TERRAPIN BRIGHT GREEN - BIOINSPIRED INNOVATION CASE STUDY

EFFICIENT HEAT TRANSFER IN MANUFACTURING

"We are thrilled to discover the full potential this technology can have for making more energy-efficient molds that result in tangible energy, cost, and productivity benefits for our customers, our business and New York State."

– Bob Bechtold, President of HARBEC

Partner Company

HARBEC, Inc.; Ontario, New York

Topical Experts

Dr. Abe Stroock, Cornell Univ.
Dr. Jiandi Wan, RIT

Industrial Challenge

Decrease energy use and cycle time in injection molding

Biological Inspiration

Efficient heat and fluid transfer in plant leaves

Result

Both cycle time and energy use were reduced by more than 20%

Key Advantages

Improved product quality
Faster production
Reduced costs

Market Readiness

In Market

Related Industries

Data Centers
Electronics
Food Manufacturing
HVAC & Refrigeration
Industrial Machinery
Plastic Products

LEVERAGING ADDITIVE MANUFACTURING AND BIOINSPIRED INNOVATION

The bioinspired innovation team at Terrapin works with companies to solve technology challenges by developing innovative products and processes inspired by nature. We collaborate with R&D, design, and engineering teams to develop these solutions. Our projects increase our clients' profitability by lowering their risk and costs, reducing their energy and material use, and creating high-value products and processes. Tackling technology challenges produces the greatest results when a diverse set of stakeholders—a team's engineers, technicians, and managers, as well as external experts, are able to explore a wide solution space together. This case study reports how Terrapin assisted HARBEC Inc., a plastic and metal parts manufacturer, in utilizing bioinspired design to improve a key manufacturing process.

Bob Bechtold, the founder and president of HARBEC, met our team during a workshop we offered in 2010. These workshops allow manufacturers and technology teams to better understand the bioinspired design process. Bob was intrigued by the potential of biologically-inspired design and engineering and saw value in learning more about how they could be applied at HARBEC. After the workshop, our conversations with Bob evolved into a concept for a research project. We wanted to combine our bioinspired design process with opportunities enabled by additive manufacturing. Doing so would allow HARBEC to innovate on two fundamental components of injection molding: mold design and heat transfer.

THE INDUSTRIAL CHALLENGE

During the injection molding process, solid plastic is heated until it liquefies; in HARBEC's case, this occurs at temperatures ranging from 150 to 700°F, depending on the polymer. The molten plastic is pressed into a cavity inside

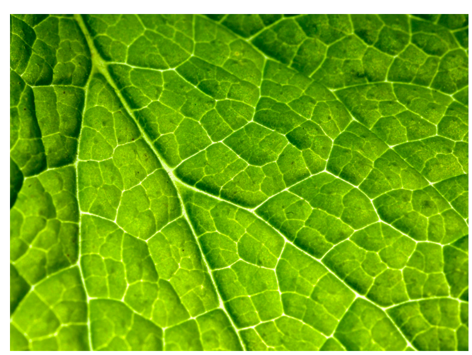
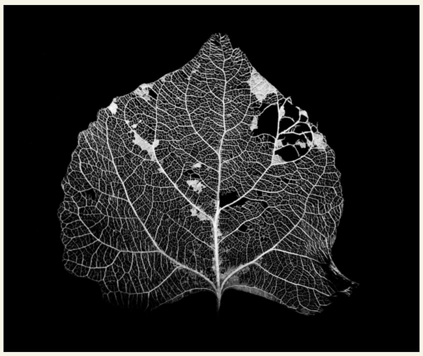


Figure 1. The flow of fluids in interconnected and branching veins are characteristic of leaves in dicot plants. Copyright: Andrew Magill/Flickr

HEAT DISSIPATION IN NATURE



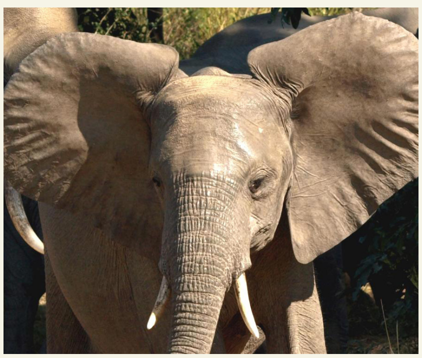


Figure 2. The physical layout of arteries in the brains of fast running mammals, vessels in ears and leaves, and channels in termite mounds and the human lung illustrate the diversity of nature's solutions for dissipating heat. Copyright (from top to bottom): Martijn.Munneke/ Flickr; Shaun Fisher/Flickr; smshubert6/ Flickr; Jon Connell/Flickr.

a metal mold. The mold is then cooled until the plastic part can be ejected from the mold without deforming. This series of steps—melt, press, cool, eject—is called a cycle. As one can imagine, the duration of each cycle is critical when manufacturing thousands or even millions of parts for a customer.

Conventionally, molds are made by milling material from a solid block of metal and drilling holes in several locations to allow liquid coolant to flow through the metal volume, extracting and carrying off heat as it passes by the molten. Circulating coolant allows the plastic to cool faster. Faster cooling means shorter cycle times and increased production. However, the efficiency of conventional cooling is limited by the types of channels that can be created using subtractive methods. The cooling channels are wide, straight, and often cannot be located close to the cavity. As they get further from the cavity, the time and energy needed to cool the plastic increases. With this in mind, our bioinspired innovation team honed in on the challenge: decrease the time and energy spent during the cooling phase of the injection molding process.

At this stage of a project, Terrapin will often reframe the challenge in biological terms. Rather than starting from a standard engineering perspective, we asked "How does nature dissipate heat?" This enabled the team to identify, question, and dislodge deep-seated assumptions and explore a wider set of solutions. Having made a key shift in mindset, we began researching natural systems that are effective at dissipating heat.

THE BIOINSPIRED SOLUTION

Nature has evolved many powerful systems to cool organisms efficiently. Our team analyzed organisms with heat dissipating structures or strategies. These included arteries in the depths of mammalian brains[1], webs of vessels embedded in large ears and leaves[2], and channels in termite mounds[3] and the human lung. Many of these designs feature circuitous structures that would be impossible to produce using conventional means. Fortunately, HARBEC was an early adopter of additive manufacturing (also known as 3D printing) to supplement their subtractive fabrication techniques. Using direct metal laser sintering, they are able to "print" molds that incorporate geometrically complex features deep inside the mold, even at very small scales.

The team believed that combining additive manufacturing with Terrapin's insights from nature's designs could yield a breakthrough for HARBEC. However, translating a kernel of inspiration from a natural system into a novel engineering solution requires specialized knowledge and expertise.

To ensure the project's success, Terrapin introduced the HARBEC team to two researchers from our network: Dr. Abraham Stroock, an expert in vascular systems at Cornell University, and Dr. Jiandi Wan, an expert in microvascular engineering at RIT. They provided HARBEC's engineering team with technical guidance and a scientific framework for developing and evaluating design concepts.

HARBEC's engineering and manufacturing teams convened for several brainstorming sessions to weigh the potential of these concepts. The engineering team proposed ways to translate bioinspired models into testable prototypes, while the technicians vetted the designs against the company's manufacturing capabilities. As they filtered through a wide range of ideas, the engineering team used computer modeling to ensure the manufacturability and performance of potential solutions. In terms of feasibility and efficiency of thermal energy dissipation, a design inspired by principles seen in the leaves of dicot plants offered a promising path forward.

Specifically, dicot leaves provided a way to innovate on a type of cooling known as conformal cooling. While conventional cooling in molds employs linear paths, conformal cooling uses channels positioned closer to the heated plastic, conforming to the contours of the mold cavity. This allows heat to be extracted faster, using less energy. While conformal cooling is becoming more common in

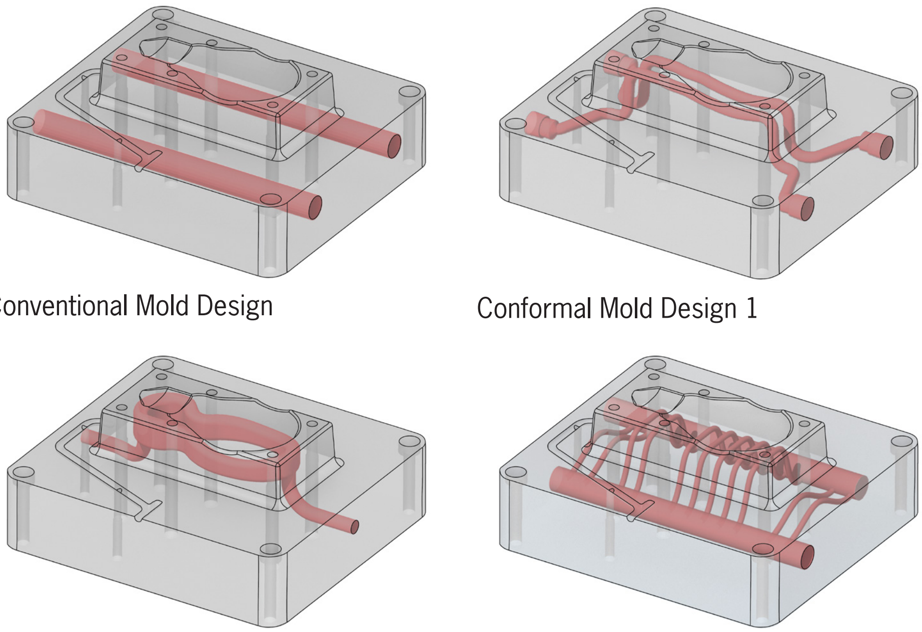


Figure 3: The four different cooling channel designs are highlighted in red in these renderings. Top left features conventional cooling channels. Top right and bottom left feature conformal cooling channels. Bottom right features HARBEC's dicot-inspired cooling channel. The vertical channels visible are used to align, join, and press the two halves of the mold and to eject the cooled part. Copyright: HARBEC & Terrapin.

industry, HARBEC believed they could improve even on these more advanced designs.

The fluid-carrying channels of dicot leaves generally feature a main trunk with branching secondary and tertiary channels that interconnect. This hierarchical branching creates a web of channels that allows fluid (and, importantly, thermal energy) to move efficiently from a reservoir through a volume. Water moves efficiently from the plant stem throughout the leaf and then returns to the stem. Inspired by this design, the team envisioned a system that would allow coolant to flow from a single inlet and more efficiently permeate and cool the mold.

With guidance from Dr. Wan and Dr. Stroock, HARBEC used computer aided-design (CAD) tools to iteratively model new molds that featured dicot-inspired cooling channels ("dicot molds"). Equations for volumetric flow rates were used to model the appropriate diameters and lengths of the cooling channels[4]. After simulating the fluid dynamics of the molds, the engineers and technicians printed an aluminum prototype. They also fabricated three additional molds containing the same cavity: one with conventional cooling channels and two with conformal channels. While all four molds would produce the same plastic part, the three additional molds would be used as benchmarks to compare the performance of the dicot mold.

THE RESULTS

The four molds were made of aluminum to simulate a low volume production run (100,000 cycles). They were subjected to tests that evaluated the time and energy required to properly cool each plastic part. To gather energy use data, HARBEC ran the injection molding process for 50 cycles on each of the four molds. The results were impressive: the dicot mold outperformed the conventional molds as well as the more sophisticated conformal molds. In this test setup, the dicot mold cooled parts more than 21% faster than conventional molds and even outperformed an industry-leading conformal design (represented by "Conformal Mold Design 2" in Figure 3) by over 4%. In the highly competitive

The dicot mold reduced the time and energy used more than 20% compared to conventional molds.

Table 1: Percent Decrease in Time for Cooling Step

Mold Design	Compared to Conventional Mold
Conformal 1	2.0%
Conformal 2	17.1%
Dicot	21.8%

Source: HARBEC White Paper

Table 2: Time and Cost Analysis for a Low Volume Run (100,000 cycles)

Mold Design	Production Time (days)	Energy Consumption (kWh)	Energy Cost @ $0.13/kWh
Conventional	30.44	1148.91	$149.36
Conformal 1	29.82	1125.76	$146.35
Conformal 2	25.22	951.89	$123.75
Dicot	23.79	898.16	$116.76

Source: HARBEC White Paper

plastic manufacturing sector, these time and energy savings are critical to meeting customers' expectations for low pricing and short turnaround time.

Table 1 compares the results of the four molds over 50 cycles. Table 2 extrapolates the results to show what the time and energy savings would be over a production run of 100,000 cycles. The time savings would be significant, with the dicot mold reducing a low volume production run by nearly seven days. Also, because energy use is tied to the cooling step, the new molds would reduce energy consumption by the same 21.8% as the cooling time. The avoided energy use is significant when considering utility rates; manufacturers paying variable rates can use dicot molds to reduce energy costs during peak hours, leveling out their cost of energy.

For customers who might be skeptical about investing in a new type of mold, HARBEC offers CAD simulations that demonstrate the reduction in cycle time in dicot molds. The reduction in total production time is valuable to HARBEC's customers, even on small orders. The new molds enable HARBEC to satisfy narrow fulfillment windows.

HARBEC's general manager Keith Schneider summarized the benefits of the bioinspired molds: "Reducing cycle time has a huge impact on pricing for our customers. Orders are priced based on how long they are in the press. So, if that is reduced, it's great for the customer. And if we can save energy, that's great for us as well."

By working with Terrapin's bioinspired innovation team and leveraging our network of experts, HARBEC made a significant breakthrough in a tried-and-true industrial process. The company is now able to design and build molds with performance characteristics that were not previously attainable. While other manufacturers are using additive manufacturing to build injection molds, HARBEC is the only company making this type of bioinspired mold. The project was also an opportunity for HARBEC to expand its capabilities with respect to additive manufacturing, keeping the company ahead of the competition as more manufacturers incorporate the technology.

SOURCES

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5. Cover image courtesy of Cas Smith.

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Terrapin is an environmental consulting and strategic planning firm committed to improving the human environment through high performance development, policy, and related research. We work with companies, researchers, and organizations to transition biologically-inspired technology from idea to the market. Read about more of our work in *Tapping into Nature*, visit us at www.terrapinbrightgreen.com, or email us at biomimicry@terrapinbg.com.

HARBEC

Founded by Bob Bechtold in 1977, HARBEC's mission is to provide tightly toleranced prototypes, tooling, machined components and quality injection molded parts in a sustainable manner with a social conscience. They provide superior customer service, satisfaction and timely delivery of custom engineered solutions. HARBEC proudly fosters an atmosphere of encouragement and respect for the health and prosperity of their customers, employees, and the global community.