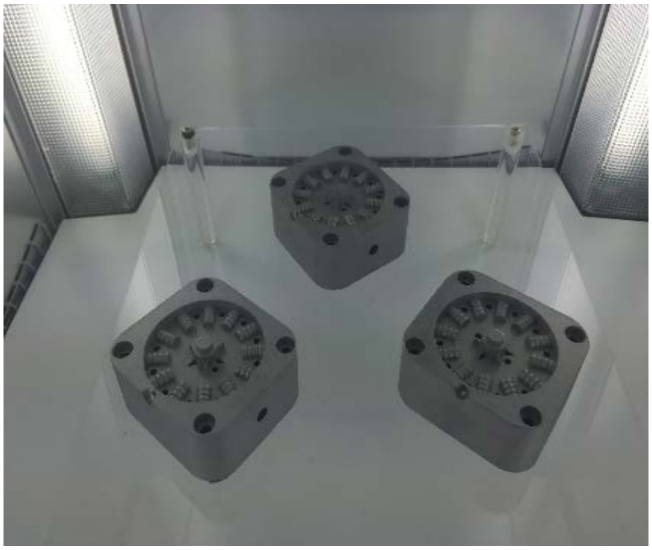
To verify the accuracy and repeatability of the M290 machine, HARBEC completed multiple scale builds. The scale builds featured geometries that allowed efficient interpretation of dimensions in all three axes. Figure 1 shows the geometry used to perform this test procedure.

Figure 1. Accuracy and Scale Test



Upon verification of machine accuracy, HARBEC commenced manufacturing the sample mold in Figure 2. Three builds were completed in the machine. The same cavity geometry was used for each build to allow for an accurate comparison. When completed, each cavity was labeled, measured, and assessed for quality.

Figure 2. **Repeatability Test**



2.2 Project Scope

The main objective for this study is to explore the benefits of using biomimicry in the design of conformally cooled plastic injection mold cavities.

Among the individuals who participated in this project, HARBEC dedicated two people to research different options for biomimicry in mold cooling. Testing was performed to compare biomimicry cooling lines with conventional machined and conventional conformal cooling lines. These case studies focused primarily on areas that could prove to be advantageous to the injection molding process. Energy usage, material usage, and total time required to build a mold cavity were recorded in each study. All collected data was compiled for comparison.

2.3 Selection of the Natural System to be Mimicked

A number of natural structures were analyzed and reviewed with subcontractors Dr. Abraham Stroock and Dr. Jiandi Wan. HARBEC designated two engineers to work with the subcontractors to select the natural system to be mimicked.

Stroock is a professor of chemical and biomolecular engineering at Cornell University.[2] His research focuses on manipulating dynamics and chemical processes on micrometer scales. Wan is an assistant professor of microsystems engineering at the Rochester Institute of Technology.[3] His research interests include microfluidics, functional materials, cellular signaling dynamics, and photo-induced charge transfer phenomenon and he has published nearly 30 peer reviewed journal papers

Each expert provided HARBEC with different natural cooling system examples as well as means for calculating their effectiveness. Systems that were reviewed include:

- Capillary action in plants.
- Convection cooling in termite mounds.
- Large, thin animal ears that act as heat sinking fins.
- Vein structures in the mammalian vascular system and leaves.

After reviewing potential positives and negatives of each system, the team decided to use internal vein structure of leaves to provide a blueprint for implementing biomimicry into mold design. They found incorporating capillary action into a mold design was not possible because the current additive manufacturing technology does not allow growth of capillary structures small enough to take advantage of the capillary action phenomenon.

They also decided that although termite mounds achieve strong convectional cooling without the input of energy, the fact that they use air as a heat transfer media and not a liquid makes it impossible to implement in a mold design. Termites strategically place vents in their mounds to force cool air to move from the bottom of the mound to the top. Air does not have a high enough heat transfer coefficient to effectively cool molds.

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[2] Stroock profile, https://www.cheme.cornell.edu/people/profile.cfm?netid=ads10

[3] Wan profile, https://www.rit.edu/kgcoe/staff/jiandi-wan

As for the animal ear model, although heat sinks are a common cooling system used in human-designed industrial applications, the system designed for mold cooling would be so far removed from the design of an animal ear that it cannot effectively be called biomimicry.

Once the vein structure of leaves was selected, HARBEC analyzed monocot and dicot leaf structures for feasibility. Monocot leaves have a straight vein structures that are common in grasses and similar grass-like plants (Figure 3). Dicot leaves contain a vein structure that is often referred to as “net-veined” (Figure 4). This type of vein structure contains large straight veins that feed smaller veins that connect the larger veins creating a net-like effect.

Figure 3. Dicot Leaf

Figure 4. Monocot Leaf

The decision was made to use the dicot leaf vein structure for two main reasons. First, the dicot structure will allow more options to increase cooling surface area when compared to monocot structures. Secondly, the dicot geometry contains large main channels with off-shoot smaller veins. When balanced properly, it was assumed that the dicot structures will provide additional turbulence for the flowing coolant, thus eliminating issues with laminar flows that could be present with monocot structures.

2.4 Mold Design with Conformal Cooling

After HARBEC's engineering team reviewed the dicot structures in various size leaves, they noted that in most cases vein diameter was proportionate to leaf size. Smaller leaves tend to have smaller diameter veins, while larger leaves tend to have larger diameter veins. Injection mold cavities can be compared to leaves because both have relatively wide, flat surface areas that are used to dissipate heat. The heat transfer method for leaves relies on evaporation while molds rely on conductive heat transfer. Although the method for heat dissipation between the two models are different, the method for getting the cooling liquid to reach a maximum surface area is more important in this case. HARBEC decided to approach developing the modeling parameters using this observation. When designing dicot structures, HARBEC reviews the overall mold and part size to determine the adequate diameter veins. Prior to testing, an increase in volume of cooling fluid in the mold was assumed to be advantageous. Typically, HARBEC's dicot designs default to larger diameter cooling channels when possible.

The pressure of both the cooling water and the injection molding process limit the distance between the cooling channel wall and mold surface to at least 0.10-inch to prevent the wall from breaking. Additionally, the cooling channels are limited to the space between the bottom of the mold and the surface of the part (less than 0.5 inches in some places) to limit material and machining costs. Cooling channels are often the last feature designed in the mold cavity and must also avoid features such as sprue bushings, ejector pins, and core pins while maintaining the 0.1-inch wall thickness.

The branching structure is based off of these limitations as well as another factor. Leaves can have a complex hydraulic system and still have balanced fluid flow throughout because evaporation of water at the ends of capillaries create a pressure differential (vacuum) in which water from the stem will rush in to fill. No fluid rushes to fill a mold with only one or two exit locations and a complex cooling structure.

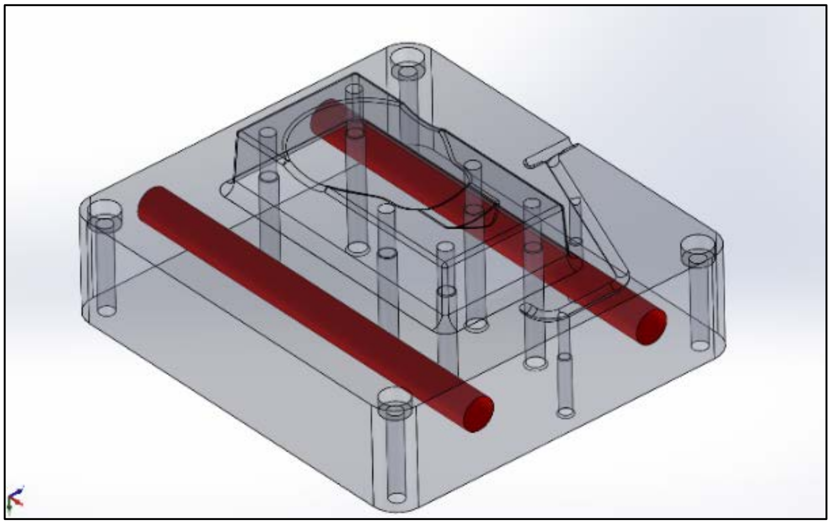
The fluid will naturally take the path of least resistance and a balanced flow will not be achieved unless the flow is explicitly directed to do so with differing channel diameters and lengths because the cooling liquid is incompressible.[4] As each main cooling channel branches out, the diameter must decrease to maintain the fluid pressure and ensure turbulent flow for maximum heat transfer.

Although the DMLS process can be modeled and simulated, it leaves compacted powder in the cooling channels that must be evacuated. A combination of compressed air and vibration is used to clear the channels. Channels less than 0.1-inch in diameter have a high probability of clogging, especially in branched networks where the compressed air will take the path of least resistance. Because the diameter of the channels must be reduced each time the network branches, these potential clogs limit the number of branches that can be made in the system.

2.5 Building Mold Cavities in DMLS

HARBEC used modeling software called SolidWorks to develop three-dimensional models for the different cooling channels. The four different configurations are shown in Figures 5 through 8.

Figure 5. Conventional Configuration in SolidWorks



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[4] Cengel, Yunus A., and John M. Cimbala. Fluid Mechanics: Fundamentals and Applications. 2nd ed. Singapore: McGraw-Hill Higher Education, 2010. 58-59. Print.

Figure 6. **Standard Conformal Configuration in SolidWorks**

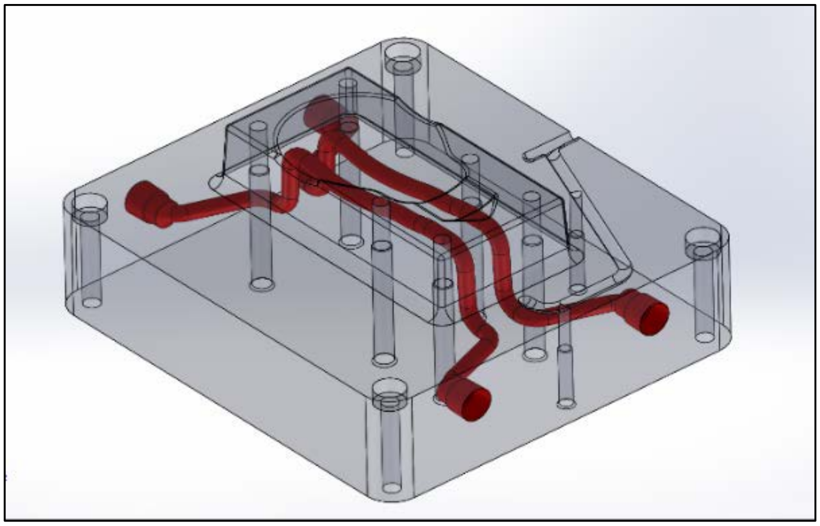


Figure 7. **Standard Conformal Configuration in SolidWorks**

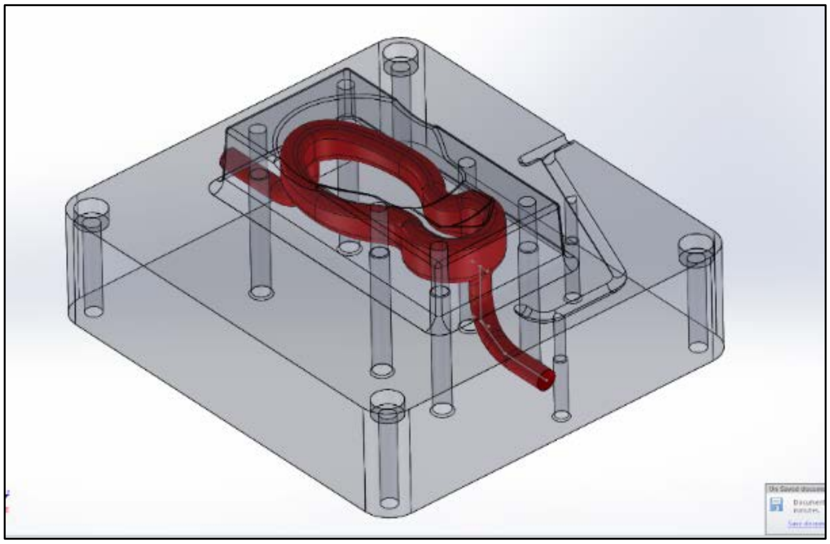
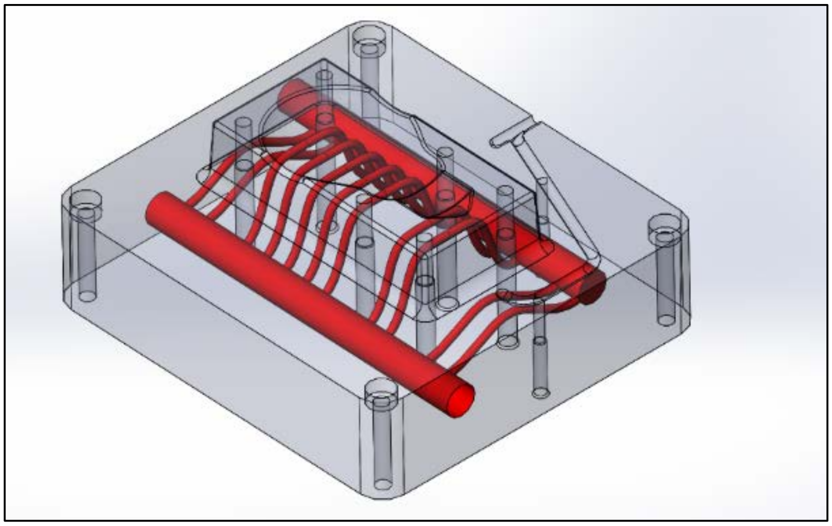


Figure 8. **Dicot Configuration in SolidWorks**



HARBEC then ran a simulation in SolidWorks Plastics to see how effective the cooling lines would theoretically be. Figures 9 through 12 provide the results.

Figure 9. **Conventional Configuration in SolidWorks Plastics**

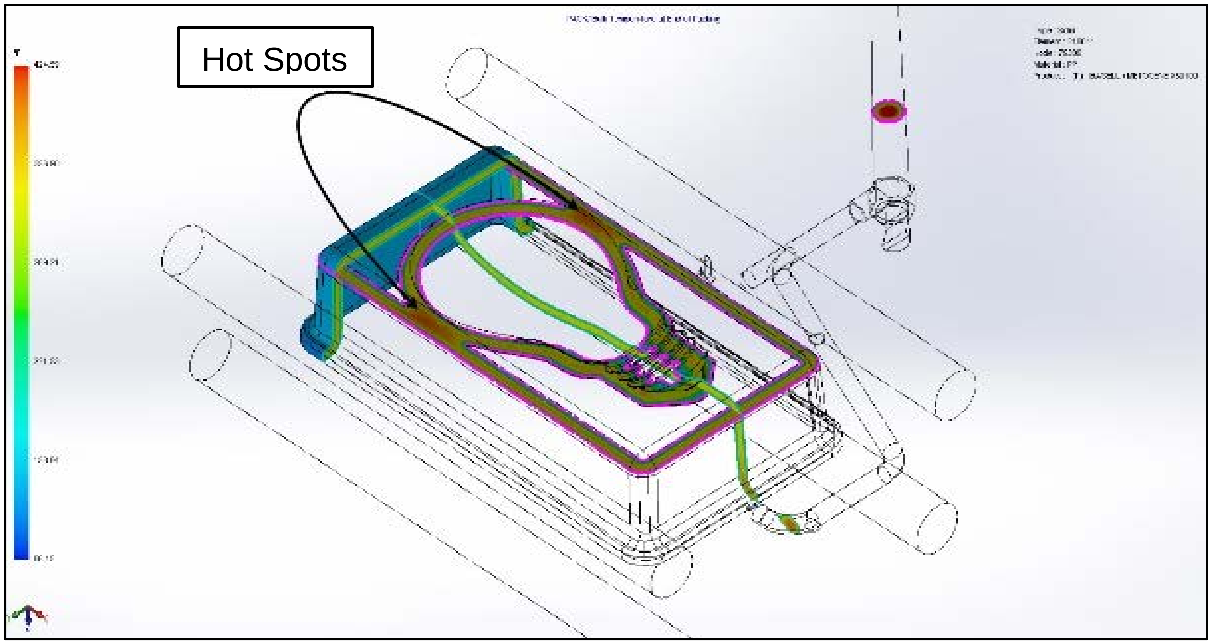
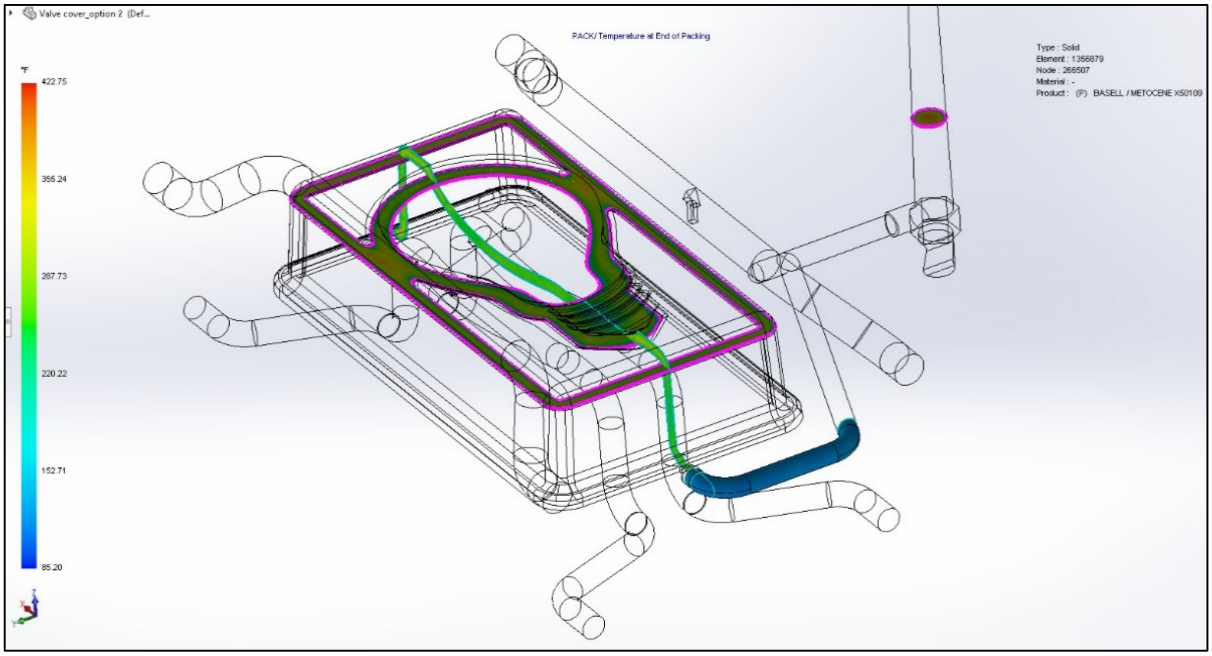
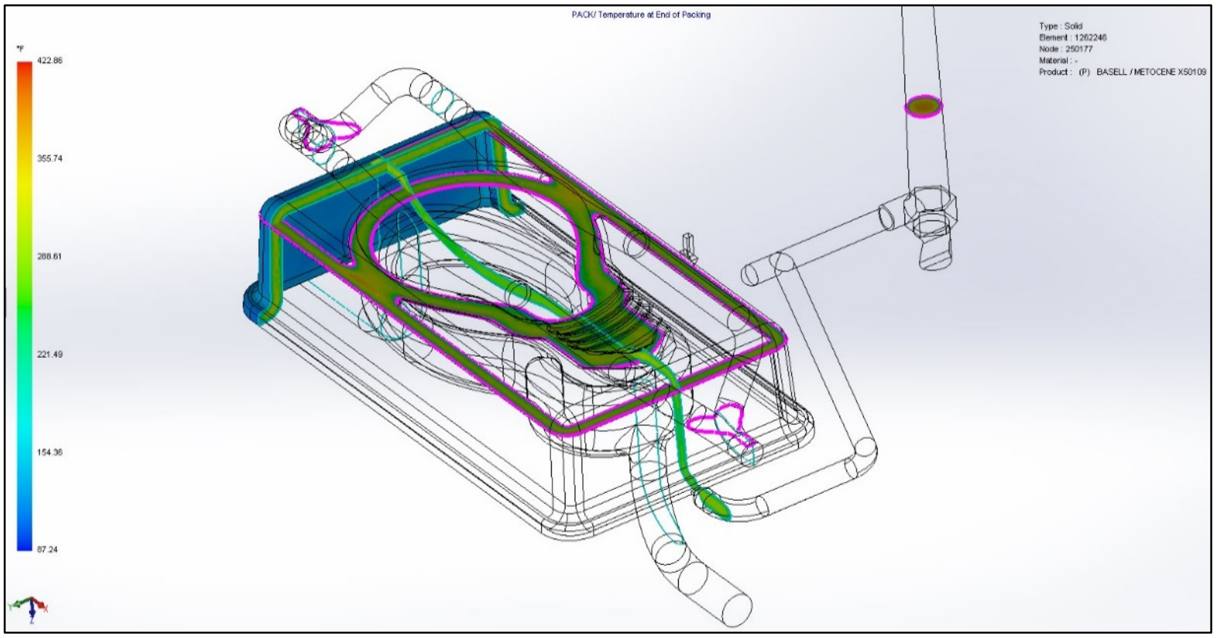


Figure 10. Standard Conformal Configuration in SolidWorks Plastics



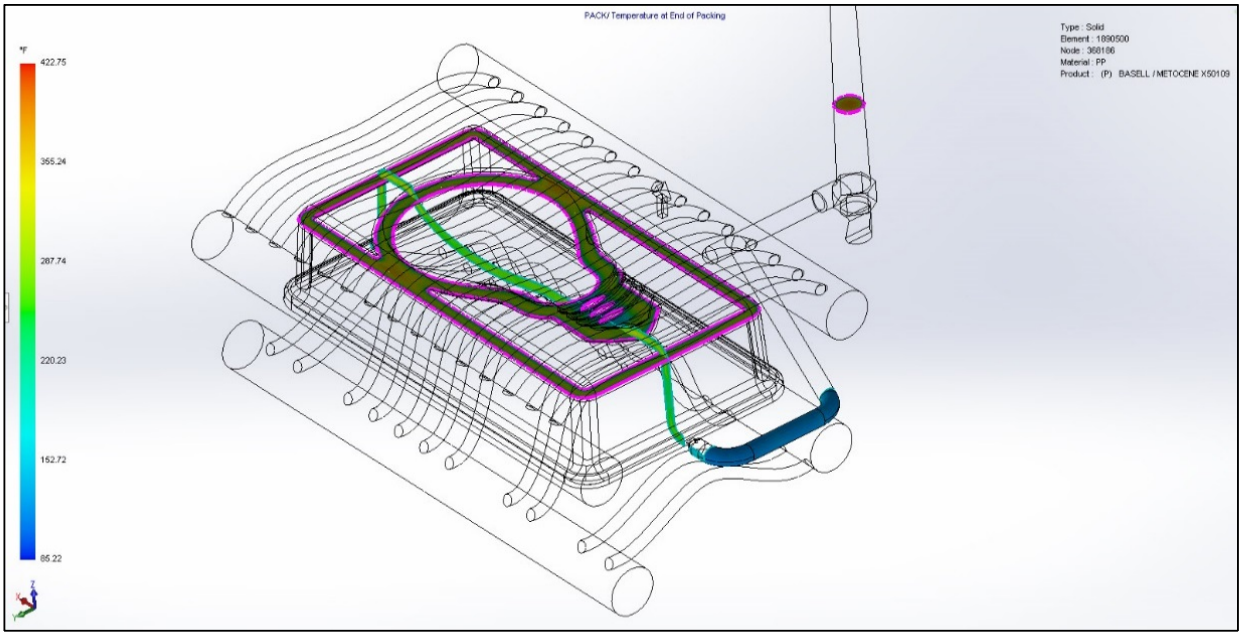
Type : Solid
Element : 1356879
Node : 266507
Material : -
Product : (P) BASELL / METOCENE X50109

Figure 11. Standard Conformal Configuration in SolidWorks Plastics



Type : Solid
Element : 1262246
Node : 250177
Material : -
Product : (P) BASELL / METOCENE X50109

Figure 12. Dicot Configuration in SolidWorks Plastics



Type : Solid
Element : 1890500
Node : 368186
Material : PP
Product : (P) BASELL / METOCENE X50109

Figure 9 shows the hot spots, which are the last areas of the part cool. All other variables being equal, it can be observed that all of the conformal cooling lines were observed to be more effective than the conventional cooling lines with regards to how well they cool the part.

After completing the four different mold cavity variations in SolidWorks, the files were converted for use in the EOS machine program. The parts needed an additional 4-mm of added stock to the bottom face of the cavity block. This space allows the technician to remove the parts from the build plate with a band saw. All of the cavities were created in an EOS M290 additive manufacturing system (Figure 13) and the material used was EOS Aluminum AlSi10Mg_200C made by Additive Manufacturing Alloys.

Figure 13. **EOS M290 Machine**

HARBEC decided to build the cavities for this study in aluminum because of the increased thermal diffusivity over steel and the previously tested DM20 material. Additionally, the parameters for building in maraging steel in the M290 machine were not yet created at the time the decision was made. Aluminum is commonly used for prototype injection molded parts and parts made at low volumes. It has a much higher thermal diffusivity than steel ($68.2*10^6$ m^2/s for aluminum versus $14.9*10^6$ m^2/s for steel). Thermal diffusivity is the measure of a material's ability to conduct thermal energy relative to its ability to store thermal energy,[5] meaning it will release heat much faster than steel. It is also cheaper than steel for DMLS, the current prices being $76/kg for aluminum versus $87/kg for the denser maraging steel and faster to machine during post processing. Steel has the advantage of being much tougher than aluminum, resulting in slower wear of the cavity surface during the life of the tool. This characteristic is ultimately why molds that need to run for more than 100,000 cycles are made with steel.

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[5] Incopera, DeWitt, Bergman and Lavine. Fundamentals of Heat and Mass Transfer. 6th ed. USA: John Wiley & Sons, Inc., 2007. 67-68.

The first blocks were built on a 5° tilt in the XZ and YZ direction. In steel, it is necessary to build parts with large surface areas on an angle to reduce the chances of warping due to the buildup of heat in the part from large areas being exposed to the laser. Subsequent cavity blocks were built flat to the plate and showed no signs of warping or loss in surface finish quality in aluminum. This is largely due to the fact that the build plate for the EOS M290 machine can heat up to 200°C, evening out the heat distribution throughout the part during the build process and greatly reducing internal stress. By being able to build the cavity blocks flat, build time was reduced by 14.5% and excess stock material was reduced by 11.5%, thereby reducing energy and raw material consumption. Additionally, the heated build platform eliminates the need to heat treat the cavities in an annealing oven after building, further reducing energy costs. At HARBEC's current energy cost rate of $0.13 per kilowatt-hour (kWh), eliminating heat treating results in a savings of $3.07 from the reduced build time (at 3.2 kWh[6]) and a savings of $1.21 at 3.1 kWh in the annealing oven for three hours.[7] These numbers are strictly the costs of energy usage and do not account for machine depreciation, maintenance, and additional machining needed to remove excess stock.

The cavity blocks are then face milled on a Computer Numerical Control (CNC) mill to provide the finished dimensions to fit properly in the mold base and ensure proper alignment between the two cavity halves. The cooling channel inlets and outlets are then tapped to attach to the plant's water system for cooling. Finally, the surface of the mold cavities are mildly polished to ensure that the molded plastic parts will release from the cavity core after the part is formed and cooled. Figure 14 and Figure 15 show the completed cavity halves.

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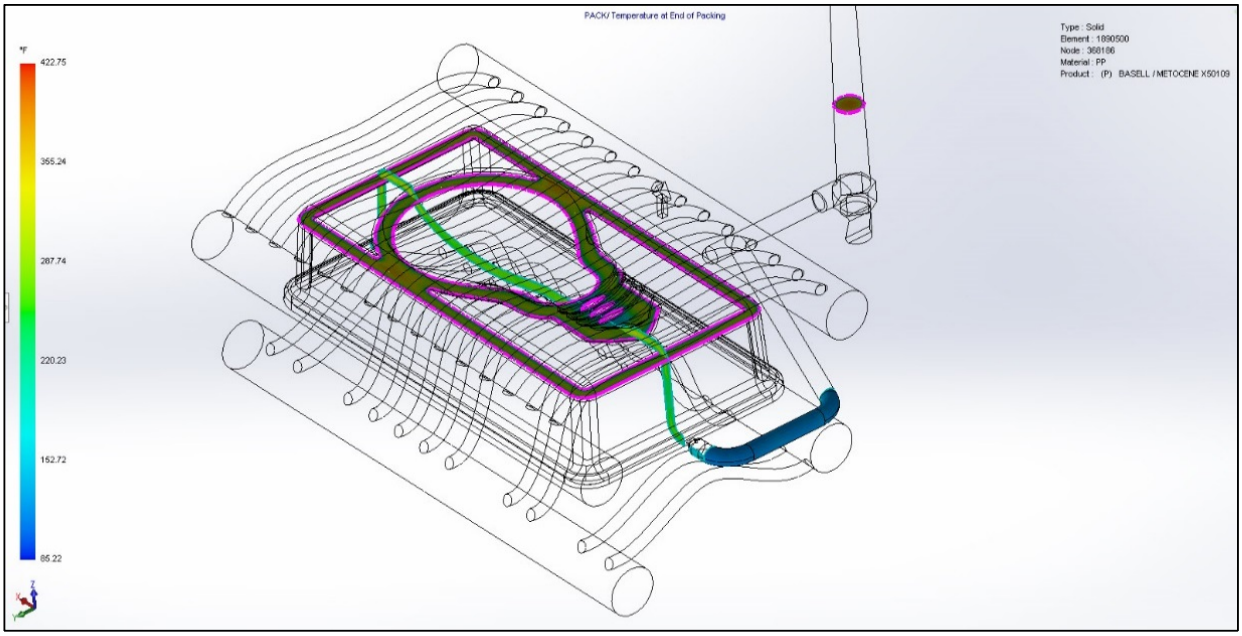
[6] EOS M 290 brochure, https://scrivito-public-cdn.s3-eu-west-1.amazonaws.com/eos/public/413c861f2843b377/93ef12304097fd70c866344575a4af31/EOS_System-DataSheet-EOS-M290.pdf

[7] EOS Aluminum_AlSi10M Material Safety Data Sheet, https://scrivito-public-cdn.s3-eu-west-1.amazonaws.com/eos/public/8837de942d78d3b3/4e099c3a857fdddca4be9d59fbb1cd74/EOS_Aluminium_AlSi10Mg_en.pdf

Figure 14. Finished Core Half

Figure 15. Finished Cover Half

Figure 12. Dicot Configuration in SolidWorks Plastics



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The tests showed a noticeable difference between the different cooling methods. The control mold (Version 1) had a 20-second cooling time and a cycle time of 26.3 seconds. The first conformal cooling mold (Version 2) had a 16-second cooling time and a cycle time of 25.77 seconds. The second conformal cooling mold (Version 3) had a 14-second cooling time and a cycle time of 21.79 seconds. The dicot mold (Version 4) had a 10-second cooling time and a cycle time of 20.56 seconds. The discrepancies between the mold cooling time and cycle time are due to the calculations that the press's computer runs during a cycle. Table 1 compares each conformal cooling cavity set to the conventional cooling set (Version 1) and shows improvements.

Table 1. Percentage Improvements for Cavities (time)

Version	Compared to Version 1 (Traditionally Machined)
1	2.0%
2	17.1%
3	21.8%

All three conformal cooling cavity sets displayed a decrease in process time over the conventional cooling mold. Additionally, the dicot model (Version 4) showed a 5.6% improvement over the best conventional conformal cooling cavity version (Version 3).

Figure 17 shows a sample of the energy usage from the same press used to run the test cavities. The actual energy usage from the test results are insignificant because the data that is important is the relative energy consumption when comparing each cavity set against one another. The figure shows an average power consumption of 1572.65 Watts.

Table 2 shows an insignificant cost savings from press energy consumption relative to the total cost of a project of this scope. These results would be typical of aluminum molds, which rarely run for more than 100,000 cycles. Significant cost savings would occur when looking at steel molds that run for over one million cycles. There are significant differences in press time and energy savings, even at a low volume such as this example.

Figure 17. Energy Consumption for Injection Molding Press

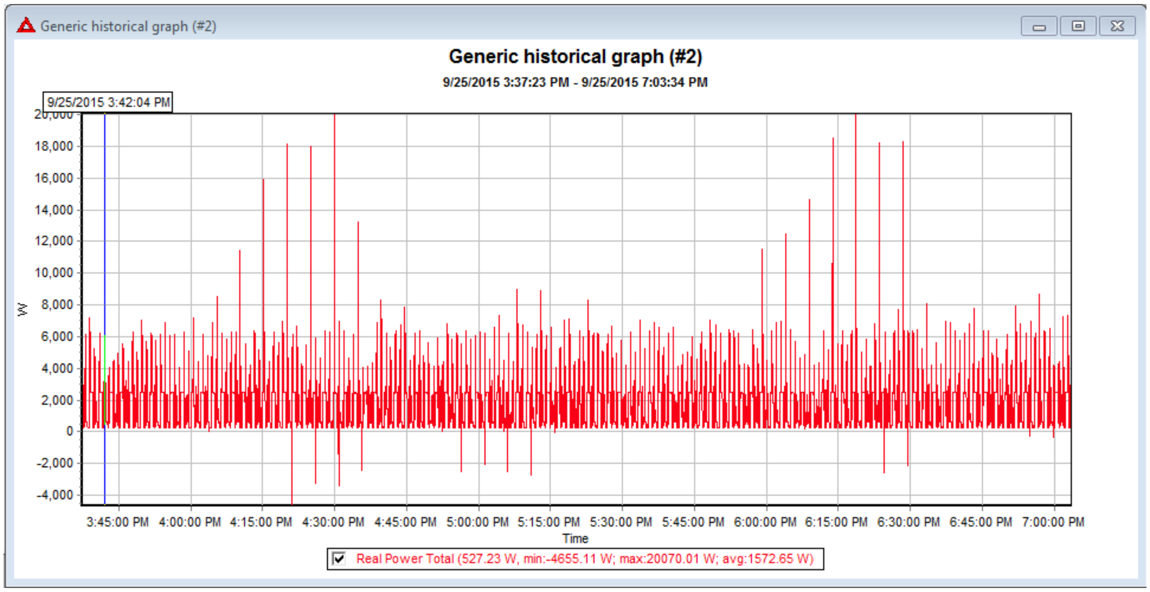


Table 2. Example Time and Cost Analysis

Version	<u>Press Time (days)</u>	<u>Energy Consumption (kWh)</u>	Energy cost @ $0.13/kWh
1	30.44	1148.91	$149.36
2	29.82	1125.76	$146.35
3	25.22	951.89	$123.75
4	23.79	898.16	$116.76

2.7 Method for Incorporating Nature-Inspired Geometries Into Mold Design

The following rules must be adhered to in order to repeatedly produce quality cooling channels based upon a dicot leaf structure:

- Use the largest-sized cooling channels allowed for that particular mold cavity. Maintain at least a 0.125-inch distance from the channel wall to each feature (impression, sprue bushing, ejector pins, etc.)
- A dicot leaf structure begins with one large “trunk” with different “branches” off of it. For molding purposes, begin with one entrance trunk, branch off of it with conformal lines, then return to an exiting trunk. Figure 18 and Figure 19 show options for multi-tiered or single-tiered branching, respectively. With more tiers comes a higher probability of powder becoming stuck in the channels after it is built.

Figure 18. **Multi-Tier Branching**

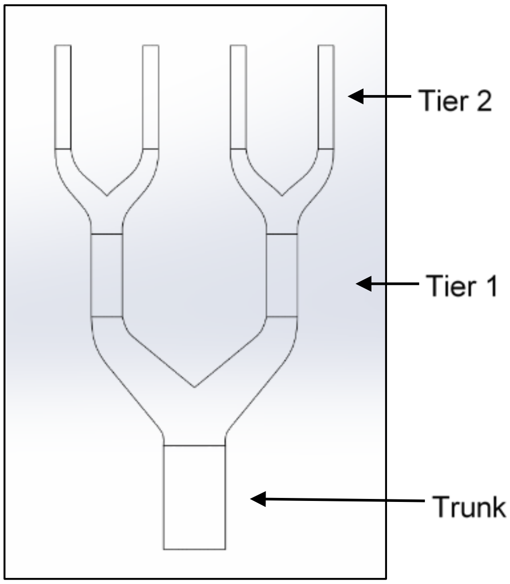
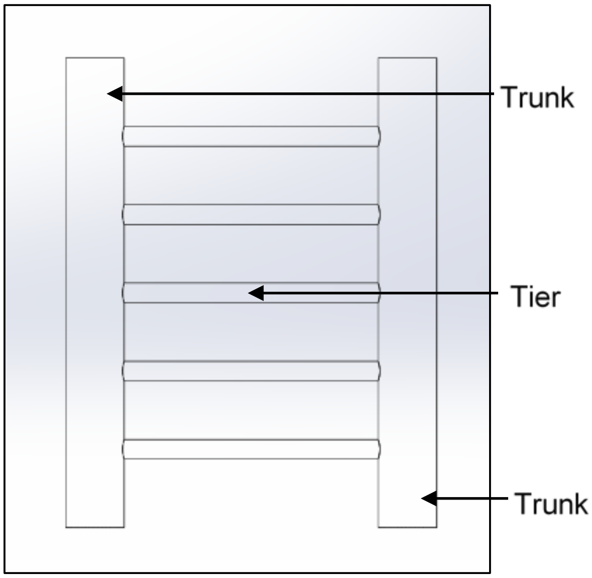


Figure 19. **Single-Tier Branching**



- Each branch must be smaller in cross-sectional area than the trunk and the branches from the previous tier.
- Circular cross-sectional areas provide the highest volumetric flow rate. Triangular and oval can also be used but are not ideal. Square cannot be used because support structures would be required to brace the ceiling of the square.
- Channel diameters should be larger than 0.1-inch to reduce the chance of powder becoming stuck in a channel and preventing fluid flow.
- A uniform cross-sectional area must be maintained for each cooling channel branch to maintain a constant flow velocity and pressure (an exception can be made as shown in the equations below).
- To maintain the most even flow possible, the channel lengths must be of equal length in each tier (an exception can be made as shown in the equations below).
- The branches in a channel can have differing lengths provided they have a similar number of directional changes. Equation 1 represents the ratios of the volumetric flow rates for parallel pipes with incompressible fluid flow.[8]

Equation 1

$$\frac{\dot{V}_1}{\dot{V}_2} = \frac{D_1^2}{D_2^2}\left(\frac{f_2}{f_1}\frac{L_2}{L_1}\frac{D_1}{D_2}\right)^{1/2}$$

Where $\dot{V}$ is volumetric flow rate, D is diameter, f is frictional coefficient, and L is channel length

In this case, the flow rates and frictional coefficients are equal and the channel lengths are fixed. Fixing D_1 allows rearrangement to Equation 1 as follows to solve for D_2 in Equation 2.

Equation 2

$$D_2 = \sqrt[5]{\frac{L_2}{L_1}D_1^5}$$

The example in Figure 20 shows how the equations would be applied. The branch on the left has a diameter of 0.125-inch and a length of 3.790-inch while the branch on the right has a length of 1.590-inch. According to the Equations the diameter of the right-side branch must be 0.105-inch to maintain the same volumetric flow rate in each channel and provide even cooling in the system. This phenomenon can be used for the opposite effect, however, if the mold designer wanted to provide more cooling to an area with a hot spot, such as a thick part wall, while providing even cooling to the rest of the mold.

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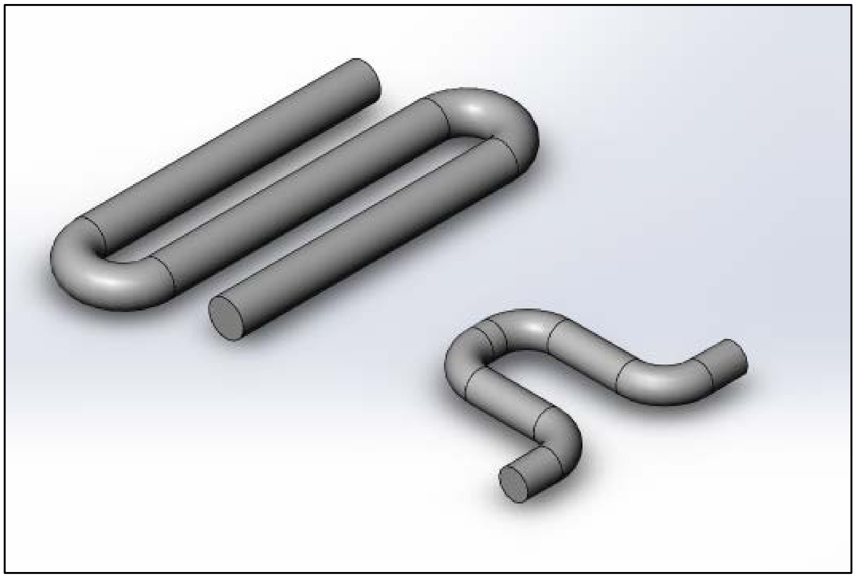
[8] Cengel, Yunus A., and John M. Cimbala. Fluid Mechanics: Fundamentals and Applications. 2nd ed. Singapore: McGraw-Hill Higher Education, 2010. 372. Print

Figure 20. Parallel Channels with Different Geometry



The most effective way to determine if a cooling channel system has been effectively designed is to use an injection mold simulation software, such as Autodesk Moldflow or Solidworks Plastics, to simulate how the mold will cool under the process conditions compared to how it would cool with conventional cooling lines. More advanced versions of the simulation software will also allow the user to view how the fluid will flow through the system so channels with undesirable flow (i.e., laminar flow) can be found and rectified.

3 Industrial Adoption

Industry adoption of conformal cooling has started to pick up in recent years. The key to adoption is awareness of DMLS technology and its relation to the injection molding industry. Many customers who produce injection molded plastic parts are either unaware of the existence of DMLS technology or have no knowledge of the capabilities and costs of producing parts in DMLS when they speak to the HARBEC sales team.

Sales teams need to be knowledgeable about the DMLS process capabilities and how to assess and sell projects that fully exploit the beneficial areas of DMLS, specifically with conformal cooling. Reducing cycle time and energy consumption should be the main selling points. Sustainability is already a key selling point at HARBEC and conformal cooling based on biomimicry is a natural extension of that point.

Sales teams can also use injection molding simulations to show customers the difference between conventional cooling and conformal cooling. The software can also convince skeptical customers who would like solid evidence that the technology will reduce cycle time for their parts.

3.1 Conformal Cooling Considerations

DMLS excels in some niche situations, but not all. Customers should consider the following points when considering DMLS:

- Will the added expense of DMLS be recouped in reduced cycle times during the molding process?
- In high-volume production. a small reduction in cycle time per part could equate to a significant savings. However, in short-run production a small cycle time savings per part could equate to a negligible cost savings.
- Can conventionally drilled waterlines be as effective in reducing heat? Typically, parts with small planar surface areas can be effectively cooled with conventional waterlines.
- Is extensive cooling needed to make a visually and dimensionally correct part? In some cases with the proper part design and molding resin, cooling can make little impact on cycle time. Typically, this encompasses low-mass weight parts that have somewhat generous dimensional tolerancing.
- Is the part size within the DMLS machine limits of 8 inches × 8 inches × 12.75 inches?

Although the DMLS process is capable of producing any given cavity within its size limits, not all cavities are suitable based purely on time and financial variables. However, these limits are quickly changing as the technology improves. The significant improvements that DMLS technology has made in just the past five years with regards to material selection, part density, build time, and surface finish has closed the gap between traditionally machined cavities and DMLS cavities.

Since HARBEC's initial study of DMLS technology in 2008, the only material available for use was Direct Metal 20, a proprietary EOS blend of bronze and nickel that printed porously. Since then, parameters for 17-4 stainless steel and maraging steel have been developed that print at over 99% density. Additionally, EOS's new M290 that was released in 2014 prints in aluminum and medical/space grade titanium. The build platform in the M290 heats to 200 °C, reducing internal stress in the part during a build and eliminating the need for post-build heat treatment for aluminum parts. Parameters for maraging steel have been recently developed for use in the M290 that print 30% faster than the M270 model.

Better air flow in the build chamber removes condensate (overexposed) powder from the surface, resulting in a smoother surface finish. More robust filter systems require less changeovers and are safer to switch out, resulting in lower maintenance costs. New post-processing companies have been created that make surface refining tumblers specifically for DMLS parts as well as methods for evacuating leftover powder from internal channels, which has been a struggle for the industry since its inception. As the awareness of DMLS technology increases, the demand for more machines will create more competition in both the machine manufacturers and material developers, further reducing costs.

DMLS should now be considered for every high volume part that comes to a mold designer, rather than as a last resort when parts are envisioned to have cooling problems. Staying on top of an emerging technology will keep companies competitive in the future when the technology becomes the standard, allowing them to be experts rather than playing catch-up.

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