



Thermoforming

Quarterly®

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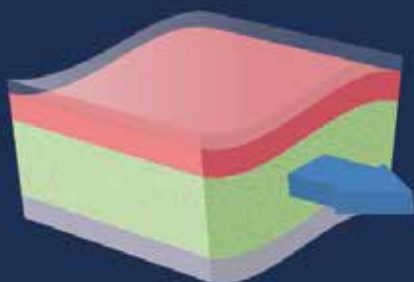
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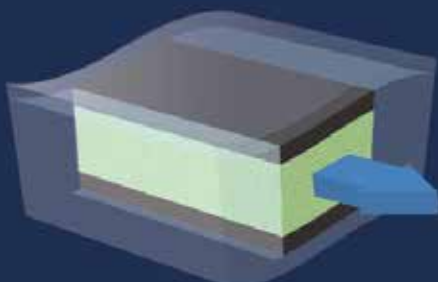
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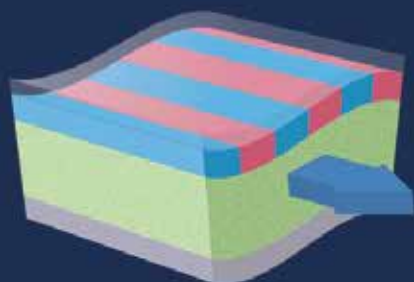
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Thermoforming Quarterly®

*A JOURNAL PUBLISHED EACH
CALENDAR QUARTER BY THE
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OF THE SOCIETY OF
PLASTICS ENGINEERS*

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*Cover Photo: A Celebration of 20
Years. Courtesy of: SPE European
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Passing the Gavel

This is my final letter to you as Chairman. My term ends after our next board meeting when the gavel will be passed to my colleague, Bret Joslyn. It has been an eventful 4 years at the helm of the board. I am grateful to my colleagues for their wisdom and expertise, their dedication to the thermoforming industry and to this division. During my tenure, we've seen wonderful conferences, amazing thermoformed parts, impressive student projects and a general sense of limitless possibilities for our industry. It is my firm belief that we are evolving faster with the adoption of new technologies and new materials. Thermoforming has very quickly become a science (if you choose) as there are so many advancements in process monitoring and data acquisition systems such as ToolVu, T-Sim and Finite Element Analysis systems readily available that help take you beyond the limits and keep you there.

The "News" section in this first issue of 2016 reveals no lack of dynamism in the thermoforming market. Plant expansions, new hires, strategic investments and M&A activity continue apace. But we still have work to do. Notably, thermoforming papers are needed at ANTEC. Upstream R&D takes time –sometimes a generation – before commercial successes are realized. Investing in new technologies can be expensive and even speculative, but without risk there can be no reward. On a positive note, partnerships between industry and academia are growing which is great news for both research and employment. When companies get involved with course design and curriculum development, they help close the skills gap by ensuring that students graduate with the relevant knowledge while earning better-than-average wages.

This year marks the 10th annual European Thermoforming Conference which will be held in Barcelona, Spain from March 10-11 (see pp. 15 for conference details). Jeff Pitt, one of the early ETD board members and a contributor to TQ, offers us

a retrospective on how a small and dedicated group built a community of thermoformers across languages and cultures. If you haven't yet been to a European Thermoforming Conference, I highly recommend that you invest in the trip. I will look forward to having a glass of cava with you there this year.

In other news from Europe, our editor reports from AMI's Thin Wall Packaging Conference in Cologne, Germany, where changing customer preferences are driving new materials development for ready-to-eat meals, dairy packaging and coffee pods. Speaking of materials development, we also feature an interesting paper from our friends at Bioplastics Magazine on plastics made from carbon dioxide (pp. 34). Finally, we can feel so much better about thermoforming plastics and the environment.

My best wishes to everyone that has supported me as Chairman. I will, of course remain on the Executive Committee as Past Chair for the next 2 years and will thereafter continue to dedicate my time to give back to the industry that has supported me for so long. I encourage you to get involved with the SPE Thermoforming Division and start by joining us as a visitor at one of our Board meetings. I ask that you join me in welcoming Bret Joslyn as your new chairman as we enter the next chapter in our history. |

A handwritten signature in black ink, appearing to read 'Mark Strachan', with a stylized flourish at the end.

Thermoforming Quarterly®

New Members

Neelakandan Chandrasekaran
3M Company
Maplewood, MO

Gaurang Pandya
Mutual Industries Ltd.
District Thane, INDIA

Patrick Spence
Bayer
Indianola, PA

Kristin DiStefano
Rutgers University
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Michael Green
Western Michigan University
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Karen Brock Amoah
Sekisui SPI
Gaithersburg, MD

Chris Pohlman
Genpak
Middletown, NY

Huyen Le
Saigonscientists
Ho Chi Minh, VIETNAM

Kasin Ruengsubanek
Parazzo Group (Thailand) Co., Ltd.
Nakorn Phathom, THAILAND

Schyler Sanks
University of Wisconsin, Madison
Verona, WI

David Shipman
Hampel Corp.
Germantown, WI

From the Editor

If you are an educator, student or advisor in a college or university with a plastics program, we want to hear from you! The SPE Thermoforming Division has a long and rich tradition of working with academic partners. From scholarships and grants to workforce development programs, the division seeks to promote a stronger bond between industry and academia. **Thermoforming Quarterly** is proud to publish news and stories related to the science and business of thermoforming:

- New materials development
- Innovative technologies
- New or expanding laboratory facilities
- New applications
- Industry partnerships
- Endowments

We are also interested in hearing from our members and colleagues around the world. If your school or institution has an international partner, please invite them to submit relevant content. We publish press releases, student essays, photos and technical papers. If you would like to arrange an interview, please contact Conor Carlin, Editor, at cpcarlin@gmail.com or 617-771-3321.

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Moderator: Jim Arnet

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Thermoformer Sportech Doubling Assembly Capacity

By Frank Antosiewicz, *Plastics News*

December 10, 2015 — Sportech Inc. plans to nearly double its complex assembly capacity, adding a new 105,000 square foot facility not far from its company headquarters in Elk River, Minn.

The company broke ground on the new facility in September and plans to move in by the end of March, according to Chief Operating Officer Jim Glomstad.

He said the plan is to consolidate several operations from smaller scattered buildings into the new building, which is about a half mile from its headquarters.

“It’s got higher ceilings to aid in warehousing and will have more automation,” Glomstad said.

The building is being constructed to take advantage of lean manufacturing principles and will be aligned to improve material flow and add more efficiency. The company will move a couple work cells that are set up in some of the smaller buildings, plus add a new work cell.

Glomstad said the building has room to grow, and that an additional 75,000 square feet of space has been pre-approved by city planners. Eventually it could be expanded to 180,000 square feet. Its headquarters building is 96,000 square feet.

Sportech designs and thermoforms components for vehicles, concentrating on power sports, agriculture, automotive, golf and turf, and other on-and-off road vehicles. It specializes in vehicle cab enclosures, body panels, windshields and styling accents.

The company was started in 1994 in a garage and has grown to an exclusive original equipment manufacturer product development partner.

The expansion is expected to create 25 more jobs. Sportech has 225 employees and has started hiring for its new building.



Ball-Shaped Yogurt Pots Thermoformed In-House

French yogurt producer shows how open-mold thermoforming technology can be used to produce custom-shaped yogurt containers for the same cost as straight-walled cups.

By Anne Marie Mohan, Senior Editor, *Packaging World*

December 14, 2015 — Over the past several years, yogurt has been a booming market in the U.S. But how can a brand owner differentiate their product from the masses in the dairy aisle? IMA Dairy & Food Group USA, formerly OYSTAR USA, has a solution that focuses on packaging differentiation. In 2015, it introduced thermoforming technology to the U.S. that allows food manufacturers to create proprietary shapes for cups, as well as bottles, at nearly the same cost as standard molds.

IMA’s Open Mold technology has been around for more than a decade in Europe. In 2006, French dairy company Senagral acquired Open Mold thermoforming to manufacture its custom “ball cups” in-house and reduce its packaging costs.

Senagral’s ball cup was originally introduced as a response to a custom “yogurt bubble” container from Dannon. Senagral designed its unique-to-brand yogurt pot with Alpla, which supplied the preformed cups to Senagral until the company’s installation of an Erca thermoforming machine. Open Mold traditionally is integrated into IMA’s Erca EF form/fill/seal machine, however Senagral was already using an Erca filling and sealing machine for the preformed cups.

“Senagral’s requirements for the thermoforming technology were that it reduce the cost of their packaging, while creating exactly the same cup shape as they had and the same top-load resistance, with an output speed of 36,000 cups an hour,” explains Dominique Schwab of Erca.

Easy integration

Senagral, formerly Senoble, produces ultra-fresh dairy products, including mixed/stewed yogurts, pudding, custards, drinking yogurt, and fresh cheese, under its own name as well as for private label, for distribution in France, Spain, and the Benelux countries. The company operates four production sites in France. The new thermoforming machine was installed in its Château-Salins plant, under the direction of Frédéric Poinas, responsible for maintenance and new construction at the facility.

As Poinas explains, the machine is set up in a dedicated room to feed two filling and sealing lines having production speeds of 22,000 and 28,000 cups/hr. Positioned between the two lines and

the thermoformer are two storage bins, each with a capacity of 320,000 cups.

The cup being produced—the ball cup—is a 125-g, translucent polystyrene yogurt container with a 69-mm dia, a height of 52 mm, and an opening diameter of 53 mm. The round container features a wave motif and a textured base. As Schwab explains, with traditional thermoforming technology, containers must be straight-walled or tapered in order to release from the production mold. Open Mold technology relies on molds divided into two halves that open to release the cup. A cutting station is integrated into the forming station to separate the cups. After forming, pushers push the cups through the film web onto a conveyor that leads to the storage bins.

Reducing material use, the thermoformer employs a plastic stretching device that minimizes the bottom thickness in unused thermoforming areas. Schwab estimates that Open Mold technology has reduced Senagral's scrap rate to 34%.

The end result of Senagral's implementation of Open Mold thermoforming has been reduced costs for packaging, including the elimination of transportation and storage of preformed cups. According to Poinas, the company achieved an ROI on the investment of the machinery and storage bins of less than three years.

Turkey's Sem Plastik to Double Capacity, Boost Exports to US

By Steve Toloken, *Plastics News*

December 30, 2015 — Turkish processor Sem Plastik San. ve Tic. AS is spending \$30 million on an expansion to double its capacity, in part because it sees increasing exports of packaging to the United States.

The Istanbul-based company, which specializes in both thermoforming and injection molding of packaging, said it sees growth from both Turkey's domestic market and from increased exports to some multinational customers.

The company said, for example, that it supplies disposable food packaging to seven of the 10 largest airlines in the world.

"The main driver is like this: First of all, we think the market in Turkey will increase, especially on the packaging side, and also the disposable market will continue to grow," said President Yavuz Eroglu, in an early December interview in his office.

"We are also selling a lot to the U.S., on the disposables side we are mainly exporting to the U.S.," he said. "We believe the U.S. market is recovering and we can see it from the numbers. This year we feel it."

The privately held company had annual sales of about 170 million Turkish lira (\$58.3 million) in 2014, with exports of about \$22 million.

Eroglu said exports could account for about 40 percent of the sales total this year, and initially are expected to be the larger driver for the expansion.

Specifically, he said Sem bought land near its current factory and will build a 215,000-square-foot plant there, adding up to 10 injection molding machines from producers in the European Union and additional capacity in thermoforming, Eroglu said.

The expansion should be completed by the end of 2017, he said.

Eroglu said Turkey has about 75 percent of the per capita plastics use of Western Europe, but he said the company expects that gap to close quickly.

New Owner Plans Growth for Virginia Thermoformer

By Michael Lauzon, *Plastics News*

January 4, 2016 — The new owner of thermoformer Virginia Industrial Plastics sees higher sales for the Elkton, VA firm.

"It was bought to grow it," said Ed Fisher, principal of Ale Holdings Inc., a newly formed company that Fisher created to acquire Virginia Industrial.

Ale acquired Virginia Industrial, formerly a family owned business, effective Dec. 1. The purchased company has annual sales exceeding \$12 million and a staff level as high as 32 during seasonal production peaks. Virginia Industrial runs two rotary thermoformers in its 86,000-square-foot plant.

"We will try to grow in current markets and in new markets," Fisher added in a phone interview.

One of Virginia Industrial's growth markets is making proprietary aftermarket parts for golf carts. The firm offers a wide range of components such as cargo boxes, roofs and dashboards. Other key, custom markets are recreation, medical, government, signage and various industrial outlets. The firm also stocks plastic shapes such as sheet and rod and counts fabrication as an important part of its business.

Virginia Industrial's capabilities include computer numerically controlled machining, prototyping and in-house mold building. It used to operate injection molding machinery but no longer does that process in house. Its thermoformers can handle sheet as large as six feet by 12 feet.

Generational Equity of Dallas advised Virginia Industrial in the deal. It specializes in middle-market mergers and acquisitions, especially in cases where private or family-owned businesses want to exit their companies.

"This successful transaction was the result of a balancing act between banks, buyers and the seller," noted Generational Equity affiliate Ahmad Behjati in a Dec. 15 news release.

Asian Firms Secure Thermoforming JV

By Paul Hill, *Plastics in Packaging*

January 11 2016 — Indian plastics manufacturer Delta Thermoformers is set to start a joint venture with China-based Zhejiang Xinyuanfang Plastic Co, as the businesses aim to expand their footprint in the Asian market.

The partnership will allow Delta to use what it calls state of the art technology through high-end machines supplied by Zhejiang, allowing it to cater for the growing Indian market.

Projected to generate revenue of \$100 million (Rs 650 crore) over the next two years, the manufacturing activities will take place from Delta's existing plant in Vasai, Maharashtra.

The deal was structured by Alcor Mergers and Acquisitions.

D&W Fine Pack expanding in SC

By Jim Johnson, *Plastics News*

January 14, 2016 — D&W Fine Pack LLC D&W Fine Pack is ranked as the third largest thermoformer in North America by *Plastics News*.

D&W Fine Pack LLC, one of the country's largest makers of thermoformed foodservice packaging, is investing \$20 million into expanding the company's manufacturing site in South Carolina.

The Elk Grove Village, Ill.-based company indicated the project has already started and is expected to create an additional 60 jobs during the next five years in Fountain Inn, S.C.

Marketing Director Fran Rizzo told *Plastics News* that she is limited in what she can reveal about the investment right now, but did indicate the project will include extrusion and converting.

"D&W Fine Pack remains committed to investing in the latest innovations, skilled employees and business partnerships that will not only strengthen its competitive advantage in the marketplace, but help generate new opportunities for employment, economic development and community relationships," CEO Kevin Andrews said in a statement.

Aside from Fountain Inn, the company has locations in San Bernardino, Calif.; Miami; Cadiz, Ky.; Elk Grove Village and Lake Zurich, Ill.; Fort Wayne, Ind.; Fort Calhoun, Neb.; Hatfield, Pa.; and Gladwin, Mich.

The South Carolina Department of Commerce issued the announcement regarding the expansion. "D&W Fine Pack's investment and the 60 new jobs it will bring to Laurens County is a big win and will have a real impact on the people of this state," Commerce Secretary Bobby Hitt said in the announcement.

D&W Fine Pack is owned by Mid Oaks Investments LLC, a Buffalo Grove, Ill.-based private investment firm.

D&W Fine Pack was created in 2010 after the acquisitions of Wilkinson Industries in 2004, Dispos-o Products Inc. in 2009, C&M Fine Pack Inc. in 2009, and Tri-City Packaging in 2010, the company previously indicated.

Mid Oaks later invested in CM Packaging Group Inc., Clear Lam Packaging Inc.'s thermoforming division, and Jet Plastica Industries Inc. to help expand D&W Fine Pack, according to the investment firm's website.

D&W Fine Pack is ranked as the third largest thermoforming company by a *Plastics News* ranking of the industry, behind Dart Container Corp. and Pactiv LLC, with an estimated \$500 million in sales.

Mid Oaks also owns Plastic Packaging Technologies LLC, a maker of flexible packaging such as pouches, bags and film roll stock.

Kiefel Acquires Bosch Sprang

Kiefel GmbH Freilassing, Germany

February 1, 2016 — Kiefel GmbH – part of the Brückner Group based in Siegsdorf, Germany – intends to acquire a 100% share in Bosch Sprang B.V. located in Sprang-Capelle, Netherlands. Both parties signed a purchase agreement last week which is still subject to the approval of the EU cartel authorities.

The main focus of Bosch Sprang, a specialist in the field of thermoforming technology, lies in the development and manufacture of tilting molds for use in the production of plastic cups. Its team of some 100 employees has made a considerable contribution to the current state of technology.

Bosch Sprang is a worldwide established supplier to producers of thermoformed rigid packaging parts. The company employs a sophisticated approach to customer service, which embraces everything from product development, prototyping, sample production and production optimization to a permanent service presence at customers' production facilities. A highly qualified workforce, top-class products, an in-house laboratory and mechanical engineering, as well as the positive reputation among customers, provide an excellent basis to further expand the company as a technology and development partner.

"This deal does not just bring together two of the technology and market world leaders but also two teams with an absolutely customer-centred approach and an eye to the future", in the words of Kiefel's CEO, Thomas J. Halletz. "The range of services supplied by Bosch Sprang also perfectly matches Kiefel's portfolio as a manufacturer of thermoforming machines, while enhancing our ability to serve the highly demanding tooling needs of the premium segment."

"Regardless of whether we supply our customers with one-off tools or we offer them an even greater range of services in close cooperation with Kiefel", says Rob Smeulders, CEO Bosch Sprang, "it is the customer who will ultimately benefit from the long expertise and the excellent service of both companies."

This will lead to an optimized interaction between machine and forming-tool.”

The company management of Bosch Sprang will be in the hands of the existing CEO Rob Smeulders and of Thorsten Emge, who is presently the Head of Central Engineering at Kiefel GmbH.

TEQ Reaches into Europe with Acquisition of Thermoformer Plastique

By Michael Lauzon, *Plastics News*

February 5, 2016 — Thermoform Engineered Quality LLC has purchased Plastique Group LLC to add production in the United Kingdom and Poland.

Thermoform Engineered Quality LLC has stretched its geographic reach into Europe with the acquisition of Plastique Group Ltd.

TEQ announced Feb. 1 it bought Plastique of Tunbridge Wells, England, a \$35-million-per-year plastic sheet thermoformer that also has wood pulp molding capability, which provides a new in-house material option for packaging customers.

“We have multiple customers in the United States who prefer we have manufacturing closer to Europe,” said TEQ President Randy Loga in a telephone interview. The deal also helps Plastique Group supply its customer base with operations in the United States, he added.

Plastique Group was directly acquired by Esco Technologies Inc., the St. Louis parent company of TEQ. Plastique Group is being combined with TEQ. Its primary markets of packaging for pharmaceuticals, personal care and specialties mesh well with TEQ’s diverse customer base. Most of TEQ’s sales are packaging for food, medical, personal care and other sectors but it also has a sizable industrial thermoforming business. Plastique Group will especially boost TEQ’s sales for medical devices and pharmaceutical packaging.

“Plastique Group is a well known thermoformer in the United Kingdom,” Loga said.

Plastique Group’s revenues will push TEQ’s annual sales close to \$100 million and its staff count to about 400, Loga estimated. Plastique Group’s manufacturing plants are in Nottingham, England, and Poznan, Poland. TEQ, headquartered in Huntley, Ill., has two manufacturing locations there and one in Fremont, Ind. It bought the latter operation last November in a deal that lifted its sales in medical packaging.

In total, TEQ now has more than 30 thermoforming lines, 17 of which are in the United States. It operates Class 100,000 and

10,000 clean rooms and Loga claims it has the largest installation of Kiefel in-line thermoformers in the United States.

TEQ notes the addition of pulp molding allows the company to offer a wider range of sustainable packaging. Customers can choose between thermoformed plastic and molded pulp, or a hybrid of both. Plastique Group can make high quality, precise packaging that is a step above most molded pulp packaging, according to TEQ. Loga said TEQ could bring the molded pulp option to U.S. production but he did not elaborate on that strategy.

TEQ bought Plastique Group from Business Growth Fund of London, which invested 5 million pounds (\$7.3 million) in the firm in July 2014 to spur growth. Plastique Group used the fund infusion to diversify into molded pulp and to expand its factory in Poland. Plastique Group became the first European producer of smooth-surface, thermoformed pulp packaging, BFG claimed in a news release.

“The similarities within the two operations are extensive and having the chance to jointly develop new market opportunities across the globe is extremely exciting,” said Plastique Group managing director John Lowe in a news release.



TEQ bought privately held Fremont Plastics Inc. in November. Fremont, founded in 1980 by Lyndon Tucker, specialized in sterile-ready and non-sterile medical goods and packaging. P&M Corporate Finance advised Tucker in the sale.

TEQ has been growing internally in addition to the recent acquisitions. In 2013 it spent \$6 million on upgrades and infrastructure in Huntley, including a second clean room and an ecologically beneficial elastomeric roof that saves it 15 percent in cooling costs.

TEQ owner Esco has other operations making engineering filtration products for aviation, space and process markets. It also has a major presence in radio-frequency shielding products, provides diagnostic instruments and owns a library of machinery test results that are useful to energy generation and similar industries around the world. Its annual sales exceed \$540 million.

“With the addition of Fremont Plastics and Plastique, both acquired at reasonable prices, we now have a technical packaging solutions business approaching \$100 million in annual revenues with above industry-average profit margins,” said Esco Chairman and CEO Vic Richey in a news release. “We now have a solid foothold in Europe and have added a new complementary technical packaging solution.” |

Industry Case Study: Cultivating World-Class Safety

By Beth Larson, Corporate Communications Specialist, Sekisui Polymer Innovations, LLC

Recently there has been a lot of news about the growth of manufacturing in the United States. The sector has been gaining traction ever since its decline hit rock bottom in 2010. Expansion is being driven by a complex mix of factors including increased commercialization of shale gas, China's rising wages, technology, reshoring initiatives, and increased productivity in the American workforce. Unfortunately, the growing talent deficiency in US manufacturing is a disconcerting counterpoint to this trend. Given predictions that there will be a two-million worker shortage in US manufacturing over the next decade, attracting and retaining skilled employees is more important than ever.

SEKISUI Polymer Innovations, LLC is wagering that one important factor is crucial in attracting and retaining workers: a corporate culture that places employee safety at its center. Ronn Cort, COO and President explains, "Our goal is to put our people first. They are our most valued and cherished asset. Aside from our moral and legal obligations to provide a safe workplace, treat everyone with respect and dignity, and compensate fairly, no other factor more strongly impacts the success of our business, and in turn, the mutual success of our customers, employees, and communities."

In 2014, the two SEKISUI companies KYDEX, LLC in Bloomsburg, PA and ALLEN Extruders, LLC in Holland, MI were combined to form SEKISUI SPI. SPI began manufacturing in Bloomsburg, PA in 1990 and in Holland, MI in 1970.

In 1962, SEKISUI Chemical Co. was the first Japanese manufacturer to establish operations in North America – prior to Toyota or Honda and before Sony came to the US. "We are fortunate to be owned by SEKISUI," Cort notes. "Because of our Japanese manufacturing heritage, we have always employed the practices of continuous improvement. It is part of everything we do and every decision we make. A safe workplace is a cardinal principle of two Japanese manufacturing traditions: *kaizen* (literally, "change good," the practice of continuous improvement) and *monozukuri*." *Monozukuri* is a Japanese term that translates as "making things," and encompasses the whole process of manufacturing, from sales to transporting goods. More important, it is the company's manufacturing philosophy and its collective consciousness. Cort continues, "One of the tenets of SEKISUI Chemical's *monozukuri* is 'product making is the development of human resources.'"

Obviously, doctrines are just words without the means and methods to live by them. SPI's safety-first standard is manifested in its safety program, which was established over a decade

ago. In 2012, the company began an intentional journey to reinvigorate their program.

It all began with a visit to Japan. Cort recalls, "We visited two of our sister SEKISUI companies that had the highest rated safety training and we visited a safety *Dojo* (training facility) in Tokyo to understand the process. A year later, we implemented our 5s program (workplace organization) and opened our first training *Dojo*." The program is now multifaceted with focus on employee accountability and empowerment, training, OSHA compliance, facility improvements, and measurement.

The program is now multifaceted with focus on employee accountability and empowerment, training, OSHA compliance, facility improvements, and measurement.

A culture of accountability and empowerment

The EHS (Environmental Health and Safety) team is responsible for championing program development and maintenance, but everyone at SPI is responsible for safety.

"It's cliché, but true: you can't have employee accountability without trust and empowerment first," states Colin Kelley, EHS Senior Training Specialist.

Over the past five years, SPI has been diligently nurturing a culture where everyone takes care of each other. That responsibility is the cultural nucleus affirmed by management. "Employees will never be disciplined for an unintentional incident or making a suggestion for improvement." Cort remarks, sharing an anecdote of his own recent misstep. "We had installed a stop sign within our Bloomsburg main campus, and by habit, I drove right by it without stopping. An employee followed me to my office and reminded me about the new sign.



FIGURE 1: SPI's Safety Moto adorns a wall in the Dojo.

I was very pleased that he felt comfortable saying something to me.” Bloomsburg main campus, and by habit, I drove right by it without stopping. An employee followed me to my office and reminded me about the new sign. I was very pleased that he felt comfortable saying something to me.”

The foundation of safety for everyone at SPI is 5s, a method that uses five steps to keep an orderly workplace. Translated from Japanese to English the steps are Sort (eliminate anything that is unnecessary), Set, (set in order), Shine (clean), Standardize (establish process), and Sustain (keep in working order).

Employees also contribute to safety through their participation in *Gemba* walks during which they search for potential hazards in the facilities. *Gemba* translates from Japanese as “real thing” and is the practice of observing work where the work is happening. SPI has noticed that *Gemba* walks result in more actionable items when employees evaluate places where they don’t usually work. Tom Kapelewski, EHS Manager explains, “When you’re in an environment every day, you get what scientists call ‘inattentional blindness’ – we consciously see only a small subset of our visual world. When we are focused on one thing, we fail to notice others.” In 2015, SPI fixed 846 of the 1,105 potential hazards reported during *Gemba* walks.

Besides the hazards reported during *Gemba* walks, employees can make suggestions for improving safety any time by entering them into a safety suggestion database on SPI’s intranet. The EHS team evaluates suggestions weekly and designates a champion for fixing each hazard.

Conducting Japanese *Kiken Yochi* or 4RKY also engenders employee support. 4RKYs anticipate hazardous situations during four rounds of analysis at the source: identify potential issues, note the top two hazards the issue might cause, determine countermeasures to solve these hazards, and vote on the two top countermeasures and implement them. These informal, often in-the-moment sessions usually take a half hour.

Training and improvements

Investing in training programs, facility and equipment improvements, and personnel also substantiate SPI’s edict that there’s nothing more important than safety.

The five-person EHS team is responsible for monitoring safety programs and procedures for all employees while ensuring the facility is in compliance with OSHA regulations. They administer extensive new hire training, equipping new staff with safety practices. Curtis Perry, SPI Training Specialist was the most recent addition to the EHS team when he joined Larry VanderBosch, EHS/ISO Manager in Holland this past April. The program’s expansion to the Holland location is inspiring, notes Kapelewski, “We’re fortunate to have a cohesive team at both locations. Curtis and Larry have been champions for capturing and passing on the spirit and intent of what we do.”

Facility and equipment improvements have ranged from relatively small purchases such as PPE (Personal Protective Equipment) and alternate tools for utility knives, to a \$650,000



FIGURE 2: Lock out tag out. One of the 26 workstations in the Dojo

fire suppression system.

Most safety training takes place in the *Training Dojos*. In Bloomsburg there are 26 stations and a meeting room for work sessions and lectures. Stations include computers for online coursework and most provide hands-on training with real equipment. Topics include operating fire extinguishers, gauging weight before lifting properly, lock out/tag out procedures for equipment maintenance, and pinch point hazards. Throughout the year all employees are required to attend annual Dojo training and each month, employees attend an hour-long SEKISUI *Safety Matters* meeting for training on safety topics and an update on company performance. Employees are required to take 40 hours of safety training in Holland and 80 in Bloomsburg before they even step onto the plant floor.

In 2013, the company continued its legacy of classroom and online training by investing in company-wide classroom training with SafeStart® (developed by Electrolab Training Systems). SafeStart® emphasizes creating a safety mindset at work and at home.

Safety rewards

A safe place to work is surely its own reward, but like many safety programs, SPI’s has its incentives. Safety Bucks rewards employee involvement with money to accrue for prizes – with a paid day off as the ultimate prize. The Safety Belt program is a seven-belt reward system that recognizes proactive safety, allowing everyone to work peer-to-peer as safety ambassadors at work, home, and on the road. Employees achieve belts based on their safety initiative including submitting hazard suggestions, completing courses, participating in safety programs and on committees, and attending OSHA training. The final belt positions an employee as part of the EHS safety team. Part of that vision is what SPI calls “The Art of Safety,” Kelley explains, “We have a number of employees who are trainers now. A major goal of our program is to have everyone trained to be a trainer.”

The environment

Safety for the environment is also paramount at SPI and managed through two standards. Both facilities are ISO 14001

certified, which helps companies achieve their environmental responsibilities. The other standard is zero emissions, which means zero waste to landfill.

SEKISUI Chemical manufacturing sites are mandated to become zero-emissions facilities. To date, all but three SEKISUI facilities in Japan and three of the 14 North American sites are certified, including SPI's Holland facility. SPI Bloomsburg is almost there, says Cort. "As environmental regulations increase, there is a massive industry shift toward sustainability. For many, the goal is zero emissions. It's relatively easy to go from 50% to 5%, but getting from 5% to zero is very difficult." Mike Angell, plant manager for SPI Holland elaborates on the far-reaching advantages of zero emissions, "Being good stewards of the planet is an admirable achievement, but the benefits don't stop there. Our zero emissions certification definitely helped with our ISO 14001 certification. And, when we conduct tours with customers or suppliers and explain our program, they are visibly impressed and ask for more information so they can mirror our efforts."

The journey continues

By reasonable accounts, the safety program at SPI is robust and world-class, but their leadership acknowledges there's always opportunity to improve. "Of course we're never finished improving safety. But our measurements show that what we are doing is working. Our culture is steadfast and moving in the right direction," reports Aaron Douglass, EHS Coordinator.

Cort agrees, "When decisions are required, especially in-the-moment decisions, culture is what steers behavior. Culture takes away ambiguity. Our people know how to act safely."

SEKISUI SPI invents and manufactures KYDEX® and ALLEN® branded thermoplastic sheet products, which are specified in demanding applications such as aircraft interior components, medical imaging machines, mass transit interiors, and heavy equipment and agriculture. Owned by SEKISUI Chemical Co., SPI employs 200 people in its two Bloomsburg, PA facilities and 100 in its Holland, MI plant.

SOURCES

*<http://www2.deloitte.com/us/en/pages/about-deloitte/articles/press-releases/skills-gap-public-perceptions.html>

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Celebrating a Milestone

By Jeff Pitt, Plas-Logic Ltd.

The SPE Thermoforming Division is renowned for its professionalism, dedication to its craft and for the excellent conferences it holds annually.

Over the past few decades, these factors have been the major drivers for members within the global thermoforming community to congregate, to network and to learn at these prestigious events.

25 years ago, a small group of European thermoformers would meet regularly at the Thermoforming Conferences and in doing so became good friends and subsequently forged a trade partnership. In parallel, their frequent visits to the US also laid the foundation for professional international friendships. It was these strong relationships between the respective boards that led to the efforts of both parties to develop an independent European Thermoforming Division of the SPE.

The Thermoforming Division totally supported this bold initiative. With countless volunteer hours from a team that included John Griep, Jim Throne, Art Buckel, Steve Hasselbach, Steve Murrill and Gwen Mathis (to name but a few), the US division leaders promoted the alliance which resulted in the Europeans organizing a preliminary thermoforming conference in Manfred Jacobs's facilities in Wilhelmsdorf, Germany.

Obviously, this proposal was not without its commercial risks, but almost to a man, everyone involved at the time agreed that the only way to assess the interest levels of the Europeans in

developing such an industry trade organization was to hold the event and test the waters for themselves.

Over 60 invited guests attended the two-day European event which was immediately viewed as an unequivocal success. Spurred on by the positive responses, the decision was made not only to form the division, but also to attempt to hold an international thermoforming conference in Ghent, Belgium in March 1998.

The inaugural conference saw over 180 attendees from 23 different countries meeting for two and a half days of technical seminars, topical debate and interactive networking. The Conference was also heralded as an enormous success and subsequently the decision was made by the executive committee to hold biennial thermoforming conferences.

The second conference returned to Ghent in March 2000. Subsequent events followed in Zurich 2002, Viareggio 2004, Salzburg 2006, Berlin 2008, Antwerp 2010, Venice 2012 and Prague 2014.

Although the route to the 10th European Thermoforming Division Conference has not always been an easy one, 20 years from when the decision was first made to embark on this project, the European Thermoforming Division (ETD) Board is now as strong, diverse and motivated as it has ever been. This team of dedicated industry professionals are totally focused on ensuring that this flagship event in Sitges, Barcelona from 10th–11th March inclusive, will retain its reputation for being the single-most important event in the calendar for the thermoforming industry. An event not to be missed indeed. |





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- **The Future Use of Plastics**
- **Case Study – Business Case for “Recycling”**

3D Developments Session

- **The Latest Update on 3D-Tec –**
A technical review of Additive Manufacturing: When 3D Printing turns a Hyperflexible Manufacturing Method
- **Tooling in Thermoforming by 3D –**
Improvements on Tooling for the Thermoforming Industry, promoted by the adoption of 3D Printing Fabrication
- **3D Printing in the Industry –**
The Sweet Spots of 3D Printing for the Thermoforming Industry
- **Creative Design – a Philosophy to help develop Thermoforming Market Potential**
How can ‘Design Thinking’ help to create Thermoplastic Material Solutions that differentiate products and stands out in the Market Place?

Thin Gauge Session

- **The Thermoformed Coffee Capsules Market 2016**
Delivering a great Cup of Coffee!
- **IML-T - In Mould Labeling Technology Update:**
 - **Filed Report and New Applications for IML-T for Lids**
 - **Thermoform or Injection IML?**
- **Fresh Food Market –**
Latest Trends and how to grow and succeed?
- **Thermoforming - a Spanish Experience**
Enhancing the Coffee experience with a barrier capsule

Friday, 11 March 2016

Heavy Gauge Session

- **Lean Manufacturing – Proof that the ‘Old Way’ isn’t always the best Way!**
A case study of smart Production Techniques
- **Workshop/Panel Heavy Gauge Thermoforming: The exciting future of Thermoforming in the USA versus in Europe,**
The Heavy Gauge Thermoforming Past & Future
- **Keynote: Future Trends in Automotive Lighting and the Contribution of Thermoformed Materials**
- **New Developments on Sheet Extrusion:**
Technology Workshop: Q&A with the Experts

General Session

- **Optimization of Thermoforming Processes by means of combined in-situ Measurements and Simulations**
- **Increasing Material Efficiency by Inline Sheet Thickness Measurement**
- **Heat under Control –**
Novel Contact Heating Technology for Thermoform Evolutions
- **Determination of Temperature Profiles across Sheet Thickness during Heating Phase of Thermoforming Processes**
- **Optimization of the Heating Process during Thermoforming of Thermoplastics**

Thermoforming Technical Problems I Wish I Could Solve

What's the Issue with Forming Low-Density Foam Sheet? Part 3

By Jim Throne, Dunedin, FL

Prologue

Welcome back. This is the third and final part of a short series that deals with low-density foams. So far, we've considered heating low-density foam to its forming temperature. We discussed the issue of overheating the foam. And we recognized that low-density foam is mostly gas surrounded by very thin plastic membranes or films. We spent some time looking at a side-bar on FTIR during which we considered all plastics in general and thin plastics in particular to volumetrically absorb inbound radiation. Now we're ready to apply the side-bar information to heating of low-density foams and conclude by considering what happens when we try to form parts from the heated sheet.

Okay, let's heat the sheet

Consider some generalities about low-density foam. The average cell size of, say, 30 kg/m³ (2 lb/ft³) PS foam is about 200 microns or about 0.008 inches. Consider the wall thickness in the top of an egg carton to be about 0.080 inches or about 10 cells thick. Say the typical cell wall thickness is about 10 microns. There are about 11 cell walls that are parallel to the sheet surface, with a total plastic thickness of 11 x 0.0004 = 0.005 inches. From the last graph in our FTIR study we see that less than 60% of the inbound radiant energy is absorbed by the cell walls.

So, one answer to heating foam is to increase the temperature, right? Wrong. Overheating foam sheet can be disastrous. As a result, most foam thermoformers use gentle heating techniques. Foam ovens operate at low temperatures (~450-500F or 230-260C) and often are quite long. This allows the operator to allow the sheet to soak up the heat, to "sneak up" on the forming temperature range, as it were. This helps ensure that the sheet is at a near-uniform temperature throughout its thickness when it is ready to be formed.

So what is the forming temperature range?

The foam forming temperature range is usually quite a bit below that for the unfoamed plastic. This graph compares the effective areal draw ratios of foamed and unfoamed PS.

As is apparent, this foam has a very narrow forming window of only a few degrees above its glass transition temperature of 100+C. In short, the plastic may be in its rubbery elastic state but it is nowhere near its traditional forming temperature range. Oh, and what about the entrapped air? Aha! Trying to push a foamed sheet into a specific shape is akin to pushing on a myriad of highly resistant pillows.

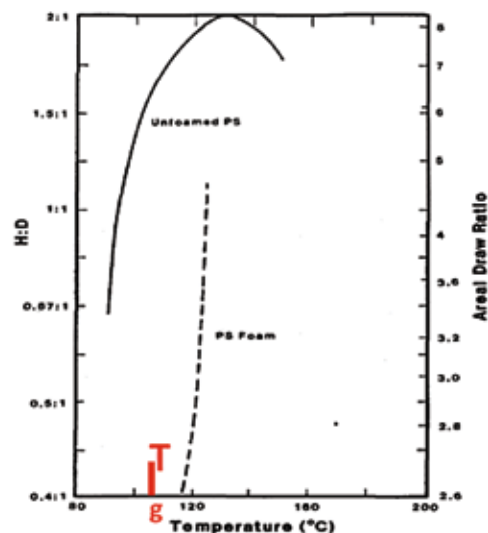


FIGURE 1: Graph showing areal draw ratio of foamed and unfoamed PS

So how do we form something this stiff?

Simply put, we squash it between two mold halves, called matched tooling. Of course, if we tried to do that with unfoamed PS at, say, 120C, we would split the sheet in many places. So why can we squish foam without it splitting into many places? Let's take a ubiquitous example – the egg carton:



FIGURE 2: Typical example of the classic foamed egg carton

The thickness of the foam typically ranges from about 0.08 inches (2.032mm) on the shallow-draft lid to about 0.008 inches (0.2032mm) at the bottom of the egg cup. To achieve this dramatic reduction in thickness we use matched tooling.

But instead of the foam being stretched in a shearing fashion, it is shear-compressed. This means that the cell membranes (near)-perpendicular to draw direction fold and/or rupture whereas cell membranes (near)-parallel to draw direction

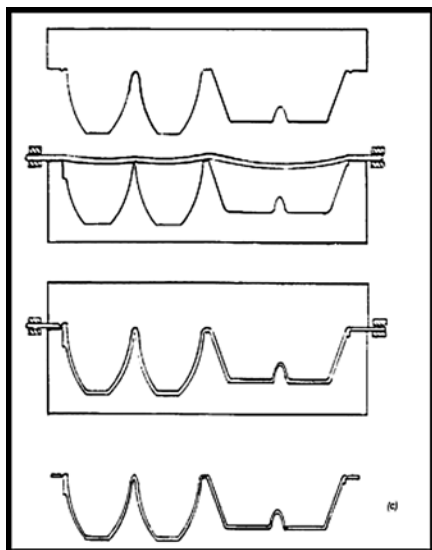


FIGURE 3: *diagram of matched tooling for egg carton forming*

orient - without substantial stretching - in draw direction as we see in the schematic and in photo-micrographs. So, while some of the cell membranes may rupture or tear, those typically parallel to the draw direction remain intact, thereby yielding a supposedly liquid-tight – or in the case of the egg carton, a yolk and egg white-tight – container. Of course, foams are opaque to us. As a result, every shopper dutifully opens each carton to ensure that all is well with the hens' products. So, while some of the cell membranes may rupture or tear, those typically parallel to the draw direction remain intact, thereby yielding a supposedly liquid-tight – or in the case of the egg carton, a yolk and egg white-tight – container. Of course, foams are opaque to us. As a result, every shopper dutifully opens each carton to ensure that all is well with the hens' products.

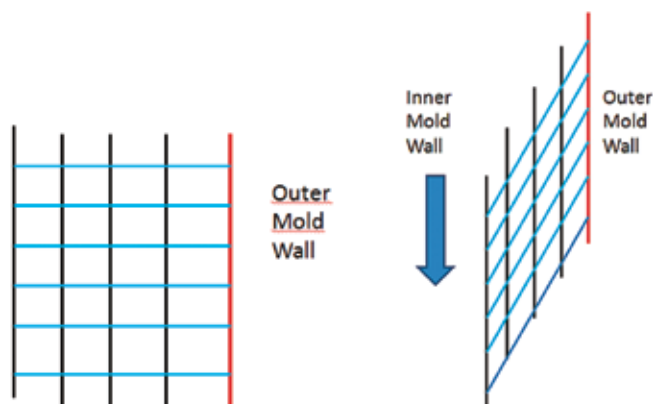


FIGURE 4: *schematic of inner and outer mold walls*

So, while some of the cell membranes may rupture or tear, those typically parallel to the draw direction remain intact, thereby yielding a supposedly liquid-tight – or in the case of the egg carton, a yolk and egg white-tight – container. Of course, foams are opaque to us. As a result, every shopper dutifully opens each carton to ensure that all is well with the hens' products.

So why does this area need more study?

The interactions between foam sheet temperature, applied force, foam density, and the extant plastic properties (such as Tg and the range of the temperature-dependent rubbery-elastic



FIGURE 5: *photograph showing draw direction of foam (?)*

region) are quite complex and a thorough understanding of the technology is lacking. In addition, we have yet to discuss the effect of dissolved foaming agent gas on the rubbery-elastic nature of the foam. Without a firm technical understanding, we cannot hope to improve on or optimize the process. |

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Advanced Analysis of Thermoforming Films

[Editor's note: The following article is adapted from Advanced Thermoforming by Sven Engelmann Dipl. -Ing. Mr. Engelmann has a distinguished career in polymer science and thermoforming technology. Mr. Engelmann was a development engineer for thermoforming technology and polymer materials at Illig and the Director of Polymer Technology at Gerhard Schubert GmbH, a leading designer and manufacturer of innovative form/fill/seal technologies. In addition to his work in the private sector, he is a lecturer at the University of Stuttgart and the Aalen University of Applied Sciences where he teaches "Basics of Thermoforming." He is the author of numerous articles published in both the US and Europe on thermoforming, polymer processing and injection molding. His recent book, published by Wiley, can be purchased on Amazon. He can be contacted via s.engelmann@ebb-microparts.de]

Written in cooperation with Manfred Reichert, Remshalden, Germany

The methods used for advanced analyses of thermoforming films are differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and torsion pendulum resistance.¹ These methods are described here to show how the behavior of thermoforming films can be recognized and evaluated before they are processed on the thermoforming machine. For example, films made by different manufacturers that nominally seem to be the same often have significantly different behaviors on the thermoforming machine tracing reliable information before processing will improve. However, it is often necessary to consult specialized institutes to obtain more exact analyses and interpretations.

23.1 Product Quality Demands

The quality of the films to be thermoformed is extremely important. The production of cups, bowls, and so forth, from a flat film constitutes a very important process step for the packaging of food.

The operating behavior of a thermoforming machine is considerably affected by the quality of the films and ultimately the operating behavior determines the efficiency and the productivity of the production process. Film that is not machine processible or that is inferior in quality can cause serious machine malfunctions and disrupt the whole thermoforming process.

In practice, it often difficult to trace malfunctions to definite causes:

- Is the malfunction caused by the machine? For example,

problems with the heating of the film or problems during the actual thermoforming process may be caused by a bad calibration of the process sequence, a damaged material being used, or the wrong material for the plug-assists, and so forth.

- Is the malfunction caused by the quality of the film? The quality may vary or have irregularities.
- Is the malfunction due to both machine and film incurring problems?

The many possible causes of malfunction need to be analysed in each individual case. Regarding the film, its quality is very important and should be analyzed exactly by using the suitable analysis methods.

Because the materials used in thermoforming films are continually evolving, this places increasing pressure on the operators of thermoforming lines to test the films. There is today demand for better and, above all, consistent quality of the manufactured containers as well as for the use of thinner films to save on the cost of packaging materials and thus raise economic efficiency. To this end it is absolutely necessary to ensure that the film has good machinability before thermoforming process begins on the machine.

The situation is exacerbated by the fact that films like polypropylene (PP), which is relatively difficult to process, are being more and more utilized. PP is a semicrystalline plastic. In simple terms, this means that the material can only be heated in a very narrow temperature range, and this presents relatively high requirements for the construction of the heating station of the machine. The temperature ranges for the processing of other readily available materials such as polystyrene (PS) and polyvinyl chloride (PVC), which have amorphous characteristics, is wider.

In a PP film the morphology (i.e., its inner amorphous state structure with its semicrystalline configuration) also influences the thermoforming process. Other influences are the nature of the film extrusion process, the PP types used, and the conditions for the storing of the films.

An extensive analysis of films and their quality control must, as far as possible, facilitate the acquisition and evaluation of these quality features. Until now only the so-called monofilms (PP and PS) were discussed; however, in practice, multilayer films are often used for the packaging of damageable products that have to have a very long shelf life. So such multilayer films have an additional barrier layer against oxygen and/or water vapor.

For all these films a definition is necessary, and should be as exact as possible. Recall the classic test methods described in Chapter 22, as were used for an exact assessment of the

film quality:

- Free shrinkage measurement
- Thickness measurement (thickness of the complete film and thickness of the individual layers)
- Tensile strength test
- Surface texture (gloss factor)
- Flame coloration (rapid test in order to determine the material

However, these classic methods are not sufficient because they have only a limited informative value. By their means neither the basic material nor its quality can be identified. A pronouncement concerning the respective amorphous state structure and thus the film's thermoformability is only conditionally possible.

Often the films from different manufacturers nominally seem to be the same. Sometimes, with the above-mentioned methods, a detailed analysis of the films is not possible.

Some films may even present differences that are not easily discernible. These differences may originate from the quality of the raw materials or from the number and quality of the additives in the film. It is also possible for recycled material to be utilized as one layer of the film—however, this layer must not come in contact with the product. Finally, the production of a film—meaning the technology of the film extrusion process—can differ from manufacturer to manufacturer.

All these factors may have an impact on the processing behavior of the machine.

Besides the classic testing methods, optimized and practice-oriented methods for analyzing thermoforming films can obtain valuable additional information. These methods complement the conventional methods and remove some of their disadvantages:

- DSC (differential scanning calorimetry)
- DMA (dynamic mechanical analysis) • Torsion pendulum test
- The torsion pendulum test is close to DMA and is used by some companies as quality test method.

23.2 Differential Scanning Calorimetry

With help of the differential scanning calorimetry (DSC) method, thermal effects are determined that are connected to physical transformations such as glass transition, melting, and crystallization. Glass transition is the reversible transition in amorphous materials or in amorphous regions within semicrystalline materials from a hard and relatively brittle state into a molten or rubber-like state. Furthermore the specific thermal capacity of the films can also be determined through DSC. The DSC is defined according to DIN 51007 and DIN 53765.

For DSC the material is subjected to a controlled temperature/time program whereby the heat flow absorbed and released from the sample is measured. The temperature difference between the sample and a reference constitutes the measurement. This temperature difference is proportional to the heat flow that is absorbed or released from the sample. Thus all physical and

chemical processes that are related to a thermal effect can be characterized. It is possible to obtain information about endothermal and exothermal heat tones, and thus it is easily possible to discern material differences within the various film batches.

The DSC offers the best means for recognizing differences in materials. The practical reason for using the DSC method of analysis is as follows: thermoforming machines are adjusted to a particular kind of film for the acceptance runs as defined by the reference film. A DSC analysis of this film is carried out and the data are recorded in a reference diagram. If the customer later uses films that are different from the one defined during the acceptance test—and which may be characterized by a different, or worse thermoforming, behavior on the machine—this can rapidly and easily be determined through DSC, which registers the thermal behavior of the samples. A characteristic “fingerprint” of the tested film is thus obtained.

At this point an example for the application of the DSC analysis for the industry should be mentioned. A dairy company carried out tests with PS thermoforming films from different manufacturers. These films had a different thermoforming behavior (although they should nominally all possess the same qualities). With help of the DSC analysis it could be proved that the results (thermal capacity, glass transition temperatures) for the film that featured good thermoforming behavior were different from the results for the film with worse thermoforming behavior.

The DSC signal relating to the first heating beyond the softening point provides the thermomechanic history of the material and thus important information concerning its processing (e.g., relating to the production of the film). With the material completely softened, its previous history is “erased.” The subsequent cooling creates a homogeneous condition and determines the material's solidification behavior is indicative of its crystallization behavior. The material's properties at the second heating of the material thus forms the basis for the direct comparability of this material with other samples. DSC also detects:

- Different basic materials
- Different conditions for the production of films

For the inspection of incoming goods it is therefore recommended that the films be examined using DSC to ensure that the thermoforming process will proceed safely.

However, it is not always possible to obtain by DSC analysis exact information on the thermoforming behavior of a film. For this purpose two other methods may be appropriate: dynamic mechanical analysis and the torsion pendulum test.

23.3 DMA (Dynamic Mechanical Analysis)

With help of DMA the viscoelastic properties of films are determined. Plastic always consists of two components: a viscous component and an elastic component. The proportion of these two components—whether more viscous or more elastic—allows conclusions to be made about the thermoformability of a film.

With DMA—and unlike the DSC analysis—it is possible to analyze the potential thermoformability of films. The result of a DMA measurement is, on the one hand, the so-called storage modulus or E -modulus E' of a material that makes it possible to determine the rigidity of a plastic material. On the other hand, the second result of the analysis, the so-called loss modulus E'' , describes its viscous behavior as a plastic.

The basic material characteristics determined by means of DMA are in accordance with DIN 53440, DIN 53513 as well as ASTM D 4065-90. Precise statements relating to the mechanical behavior of a sample are possible. The mechanical characteristics are determined in relation to the temperature and a possible stress rate/frequency. The E -modulus is a measurement for the solidity or the rigidity of a sample and gives a precise value as to the formability of the material. The loss modulus, in contrast, gives statements about the viscous components, which are also important for formability.

DMA is an analysis that is universally applicable and provides a complete characteristic of a film. Beside the information above, DMA provides, at the same time, information on glass transitions and the strain characteristics of a material.

23.3.1 The Functional Principle

A sample is subjected to harmonic—as defined by amplitude and phase—excitation from an oscillating dynamic load $F(t)$, which creates a deformation in the sample. The sample's reaction to this oscillation is analyzed (according to amplitude height and phasing), and information about the rigidity of the material is obtained. Depending on the kind of material (more viscous or more elastic), an input signal is given to the “oscillating” excitation, which includes a more or less “phase lag.” Expressed in simplified terms, for a completely elastic material (rubber ball) there is no internal damping through the excitation, the phase lag is 0. For a completely viscous material (honey) the energy brought into the material is entirely “dissipated” (absorbed). No energy can be stored elastically. The phase lag is 90°. The tested plastic films always consist of a viscous and an elastic proportion. According to the quality of the material the percentages of these two components vary (the value of the phase lag lies somewhere between 0 and 90°), which can have various effects on a plastic's thermoformability.

23.3.2 The Complex E -modulus E^* in Conjunction with Temperature

The complex E -modulus E^* consists of the storage modulus E' and the loss modulus E'' . For a purely elastic material the complex E -modulus E^* equals the storage modulus E' (phase lag = 0). The other extreme is a purely viscous material: the complex E -modulus E^* equals the loss modulus E'' (phase lag = 90°).

There are two curves that have a phase lag of the angle ω . The two lower curves are the characteristics/gradient of $\tan \delta$, where $\tan \delta$ is the so-called loss factor: the relation of the loss modulus E'' to the storage modulus E' . It is a measurement of the internal dampening of the film. A high value indicates the presence of a raw material having a pronounced viscous forming part. A low value indicates that the film would be difficult to use for

thermoforming purposes because the forming energy is, to a large extent, elastically stored, so subsequent to the removal of the forming force during the thermoforming process the film would be elastically reset.

DMA proves to the extent to which a material manifests viscous or elastic behavior. The percentage of viscous and elastic parts has an effect on the thermo-formability of the film. DMA results can be further illustrated by means of a so-called strain sweep. The complex E -modulus E^* response to dynamic strain is depicted, where the temperature remains constant during the whole process. Tested in the example is the behavior of PP films that were manufactured by different procedures.

23.4 Torsion Pendulum Test

The torsion pendulum test is another form of dynamic mechanical analysis, but it tests the mechanical thermal behavior of thermoforming films. By the corresponding differences in the characteristic curve progression of semicrystalline thermoplastics, conclusions can be drawn about the thermoforming behavior. In this test the characteristic conditions and transitions for the heating of the plastic are described. These characteristic curves of the mechanic thermal behavior depicts, on the one hand, the behavior of amorphous plastics (as PS) and, on the other hand, the behavior of semicrystalline plastics (as PP).

The curves visualize the fact that semicrystalline PP is somewhat more difficult to thermoform than amorphous PS. For each plastic the behavior of the shear modulus (elastic component) and the loss factor in referenced to the shown temperature. For amorphous plastics the shear modulus in the range of the glass transition temperatures drops relatively moderately. For semicrystalline plastics, on the contrary, an abrupt drop of the shear modulus at the temperature of the crystallite melting range can be observed, which signifies that the thermoforming of these materials will be more difficult.

23.5 Summary

- DSC analysis is the most field-tested method.
- Measurements by DMA facilitate recording of the viscoelastic characteristics of the film that determine the thermoforming behavior. When combined with the DSC analysis, films can be clearly identified.
- No prediction about the machinability of a film can be made, however, as the terms “machinability” and “thermoforming quality” are not yet clearly defined.
- Hypothetically DMA can be carried out to measure unknown contents of films. However, in practice, the correlation of the DMA results with the actual thermoforming results on the machine needs further study.
- The torsion pendulum test is close to DMA and is used by some companies as quality test method.
- End users only rarely test films with any of the methods mentioned above; they are rather dependent on companies or institutes that specialize in these analyses and provide interpretations of the results, and enabling compilation of analysis results with those of the thermoforming process by experiments

on a machine. The venue for the testing would, of course, be determined by the cost and the time needed for outside tests.

1. Dr. Manfred Reichert, InnoNET—Partner in Cooperation with Innoform Coaching GbR, Hasbergen and Innoform GmbH Testservice, Oldenburg, Germany, Inno—Letter Thermoformen, Analytik von Thermoformfolien Teil 2, Innoform GmbH, Oldenburg, Innoform Coaching GbR, Hasbergen, 2010. *Advanced Thermoforming: Methods, Machines and Materials, Applications and Automation, First Edition. Sven Engelmann. I*

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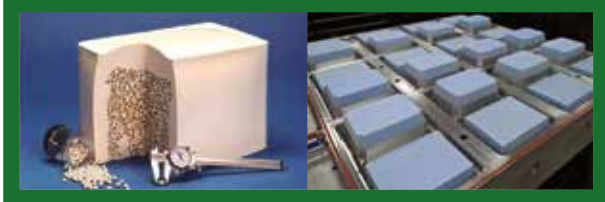
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The Myth of Radiopacity

By Jim Throne, Consultant, Dunedin, Florida

Abstract

In this work, I present an alternative approach to understanding the way radiant energy heats plastic sheet.

Introduction

In thermoforming, plastic sheet must be heated to an appropriate forming temperature before mechanically and/or pneumatically being shaped into desired products. There are three generally accepted modes of heat transfer – conduction, convection, and radiation. Conduction involves direct contact of the sheet with a solid heating source. Convection is heat transfer between a fluid, usually air, and the solid sheet. And radiation is electromagnetic energy interchange between a remote heating source and the solid sheet.

Contact or conduction heating is preferred for sheet – sometimes called film or foil – with thickness substantially less than 1.5 mm and often less than 250 μm . Hot air oven or convection heating is recommended for sheet – sometimes called plate – with thickness substantially greater than 3 mm and often greater than 12 mm.

For sheet having thickness between foil and plate, all three heating modes are in play. These are shown in schematic in Figure 1. The relative importance of each depends on sheet thickness and availability of heating sources.

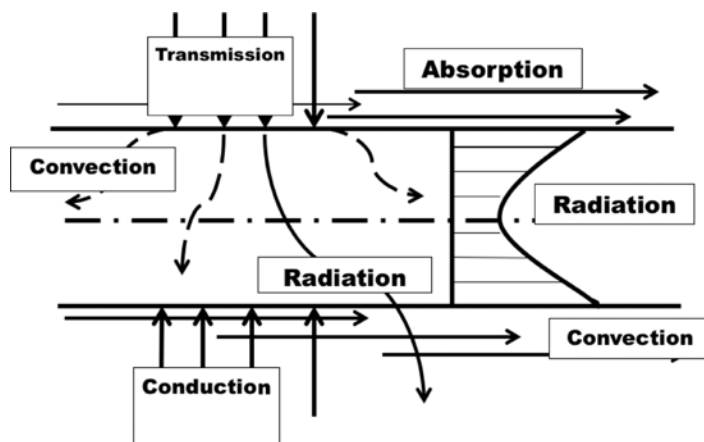


FIGURE 1: Conduction, convection, and radiation schematic in planar sheet

In this article, I examine the characteristics of inbound radiant energy from the point of view of the sheet. In particular, I am interested in energy uptake in the first few mm of the sheet surface. While I will concentrate on monolithic sheet, certain aspects will also pertain to multilayer sheet. I'll give a more

detailed analysis of multilayer sheet in another article.

Caveat Lector. I am positing an alternate approach to radiant heating of plastic sheet. I am in no way offering an exhaustive review of the theories of conduction and radiation heating of planar surfaces. Readers who wish more in-depth analyses need to seek authorities in the three modes of heat transfer [1-3].

What is Radiopacity?

An object that obstructs the passage of radiant energy from any source is called radiopaque. For my thesis here, this means that all the inbound energy from radiant heater is absorbed by the sheet. And further, all the inbound energy is entirely absorbed on the surface of the sheet. And even further, all the absorbed energy is conducted from the surface to the core of the sheet.

These assumptions enable me to neatly categorize radiation (a surface effect) from conduction (a volumetric effect). Consider this mathematically. The general time-dependent conduction-convection-radiation equation that describes heating of a solid object is:

$$\text{Equation 1} \quad \rho c_p \frac{\partial T}{\partial \theta} = k \nabla^2 T + Q(x, y, z; \theta)$$

Where ρ is plastic density, c_p is plastic heat capacity, k is plastic thermal conductivity, T is plastic temperature, Q is the internal heat generation term, x - y - z are rectangular coordinates and θ is time.

This equation is accompanied by boundary conditions (one for each surface of the object) and an initial condition (usually the initial temperature of the object). The solution to this equation depends on the characteristics of the energy received at the sheet surfaces as well as internal heat generation. I normally simplify this by assuming that the sheet thickness dimension is substantially smaller than its surface dimensions.

$$\text{Equation 2} \quad \rho c_p \frac{\partial T}{\partial \theta} = k \frac{\partial^2 T}{\partial x^2} + Q(x, y, z; \theta)$$

Because the sheet is passive – meaning that there is no mechanism for internal heat generation – it seems appropriate to omit the “ Q ” term. This leaves the traditional one-dimensional transient heat conduction equation:

$$\text{Equation 3} \quad \rho c_p \frac{\partial T}{\partial \theta} = k \frac{\partial^2 T}{\partial x^2}$$

Energy is supplied to the passive sheet through conduction and radiation at each of the sheet surfaces. The equations that describe this are technically called boundary conditions and are written as:

$$\text{Equation 4} \quad k \frac{\partial T}{\partial x} (x = L, \theta > 0) = h(T_{\text{air}} - T) + G(T_{\text{heater}}^{*4} - T^{*4})$$

$$\text{Equation 5} \quad -k \frac{\partial T}{\partial x} (x = 0, \theta > 0) = h(T_{\text{air}} - T) + G(T_{\text{heater}}^{*4} - T^{*4})$$



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In these equations, the first term on the right is the energy input to the sheet surface ($x=0$ or $x=L$) from convection, where h is the convective heat transfer coefficient. The second term on the right is the energy input to the sheet surface from radiation. G is a parameter that incorporates geometry and certain radiation characteristics of both the heater and the sheet. The asterisk indicates that the temperature is the absolute value.

In addition, the initial sheet temperature is needed to begin the solution of the parabolic equation, sometimes called a “marching” equation:

$$\text{Equation 6} \quad T(0 \leq x \leq L; \theta = 0) = T_0$$

Where T_0 is the initial uniform sheet temperature.

This set of equations (3-6) mathematically describes the heating of passive radiopaque sheet. These are often referred to as transient one-dimensional boundary value equations. I’ve used them in many articles and books to describe the various aspects of heating thermoformable sheet [4].

Finite difference equations are the standard method of solution. Although the explicit form of the equations has greater chance of error generation, I find it accurate enough for most heat conduction problems.

Here now is the reason for this article. For a long time, I wondered whether plastic sheets really heat in accordance with these dicta. In other words, are plastics really radiopaque to incident radiation?

What’s Wrong with Radiopacity?

To begin, consider the entire electromagnetic spectrum, Figure 2. Wavelength is usually given in microns (μm). We see in the 0.38-0.7 μm wavelength range. We usually radiantly heat plastic sheet in the far infrared range or in the 2.5-10 μm wavelength range.

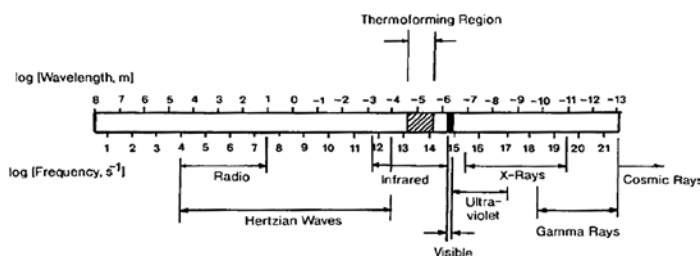


FIGURE 2: *Electromagnetic spectrum. Note visible wavelength range (0.38-0.7 μm) and far infrared wavelength range for thermoforming*

The father of heat conduction theory is Jean-Baptiste Joseph Fourier, a nineteenth-century physicist-mathematician dude [5]. Fourier Transform Infrared (FTIR) Spectroscopy, an analytic way of determining the wavelength-dependent measure of far infrared energy that passes through thin films, is based on his arithmetic. An example of infrared wavelength-dependent transmissivity is shown in Figure 3, for polyethylene. In essence, these scans represent the chemical make-up of our materials.

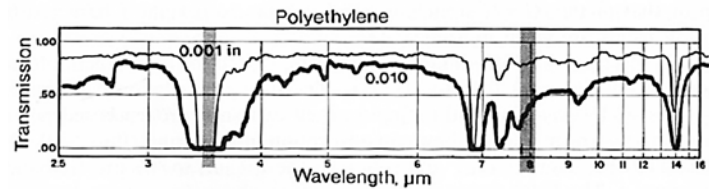


FIGURE 3: *Fourier Transform Infrared spectrum for Polyethylene*

As an example, the C-H bond absorbs all inbound radiant energy around the 3.5 μm wavelength. Equation 5 relates the peak radiant temperature to a specific wavelength. For 3.5 μm , the peak temperature is 555 °C.

$$\text{Equation 7} \quad T^* (\text{°R}) = 2897.6 / \lambda_{\text{max}}$$

As a result, In my seminars I often point out that a specific plastic heats most efficiently when the heater temperature is set where transmissivity is at its lowest point.

A while back, it occurred to me that the FTIR scans also provided a clue as to why thin films do not heat as efficiently as predicted by the radiopaque models given above. In a word, a portion of inbound radiant energy was being transmitted completely through the films. In essence, not only are the films semi-transparent (or semi-opaque), they are volumetrically absorbing. I’ll return to the issue of heating thin films in a subsequent paper.

Consider this: If thin films are absorbing radiant energy volumetrically, so are thicker sheets. So, can we consider thick sheets to be radiopaque?

Consider the polyethylene FTIR on more detail. Two aspects of the scans are apparent. Transmissivity is both wavelength-dependent and thickness-dependent. Plastics react to inbound radiation in three ways. It can reflect, absorb, or transmit. Essentially all plastics reflect only a small portion of inbound energy. For this discourse, I consider radiation to be negligible. The FTIR scans show transmission. I conclude that if, for example, 50% of inbound energy is transmitted, the remaining 50% is absorbed.

Because transmission (and therefore absorption) is thickness-dependent, it is possible to characterize the thickness-dependent transmissivity as Equation 6:

$$\text{Equation 8} \quad \tau(\lambda) = e^{-\beta(\lambda)x}$$

Where $\beta(\lambda)$ is a plastic-specific wavelength-dependent extinction coefficient and x is the distance in from the sheet surface.

Technically the extinction coefficient should be constant and independent of sheet thickness. I’ve spent some time trying to extract extinction coefficients from FTIR scans such as those in Figures 3-5.

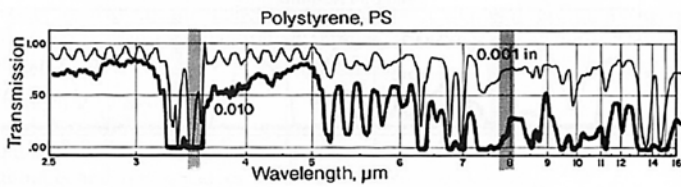


FIGURE 4: Fourier Transform Infrared spectrum for Polystyrene

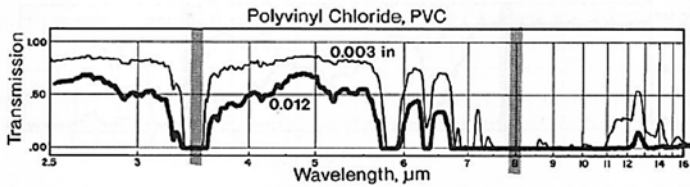


FIGURE 5: Fourier Transform Infrared spectrum for Polyvinyl Chloride

Average transmissivity values and extinction coefficients for these three plastics are shown in Tables 1 and 2:

Table 1
Average Transmissivity Values (4-7 μm)

Plastic	Transmissivity for thin film	Transmissivity for thick film
PE	0.88 @ 0.0254 mm	0.56 @ 0.254 mm
PS	0.76 @ 0.0254 mm	0.35 @ 0.254 mm
PVC	0.62 @ 0.0762 mm	0.44 @ 0.305 mm

Table 2
Extinction Coefficient Values (4-7 μm)

Plastic	Coefficient, mm-1 for thin film	Coefficient, mm-1 for thick film
PE	5.03	2.22
PS	1.8	4.13
PVC	6.27	2.70

As is apparent, the coefficient values appear to decrease with increasing film thickness. Of course, the caveats here are that I am working with only two thickness values and that I am averaging the transmissivities across a small (but important) portion of the far infrared spectrum. I'll discuss this conundrum in more detail in another technical paper. Now I want to return to the issue of radiopacity.

It is apparent from even casual observation of the FTIR scans that if the sheet is thick enough, radiant energy transmission is zero and absorption is unity. In short, then if the sheet is thick enough it appears to be radiopaque.

So what is the problem, you ask? According to the traditional radiopaque model, Equations 3-6 demand that the inbound energy be totally absorbed at the sheet surface. But if the plastic behaves as shown in the FTIR scans, the radiant-convective boundary condition is wrong. According to the volumetric-absorption Equation 6, the total amount of radiation absorbed at $x=0$ sheet surface is zero.

I agree that the volumetric-absorption region of the sheet is very small. For many plastics, polyethylene being the exception, it is perhaps less than 0.5-1.0 mm. Beyond this thickness the sheet is truly radiopaque, with conduction being the only method of energy transfer to the sheet core. But the region at or near the sheet surface is quite important. It is often the positive or display surface of the formed part. The sheet may be multilayered or foamed. For the rest of this article, I propose examining model building for what I will now (incorrectly) call near-radiopacity.

Model Building for Near-Radiopacity

Again the problem is the radiant boundary condition of the radiopaque model. I think there are (at least) two approaches to modifying the conduction model.

The first method is to consider the sheet to be of two plies of identical plastic. The first ply is the surface ply. Inbound radiant energy is volumetrically and totally absorbed in this ply. The second ply is the core. Energy is transmitted from the ply interface to the core only via conduction. I believe that this two-ply method has some credibility when dealing with multilayer sheet. I think a variation of the Kubelka-Munk analysis [6] will work well there. But for now I'll set this aside to concentrate on a second variation.

This approach returns to the general heat conduction equation that incorporates the internal energy generation term, Equation 1. Consider the inbound energy as behaving as ersatz internal heat generation. Here's how I think this can work. Recall that I am ignoring reflectivity. As a result, absorptivity + transmissivity = 1 [$\alpha + \tau = 1$]. Consider α , the thickness-dependent absorptivity:

$$\text{Equation 9} \quad \alpha = 1 - \tau = 1 - e^{-\beta x}$$

For now I assume that the extinction absorption coefficient β is truly constant. Now Equation 1, for transient one-dimensional heat conduction becomes:

$$\text{Equation 10} \quad \rho c_p \frac{\partial T}{\partial \theta} = k \frac{\partial^2 T}{\partial x^2} + Q'(1 - e^{-\beta x})$$

What is Q' ? The total amount of radiant energy interchange for the semi-radiopaque plastic is the same as that for the fully radiopaque model, except that the interchange occurs within the first few elements of the model instead of being at the sheet surface. The internal energy term now is written as:

$$\text{Equation 11} \quad G(T_{heater}^{*4} - T^{*4})(1 - e^{-\beta x})$$

As a result, Equation 8 now read as:

$$\text{Equation 12} \quad \rho c_p \frac{\partial T}{\partial \theta} = k \frac{\partial^2 T}{\partial x^2} + G(T_{heater}^{*4} - T^{*4})(1 - e^{-\beta x})$$

The boundary and initial conditions are now written as:

$$\text{Equation 13} \quad k \frac{\partial T}{\partial x} (x = L, \theta > 0) = h(T_{air} - T)$$

$$\text{Equation 14} \quad -k \frac{\partial T}{\partial x} (x = 0, \theta > 0) = h(T_{air} - T)$$

$$\text{Equation 15} \quad T(0 \leq x \leq L; \theta = 0) = T_0$$

Now the only surface energy interchange is that between the solid surface and the convected air. This set of equations [9-12] is again solved with finite difference method but with a major exception.

In the radiopaque model, the time-dependent sheet surface temperature is specific only to the boundary condition. Now it is imbedded in the general conduction equation. Although an implicit finite difference method such as Crank-Nicolson can be used to accommodate the imbedded sheet surface temperature, I think that the straight-forward explicit method should provide suitable accuracy for most sheet thickness cases.

How Significant is the semi-Radiopaque Approach?

The obvious answer is: It depends. There are two elements at play – the plastic response to inbound far infrared energy and the sheet thickness.

If the plastic exhibits high transmissivity resulting in a low value for the extinction coefficient, volumetric absorption could be a significant factor on conduction far into the plastic sheet. Polyethylene would be a good example of this, based on its FTIR scan, Figure 3. On the other hand, I would expect plastics with very high values of the extinction coefficient to show time-dependent temperature profiles quite similar to those determined from the traditional radiopaque model.

It's apparent that radiant energy penetration into the plastic sheet is restricted to a few mm of thickness, even in the polyethylene case. So for very thick sheet, there will probably be little difference in the time-dependent temperature profile from surface to core, regardless of which model I'd use.

What about Surface Temperature Measurement?

There is probably one factor that needs to be considered before I compare and contrast the two models. Remember the C-H bond absorption? Infrared thermometers are usually designed to measure temperature at 3.43 μm wavelength.

Consider the case where the plastic obeys the radiopaque model. All the inbound energy is absorbed precisely at the sheet surface. Because the IR thermometer measures only the surface temperature, I usually get excellent agreement between theory and experiment.

But what about the sheet that volumetrically absorbs the same amount of inbound energy? According to both FTIR scans and the concept of an extinction coefficient, radiation does not heat the sheet surface. Surface temperature increases when energy is conducted backward from the sheet interior. Therefore time-dependent IR temperature measurements of the sheet surface may have values substantially different than values predicted from the radiopacity model.

And to make this more disconcerting, different species of plastics have different values for the extinction coefficients. This means that plastics with low values should show large variance in time-dependent surface temperatures (when compared with the radiopacity model). And plastics with high values of the

coefficients should show closer agreement in measured and calculated surface temperatures.

So What?

What I have proposed here are sets of technical concepts. I have provided no real, honest-to-goodness hardcore data to substantiate my hypotheses. In a subsequent article, I'll offer examples.

Why is this approach so important, you ask? I've already given one reason – the potential mismatch between results obtained from the radiopaque model and measured temperatures. But there are far more important issues than just variations in theory and experiment. Mismatches of transmitted energy at interfaces in multilayered sheet can lead to delamination and microbubble formation. I'll examine this subject in a subsequent article.

Probably the most difficult problem that has eluded conduction/radiation mathematical model builders is a cogent description of time-dependent heating of filled or fiber-reinforced plastics. The standard radiopaque approach is to assume uniform particle/fiber distribution throughout the sheet volume. Using appropriate areas-to-volume calculations, a specific particle/fiber density is defined at the surface of the sheet. Inbound radiation energy is then proportionally absorbed on the surface by both the particle/fibers and plastic. That energy is then conducted toward the core. The particle/fiber filled sheet is considered to be homogeneous in thermal properties that are appropriately weighted for the weight fraction of particles/fibers. It should be apparent that if, instead of radiopacity, the sheet is considered semi-radiopaque (albeit homogeneous in thermal properties), the arithmetic will become quite a bit more complex. I'll save this problem for another time as well.

And one more – heating thermoplastic foam. I've spent decades trying to understand the complex way in which low-density foams heat. Over the years, I've tried to compare the way in which particle-filled plastics and cellular plastics heat. After all, I thought, foams are just particle-filled plastics with the particles having zero density. Unfortunately, although there are some similarities, the radiopaque models with this assumption simply fail to predict time-dependent energy uptake. On the other hand, a variation on the volumetric absorption model I've described here seems to be a better avenue to pursue. I cannot do this topic justice with just a single article. I need to first discuss the general nature of cellular materials. So I will reserve this mostly overlooked general topic for a much later time.

Conclusion

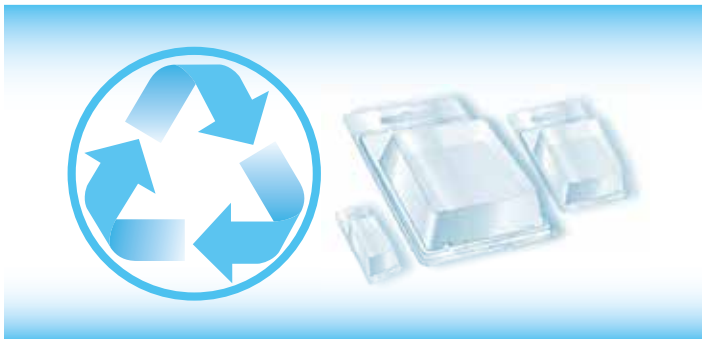
Model building of the sheet heating process is important when trying to predict thermoforming cycle times. I and many of my colleagues have relied on solving the transient one-dimensional conduction heat transfer equation with radiant/convective boundary conditions. I and many of my colleagues have assumed that all the inbound radiant energy is absorbed on the sheet surface and conducted into the sheet toward the sheet centerline or core.

In this paper, I have tried to exploit some fundamental

information from material-specific Fourier Transform Infrared Spectroscopy to create a new approach to model building – one that focuses on volumetric absorption of inbound radiant energy. Solution of the slightly more complex heat conduction equation with modified boundary conditions may lead to a better understanding of how sheet – particularly multilayer sheet – heat. And it may answer the question: Why do sheets of different plastics, when exposed to identical inbound radiant energy levels, seem to heat at different rates?

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From the Vault

[Editor's note: The Thermoforming Division recently completed work on new digital archives to capture and maintain industry knowledge gathered over the past 30 years. The following article appeared in an early newsletter and was one of the first technical articles published by the division. We hope our readers will enjoy this piece by Pete Hughes, one of the founding members of the Division.]



Understanding & Controlling Chill Marks in Thermoforming

By Pete Hughes, Hughes Plastics Co., Inc.

Pete Hughes is a graduate of Macalaster College, St. Paul, Minnesota, with a Bachelor of Science degree in 1952. After six years as an officer in the U.S. Navy, he founded The Hughes Plastics Company, Inc. in 1958. Since then,

his company has grown to have national and worldwide sales in the manufacture of plastic thermoformed and fabricated & component parts for original equipment manufacturers. In demand as a consultant, he has advised companies regarding thermoforming from California to Finland. He has lectured extensively on thermoforming and has been active with the Golden Gate Chapter of the SPE. He is currently chairman of the SPE Thermoforming Division. Several patents are currently registered in his name.

INTRODUCTION

Chill Marks: The Scourge of the Thermoforming Industry

This has been the biggest single technical difficulty at the author's plant for twenty-five years and still has not offered itself for easy solution.

Definitions

A chill mark is defined as the uneven thickness of a thermoformed part caused when material comes in contact with a mold, plug assist, pressure box, or other forming associated paraphernalia during the thermoforming process.

Chill marks, because they generally represent a lumping or uneven distribution of material, reduce the effective use

of materials. In addition, there are the obvious cosmetic discrepancies that occur and additional inconsistencies related to secondary operations.

Because almost all of the information in the paper was developed in the author's plant, it is applicable to heavy gauge sheet forming. Equipment used included a 4-station rotary machine of 1980 commercial vintage and several late model single station machines. All equipment was completely automatic except load and unload operations. All equipment represented the latest design and capital features of the thermoforming industry.

Factors Influencing Thermoforming

At the outset, it was apparent there were many factors which appear to influence chill marks and some we suspected were a factor. The following were considered and will be examined in detail in this paper:

1. Equipment
2. Material: type, thickness, and color
3. Mold temperature
4. Mold design
5. Product design
6. Forming technique
7. Blank size
8. Heating of material

Some of the above factors were examined in close, systematic detail and other factors are commented on from the viewpoint of this company's experience. It will be obvious that most factors could be a subject of a paper all by themselves. It will also be obvious the author has many more questions than answers.

An Examination of the Factors

1. Equipment

Over 25 years the author's company followed the development of most companies: starting with crude heating and vacuum devices; graduating to home-made single station machines; the addition of timers and controls; thence to commercially manufactured automatic equipment. The conclusive factors in judging equipment by this company in regard to chill mark elimination are the following:

a. Rapid Functioning: The quick transfer of material from heater to mold, the immediate application of vacuum and air pressure, the rapid movement of assisting paraphernalia are all necessary so as to "not give the material time to think." Rapid speed of mold, material and accessories are not factors in preventing chill marks but without this ability the equipment is not a part of the solution.

b. Control: Equipment should have positive control of material movement, top and bottom ram movement, air pressure, vacuum pressure, cooling, sequencing and heat. This

control is essential to be able to repeat the desired conditions to reduce or eliminate chill marks when these conditions are identified.

2. Material: Type, Thickness, and Color

To examine these factors we chose a 9-up mold with a ratio of depth of draw to width of 1:1:1. Draft was 3 degrees and mold material was aluminum epoxy. Forming technique used was vacuum snap back pulling a 3" electric eye-controlled bubble. Results measured were the range of thickness of the chill mark step and the range of length of chill marks on each type, thickness or color of material remained the same. Two samples of each material were used.

MATL.	DEPTH OF CHILL MARK	LENGTH OF CHILL MARK	COMMENTS
1/8GP ABS BLACK	.010 TO .060	1/2" TO 1 1/4" ABS	Medium Chill Marks
1/8FR ABS BLACK	.030 TO .070	3/4" TO 1 1/4"	Chill Marks Very Noticeable
1/8KYDEX WHITE	.000 TO .020	.000 TO 1/2"	Slightly Loose Pull But Looks Good
1/8NORYL BEIGE	.010 TO .060	3/8" TO 3/4"	Chill Marks Very Noticeable
3/16NORYL BLACK	.020 TO .060	1/2" TO 3/4"	Ugly
3/16KYDEX BLACK	.005 TO .030	3/8" TO 1/2"	1 Loose Pull Small Chill 1 Tight Pull Large Chill
1/8KYDEX BLACK	.005 TO .020	1/2" TO 1 1/4"	Minimal Chill Mark But Very Loose Pull
1/8NORYL BLACK	.025 TO .070	3/8" TO 3/4"	Chill Marks Very Noticeable

In general; Kydex looks best, next ABS, noryl worst. (Also, the tighter the pull, the bigger the chill marks.)

3. Mold Temperature

We have generally considered the ideal mold temperature to be just below the deflection temperature. A few months ago the author had occasion to note a part which was straight walled, deep draw, minimum radius, made of ABS being pulled with little or no chill mark in his shop. Because the part had earlier displayed chill marks he thought he would use the part to emphasize to the operator his company's belief that a hot mold was one of the chief factors involved in elimination of chill marks. Before commencing his lesson, however, he reached over to feel the mold temperature and discovered it was only warm to the touch. Postponing the lesson he discussed the apparent paradox with his thermoforming department supervisor who assured him that "some parts formed better with a warm mold." Upon further investigation the author and his engineering staff discovered additional evidence to indicate that a warm mold

often produces less chill marking than a hot mold. This apparent contradiction came to light as this paper was being written so further investigation has not taken place. The only explanation we have been able to produce is that as a mold becomes hotter the free slippage of material around the corner of a sharp radius is inhibited by hot material sticking to the mold thus creating a larger chill mark.

4. Mold Design

Here the factors considered do not include the shape of the final part (which we have termed "product design" in this paper). However, we found there were numerous mold design factors which we believe do affect chill marks.

a. Temperature Control: Although we are not sure how much this affects the chill marking we do know the addition of heating coils, fluid cavities, heaters or chillers will cause the chill marks to be consistent.

b. Mold Material: Our belief was that aluminum molds gave the best opportunity to control chill marks. Although we held this belief for over twenty years we have begun to suspect that phenolic molds may hold the answer to chill mark control in some cases. In the last three months we have built about a dozen phenolic molds with mixed results. In half the cases the results showed less chill mark than we had expected. In no case did the phenolic mold produce more chill mark than expected. However, we were not able to budget the time and money to build both an aluminum and phenolic mold of exactly the same configuration.

c. Male and Female Molds: Generally speaking we found little advantage of one over the other but again we had no opportunity to compare male to female molds in exactly the same configuration.

d. Web Blocks: Side web blocks which reduce the drag on a mold area producing a heavy chill mark seem also to reduce the amount of chill mark. The shape and location of web blocks have generally been a prerogative of toolmakers and thermoforming set-up persons at the author's company so little experimentation has been done. In addition, the primary purpose for placement of web blocks has been the reduction of webs, but this variable seems to have good possibilities.

5. Product Design

The initial design a thermoformer will recommend to a designer will be a hemisphere. Maximum draft and maximum radius results in the best material distribution and the least risk of chill marks. This is one of the few truths this paper will produce. Beyond the factors of draft and radius and ratio of depth of draw to width of the draw, there is very little a designer can do to influence this factor.

6. Forming Techniques

The extra material stretching available to the thermoformer using billow forming or snap back forming is worthwhile in almost all application of 2::1 or greater draw depth to width ratio. For shallower parts the increased risk of webbing in billow and snap back normally dictates straight vacuum or pressure forming with or without a plug assist. It is the experience of the author's company that plug-assist forming, while useful in producing more consistent wall thickness and reducing web, does little to

eliminate the chill mark problem. On the contrary, often the use of a plug assist adds a whole new set of chill mark problems. Some thermoforming experts advocate the use of felt lined vacuum boxes to pre-shape plastic prior to final forming over a mold (or using the reverse process with felt lined plug assist and a female mold} but the author's company has been unable to substantiate this theory in the prevention of chill marks.

7. Blank Size

The overall size of the material compared to the size of the mold is a definite factor in the control of chill marks. Turning a mold diagonal to the blank of material used not only uses available material to best advantage but reduces chill marking. When this is not practiced the amount of material used from the edge of the mold to the edge of the frame is dependent on the height of the mold. The author's company uses a ratio of 1:2 in this situation, i.e. if the mold height is 4" the amount of material used from the edge of the mold to the inner edge of the frame should be 2". Of course, other factors such as use of female mold, plug assists, web blocks, vacuum boxes, etc. influence the application of this ratio.

8. Heating of Material

In developing this paper only ceramic cone heaters and calrod heating was available and considered. We found little or no difference on the heating sources on chill marking. The thoroughness of heating, i.e. the evenness of heat throughout the thickness of the sheet at time of forming seemed to have an effect. Providing a slightly cooler temperature on the side of the sheet opposite the mold seems to reduce chill marking. An incompletely heated sheet, i.e. cooler in the inside than the outside, seems to reduce material flow and cause a heavier and wider chill mark.

Conclusions

What Do We Know?

- Tightly controlled equipment is essential to consistent success.
- Color and thickness have little influence in chill marking.
- A temperature controlled mold provides consistency.
- Maximum draft and radius will produce minimum chill mark.
- An increase of depth of draw ratio increases the incidence of chill marking.
- Judicious choice of blank size will reduce chill marking.



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What We Think We Know But Are Unsure Of

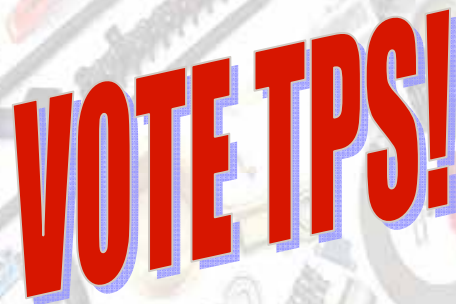
- Some types of material seem to be less susceptible to chill marks than others.
- The ability of material to slip easily around mold corners reduces chill marks.
- Web blocks reduce chill marks in some cases by reducing material drag.
- Billow forming and snap back forming reduce the incidence of chill marks.
- Careful and selective heating of material will reduce chill marking.

What We Don't Know

- What effect mold temperature has on chill marks.
- What effect the type of material has on chill marking. |

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Conor Carlin, Editor, *Thermoforming Quarterly*

This year marked the 10th anniversary of AMI's Thin Wall Packaging Conference in Europe. What started as a small gathering with only 48 people in 2005 is now an important industry event that consistently draws over 200 delegates. Brand owners, resin suppliers, converters and OEMs from both sides of the Atlantic are drawn to the city of Cologne to hear the latest developments in materials and processes for thermoformed and injection molded thin wall packaging. With conferences already established in Europe and North America, AMI is expanding to Southeast Asia next year with a new event in Singapore (September 20-21).

Martyna Fong, Packaging Consultant, of AMI opened the proceedings with a summary of industry trends over the past ten years. It was interesting to note that several themes are still evident today, including T-IML and injection compression molding. This could suggest a long technology adoption curve on the part of converters or simply a lack of compelling project economics against established processes. While IML for injection is now part of mainstream practices, T-IML has not entirely convinced major converters to switch from dry-offset and other decoration methods despite multi-year and multi-million dollar investments by OEMs. Given recent announcements from Illig on a standard platform and from Kiefel on a partnership with Marbach and Ilsemann, this could be set to change.

With ~2.9 million tons of resin and a projected CAGR of 1.1% from 2015-2020 in the EU-28 region, the TWP sector is mature, though innovations and investments continue throughout the value chain. AMI identified 4 major themes / megatrends over the decade: sustainability (light-weighting, waste and energy recovery); financial pressures (rising costs, consolidation); barrier packaging (extended shelf life, new technologies) and shelf appeal (decorative designs, customer convenience). Key innovations include technology and materials related to ready-meals and baby food while the democratization of luxury continues to drive new and sexy packaging for espresso, gelato and chocolate.

By way of comparison, AMI's data (2013) for the North American market shows ~3.5 million tons of resin in TWP with 56% used in food service applications. The Chicago-based conference is held every May and is proving to be an attraction for many of the same global players who operate in multiple markets.

PS vs PP

One distinct thread throughout the event was a running battle between PS and PP with two suppliers, Cobelplast and Coveris, claiming development of new 'snappable'

or 'breakable' polypropylene sheet. The price differential between PP and PS is a key driver of this and related developments. Though neither is yet commercialized, the implication was that, in addition to price concerns, consumers are seeking a replacement for PS based on recyclability and health concerns related to the base monomer in PS. The most visible targeted application is yogurt packs. The mechanical properties of PS impart greater stiffness which allows for multi-packs to be snapped apart. PP is less stiff and typically will hinge, not break, meaning that the material has not been an option for converters making yogurt packs. According to Coveris, these properties can now be replicated in their new PP sheet through a gas-injected middle layer that also reduces part weight. Coveris declined to disclose the structure of the sheet or the additives used. Cobelplast's approach involves PP material engineering that results in bringing the glass transition temperature from -20 to +60 degrees through the use of special additives, so it is a different way to achieve the snapping effect. Cobelplast also declined to elaborate when pressed by the moderators and audience for more specifics on the material properties.

PS has its defenders, and Dr. Isabelle Ydens of Total delivered an impressive and data-driven paper on the qualities of the now seemingly maligned polymer. Processors are moving away from PS for 3 main reasons: price, recyclability and image. The price issue is simple enough to understand: both PP and PET are roughly 25% cheaper than PS on a ~~€~~ton basis (price information at the time of writing). PS is more volatile because it is subject to other influences such as rubber, butadiene and crude oil prices. PP also offers superior thermal resistance.

On the recyclability front, PS can be reused up to 20 times, but the current waste collection infrastructure is lacking and thus a potential resource goes untapped. According to data from Total, PS has a higher energy value than other polymers which makes it a good choice for energy recovery where such programs exist. Additionally, with a high stiffness to density ratio, PS offers opportunities for downgauging. Still, with Keurig's announcement that they are moving away from a PS/EVOH/PE multilayer sheet to PP/EVOH/PP structure, consumers and recyclers have reason to believe that PS will be material non-grata in an important market segment.

But is perhaps on the topic of image where styrene will face strongest headwinds. Like many other issues surrounding the public's perception of plastics, a lack of clearly articulated facts and continued misunderstanding of what constitutes health hazards and risks seems to be part of the reason for the decline of PS.

The Wonderful World of Coffee Capsules

If one product can be said to epitomize thin wall

packaging, it would have to be the K-cup-style coffee capsule. Thermoformed or injection molded, the exponential growth of this convenient little package has provided stimulus for the entire supply chain from resin suppliers to a well-cafeinated public. That said, the environmental end-of-life questions remain thorny and unresolved. Representatives from Nestle, RPC and BASF discussed the matter head-on, with LCA data from Nestlé showing that the largest contributing factor to the overall carbon footprint of a typical Nespresso pod is the cup production and washing. Roughly 15% of the footprint is found in the production of the actual pod itself. The Nespresso website contains a wealth of data and information on Nestlé's sustainability programs. Nestlé also uses plastic coffee capsules for their Dolce Gusto machines, the second biggest brand in Europe. RPC is a provider of these capsules. There are numerous other brands in Europe using plastic capsules many of which are compatible with Nespresso machines.

Dr. Martin Bussman of BASF presented interesting data on the mechanical properties of ecovio® resins. A biopolymer based on renewable raw materials that is also biodegradable, ecovio is similar to PLA and PHA. By contrast, other bio-based, 'drop-in' materials such as bio-PE and bio-PP are not biodegradable. Understanding the application requirements for these new materials is critical to their acceptance in the market. To be considered for coffee pods, materials must have high heat stability so that they are brewable and hot-fillable. Of course, they must also be affordable. The subject of price was brought up several times by delegates during the Q+A sessions, but because most of these new materials are still in the pilot phase (such as Akestra presented by Mitsubishi Gas Chemical Company and Perstorp), their cost is 3-4x current market alternatives.

BASF continues to work on biopolymers and Dr. Bussman offered some cogent thoughts on the life cycle impact of different resins. By drawing a distinction between industrial composting and home composting, Dr. Bussman's presentation illustrated the dangers of simplistic thinking when it comes to 'green marketing' of biomaterials. The fact is that home composting does not create the right conditions for compostable materials to break down.

Innovations in Food Processing Technology

Plastic material properties are obviously important for a variety of reasons, including processability and end-of-life considerations. The continued shift of consumer tastes toward ready meals has implications for both the food itself and how it is packaged. Consumers are showing distinct preferences for natural and nutritious food choices while continuing to lead busy lives. This leads to a search for balance between health and convenience. Two papers, one from Europe and one from the US, discussed new approaches to food processing technology that seek to address this new consumer behavior.

Micvac, a Swedish company, has developed a 'system supply approach' that uses a continuous fill/seal/cook technology to deliver intelligent ready meals. Using thermoformed trays with an innovative lid stock with a valve that emits a whistle when food is cooked, the Micvac approach claims to improve

food quality, safety and shelf life. Founded in 2000, the company has patents on the product and process. They now have about 20 lines in operation around the world.

Michael Locatis of 915 Labs based in Washington State, USA, co-founded his new company to disrupt the way food is sterilized. The industry-standard retort process uses high temperatures over long periods of time which leads to poor quality food that must be further processed with additives to cover up the damage done. Microwave Assisted Thermal Sterilization (MATS) is a new solution to food packaging where food is simultaneously externally heated by a pressurized hot water bath and internally by a patented microwave. According to 915 labs, the retort process hasn't changed much since the early 1900s. Their innovation, developed at Washington State University in cooperation with US Army Labs and several major food producers, dramatically reduces the retort time leading to a higher quality product. Future possibilities include the migration of existing frozen or refrigerated products into shelf-stable formats as well as entirely new products that were previously not considered shelf-stable. Current systems show less energy use than retort systems based on studies done by the US Department of Energy.

Future Developments

Consumer preferences appear to be the single biggest driving factor behind innovations in thin wall packaging, though resin pricing is also important. Regulation will play an increasing role in some areas. France, for example, has a proposed ban on plastic disposables coming in to effect in 2020. Interested parties continue to observe the back and forth over bag bans in various US states to see what the broader implications will be for all plastics packaging.

Material science continues to evolve and with increased acceptance and understanding of LCA data, the environmental impact of plastics can and should be held up for scrutiny. New challenges and opportunities are opening up for both private and public interests, from recycling technology to waste collection infrastructure. It will be interesting to see what the Singapore event will reveal in terms of TWP through an Asian lens. |

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Plastics Made from CO₂

Carbon Dioxide as Chemical Feedstock

By Barbara Dommermuth and Achim Raschka, nova-Institut, Hürth, Germany

In the last decades much work has been done in the field of carbon dioxide capture, purification, and transformation into useful and new fuels, chemicals and polymers. The explosion of interest in CO₂ had led to a new awareness at industrial, societal, and scientific levels with the result that carbon dioxide is no longer a mere waste product, but rather an abundant, low cost raw material. Moreover, using carbon dioxide as chemical feedstock plays a key role for the sustainable future of chemical industry and opens up new prospects for solving global challenges, and in the end it could help boosting a low carb society. High on the European research agenda, scientists and engineers around the world are very active in Carbon Capture Utilization (CCU) research, especially in the fields of solar fuels (power-to-fuel, power-to-gas), but also in CO₂-based chemicals and polymers. Meanwhile the implementation is only a stone's throw from here. First pilot and commercial production plants are already installed in which CO₂ is used either directly as polymer building block or indirectly in combination with other monomers that are not CO₂-derived to obtain a large array of final plastics with tailor-made properties.

This paper mainly focused on polypropylene carbonate (PPC), polyethylene carbonate (PEC) and polyurethanes (PUR) based on CO₂ (Figure 1).

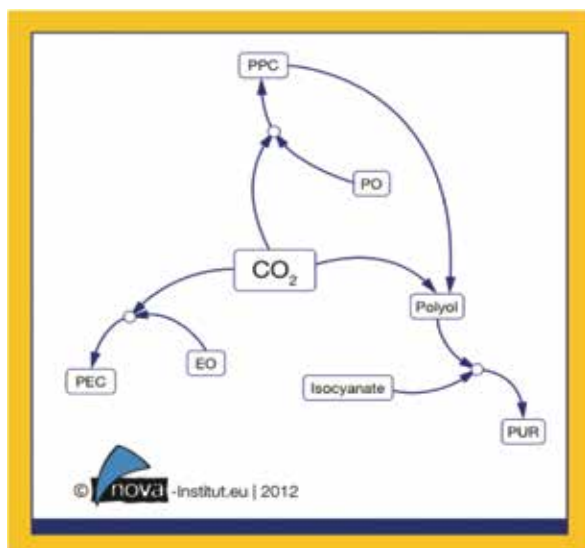


FIGURE 1: Routes to PPC, PEC and PU from CO₂ (nova-Institut GmbH, 2012)

Polypropylene carbonates (PPC) and Polyethylene carbonates (PEC)

Polypropylene carbonates (PPC) are biodegradable aliphatic polyesters and the first remarkable example of plastic that is synthesized from copolymerization of CO₂ and propylene oxide (C₃H₆O). PPC contains up to 50% CO₂ by mass, shows good biodegradability properties, high temperature stability, high elasticity and transparency, and has a memory effect. These characteristics open up a wide range of applications, including countless uses as packaging films and foams, dispersions and softeners for brittle plastics. Other big advantages of PPC are its thermoplastic behaviour, which is similar to many existing plastics, the possible combination with other polymers, and its use as filler. Moreover, PPC does not require special tailor-made machines to process it, making PPC a “ready-to-use” alternative to many existing plastics. PPC is also a good softener for biobased plastics. Many of these, for example PLA and PHA, are originally too brittle and can therefore be used for many applications only in combination with additives. Of course, it is not new, but it clearly illustrates the comprehensive application possibilities of this CO₂-based polymer: PPC gives new options and offers an extensive range of material characteristics in combination with PLA or PHA. This keeps the material biodegradable and translucent, and it can be processed without any trouble in existing machinery. In Germany some years ago, BASF, Siemens and the TU Munich worked on PPC and combined it with PHA and PLA for vacuum cleaner and refrigerator parts to demonstrate the new material's potential and properties.

Besides Novomer and Empower Materials in the USA, the Norwegian company Norner and South Korea's SK Innovation are also well-known companies who are working on PPC. Novomer, an emerging sustainable chemistry company, was founded in 2004 and focused on commercializing of high performance, cost-effective, environmentally responsible polymers and chemicals based on proprietary catalyst technology (Figure 2). This novel technology allows converting traditional chemical feedstock such as propylene oxide with carbon dioxide or carbon monoxide from pollution into cost-effective sustainable materials for a wide variety of applications from thermoplastics to coatings. This results in a family of novel PPC polymers that contain up to 50% CO₂ by weight and they are thus alternative to conventional fossil-based polyether, polyester and polycarbonate polyols currently on the market with up to 90% lower CO₂eq-emissions.

Novomer's proprietary cobalt-based catalyst system is cost-effective (20 to 40% lower cost) and produces a polymer with an extremely precise backbone, and little to no by-products. In addition, the polymerization reaction occurs at slightly above ambient temperature so the entire process generates a very small carbon footprint. The recent commercial interest necessitated an increased volume, so the process has been scaled up to produce

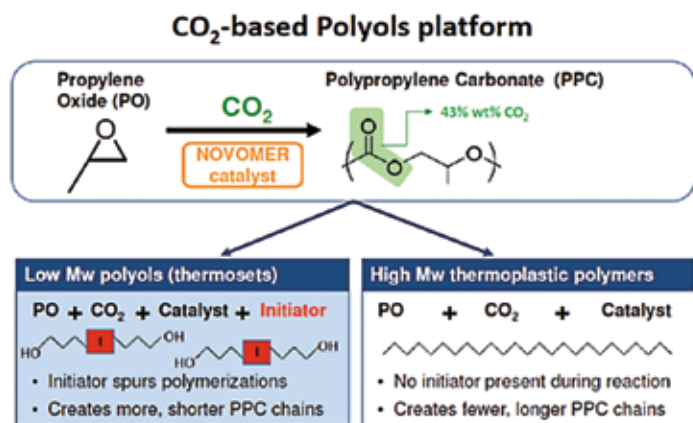


FIGURE 2: Novomer's CO₂-based polyols platform (Novomer 2014)

PPC in the multi-thousand-tonne range. Novomer has started the first commercial production of PPC in 2014 with a production capacity of 5,000 t/a at Albemarle, Houston, Texas. They are using CO₂ from ethanol fermentation, ammonia, hydrogen and ethylene oxide production, reformers, natural gas wells and the flue gas from coal-fire power plants and replace up to half of the fossil flue in the materials. End of 2014 the company has announced that Jowat AG, a leading German supplier of industrial adhesives, is the first to commercially adopt Novomer's new Converge PPC polyols. Jowat is using the polyols in polyurethane hot melt adhesive applications.

Novomer has also a proprietary technology to obtain Polyethylene Carbonate (PEC) from ethylene oxide and CO₂ by a process similar to the one used for the production of PPC. PEC is 50% CO₂ by weight and can be used in a number of applications to replace and improve traditional petroleum-based plastics currently on the market. PEC exhibits excellent oxygen barrier properties that make it useful as a barrier layer for food packaging applications. Furthermore, PEC has a significantly improved environmental footprint compared to polymers typically used as barrier layer such as ethylene vinyl alcohol (EVOH) and polyvinylidene chloride (PVDC).

Alongside SK Innovation, further companies from Asia are working in the PPC area such as Jiangsu Jinlong-CAS Chemical Co., Ltd. with a PPC production capacity of 22,000 t/a. Inner Mongolia Mengxi High-Tech Group Co., Ltd. has also been producing PPC commercially with a production capacity line of 3,000 t/a since 2004. They plan to further expand in the coming years. Both companies are from China.

Econic Technologies is a highly innovative, and fast growing chemical technology company, based at Imperial College, London. The company has developed a homogeneous bimetallic complex for the manufacturing of polymers via co-polymerisation of carbon dioxide and epoxides, for example propylene oxide and ethylene oxide. Up to 30 – 43% of petrochemical feedstock can be replaced by CO₂ from industrial waste streams such as chemical or power plants. Econic Technologies started operations in 2012 after initial investment from Imperial Innovations and Norner Verdandi to develop

the technology further towards commercial applications. The current technology is covered by a number of worldwide patents and patent applications. A further £5.1 million (€7.1 million) investment in 2013 by Jestream Capital and Imperial Innovations will be used to scale up and commercialise the technology.

Definitions: CO₂-plastic? – Bioplastic? – recycled CO₂?

It must be pointed out that it is not easy to give an unambiguous classification to PPC because its definition falling into a grey area. As discussed above, it can be produced from CO₂ recovered from flue gases and conventional propylene oxide, and in this case it cannot be defined as "biobased". It may still be attractive due to its 43% of recycled CO₂ and its full biodegradability. The production of PPC from CO₂, which is produced during the combustion of biomass, can be classified as 43% biobased and complies with the official ASTM D6866 definition. Additionally, if propylene oxide could be produced through the oxidation of biobased propylene, it could be then declared 57% biobased, or even 100% biobased if CO₂ and propylene oxide are both biobased. Since more and more plastics and chemicals will be derived from recycled CO₂ in the future, a new classification and definition such as "recycled CO₂" will be needed to avoid confusing consumers.

Polyurethanes (PUR)

Worldwide, more than 13 million tonnes of polyurethanes are produced every year for a wide variety of applications. Since researchers have found a way to incorporate CO₂ into the molecular structure of polyurethanes, this polymer is also particularly sustainable.

The Dream Production and the intensive research in CO₂ of Covestro (formerly Bayer MaterialScience) is the best-known example at the present time. After four decades of research, the group of German scientists from Covestro, RWE Power, RWTH Aachen University and CAT Catalytic Center, found a suitable catalyst to produce polyurethane blocks made from CO₂-derived polyols (where CO₂ replaces some of the mineral oils). The zinc-based catalyst allows converting propylene oxide with carbon dioxide from the flue gas, produced by coal-fired power plant of RWE Power, into a light-coloured viscous polyol, one of the two building blocks needed to produce polyurethane (Figure 3).

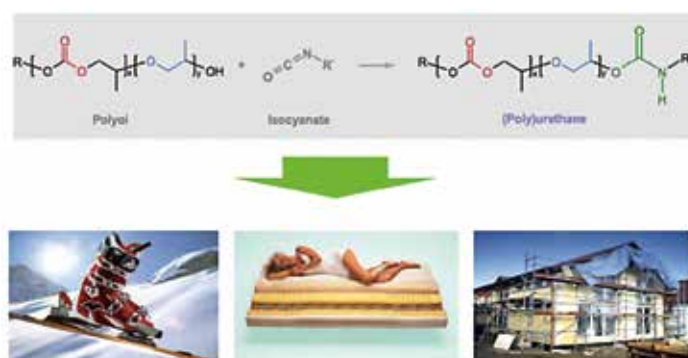


FIGURE 3: Production of polyurethane (Covestro, 2014)

In February 2011, Covestro started up a pilot plant in Leverkusen, in which CO₂ was combined with propylene oxide

on a large scale. Carbon dioxide comes from a RWE power plant near Cologne and is first separated from flue gas, liquefied, filled up in cylinders and in the end transported to Covestro.

Tests disclosed good properties of the new polyol with the result that CO₂-based polyurethanes can be used for many applications. The new polyol has the same level of quality as conventionally manufactured materials, it has an equal stability to existing products and a more sustainable impact. Other noteworthy facts are the lower heat of combustion and the reduction of costs by replacing a certain amount of petro-based propylene oxide by carbon dioxide. Not to be forgotten is the lower greenhouse gas emission, since CO₂ is chemically bound. Taken as a whole the CO₂ balance of the new process is far better than that of the conventional production method.

High-quality polyols based on CO₂ are currently not available on a commercial scale. However, after a successful pilot phase, a commercial production line with an annual capacity of 5,000 tonnes is under construction in Dormagen, Germany, as part of the Dream Production project, totalling an investment of 15 million francs. Commercial production of these CO₂-based polyols is expected to start early 2016. Polyols are initially planned for the production of flexible foam for mattresses.

While the proportion of petroleum in this chemical is 80%, Covestro aims at reducing the petro-based content to 60% in a next step. In the new process, CO₂ is used twice. First, the greenhouse gas is incorporated directly into a new kind of precursor (polyoxymethylene polycarbonate polyol, POM PET), replacing 20% of the petroleum. Second, it is also indirectly used for the production of a chemical that is also incorporated into the precursor for a further 20% saving in petroleum. As a result, the proportion of alternative raw materials is 40%. In addition, the number of plastics that can be produced using carbon dioxide is increasing: among thermoplastic polyurethanes (TPU), films and casting elastomers, it is also possible to use the new polyol in all kinds of applications, including automotive interiors, cable sheathing and sporting goods such as ski boots. This part of the Dream Polymers project is still on lab scale. It is being supported by the German Federal Ministry of Education and Research. External institutions in Germany such as the CAT Catalytic Center, the Leibniz Institute for Catalysis and the Fraunhofer Institute for Chemical Technology are also involved.

Polymers and chemicals derived from biotechnology and other processes

Beside these polymers produced by a chemical synthesis to a polyol via a metallic catalyst, some biotechnology routes for the production of well-known biobased polymers are also on their way. This is especially true for the technology to produce polyhydroxyalkanoates (PHA) and polylactic acid (PLA) based on the biotechnological production of lactic acid. These technologies using acetogenic bacteria to produce this kind of products are not on the market yet but several companies and research bodies are working on it. Examples are among others: LanzaTech (AU/USA), they are using patented, wholly-owned microbes to convert carbon rich waste resources from industries or biogenic sources into valuable fuels and chemicals

(platform chemicals and building blocks) through a process of gas fermentation. Another example but with a strong focus on fuel production is JOULE Unlimited (USA). They pioneered a unique CO₂-to-liquids conversion technology that also offers an entirely new alternative for the production of CO₂-based chemicals. Last but not least Phytonix Corporation from the United States should also be mentioned. They are producing sustainable chemicals directly from carbon dioxide, sunlight, and water via patented photobiological and genomics technology. In this manner, Phytonix produces n-butanol which can be used for the production of biobased plastics.

Without doubt, Liquid Light (USA) is one of the key players in producing major chemicals from low-cost, globally-abundant carbon dioxide. The core technology, developed initially based on licensed processes from Princeton and substantially enhanced since then, is centered on low-energy catalytic electrochemistry to convert CO₂ to chemicals, combined with hydrogenation and purification operations. Liquid Light's first process via Oxalic Acid is for the production of ethylene glycol (MEG), which is used to make a wide range of consumer products such as PET plastic bottles, antifreeze and polyester clothing. Liquid Light's technology can be used to produce more than 60 chemicals with large existing markets, including propylene, isopropanol, methylmethacrylate and acetic acid. The first commercial production plant is planned for the year 2017.

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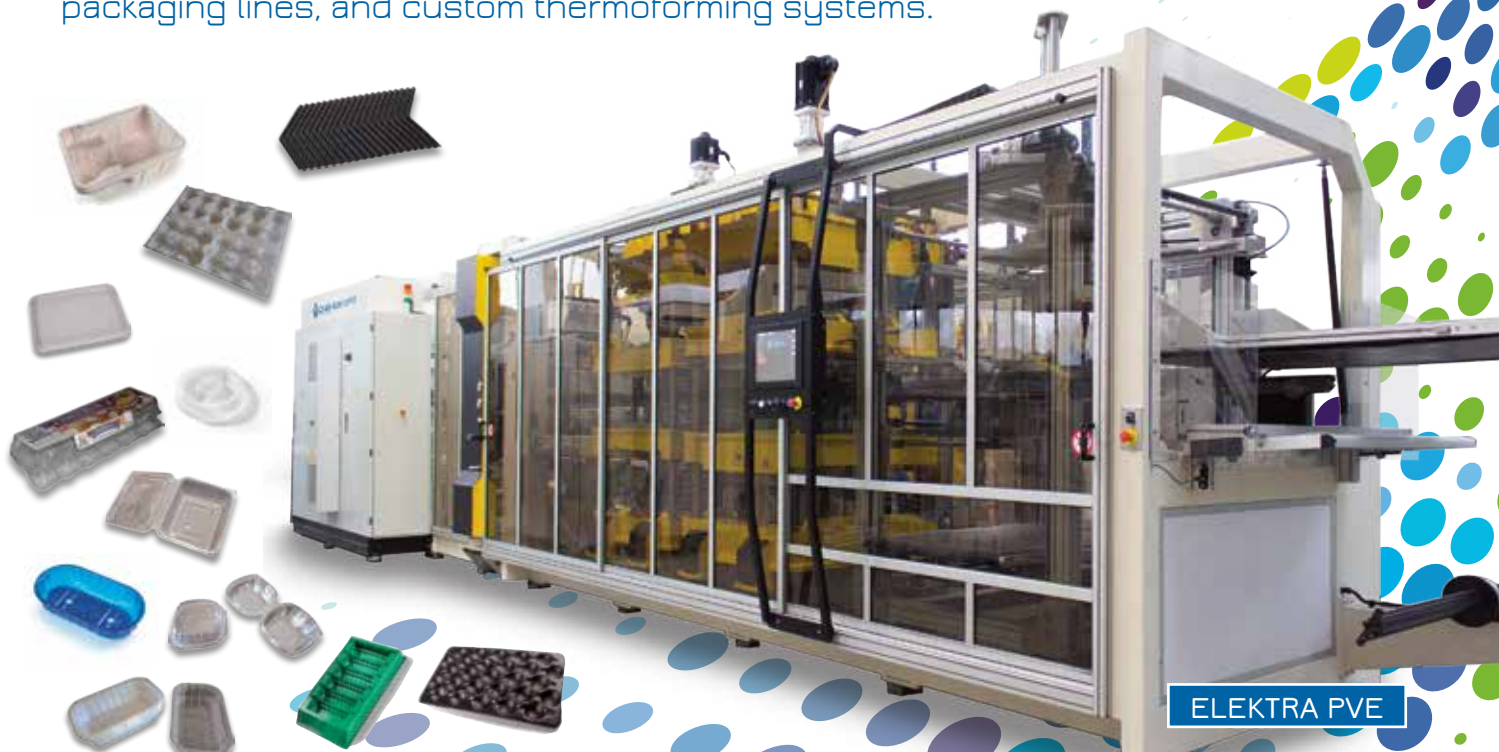
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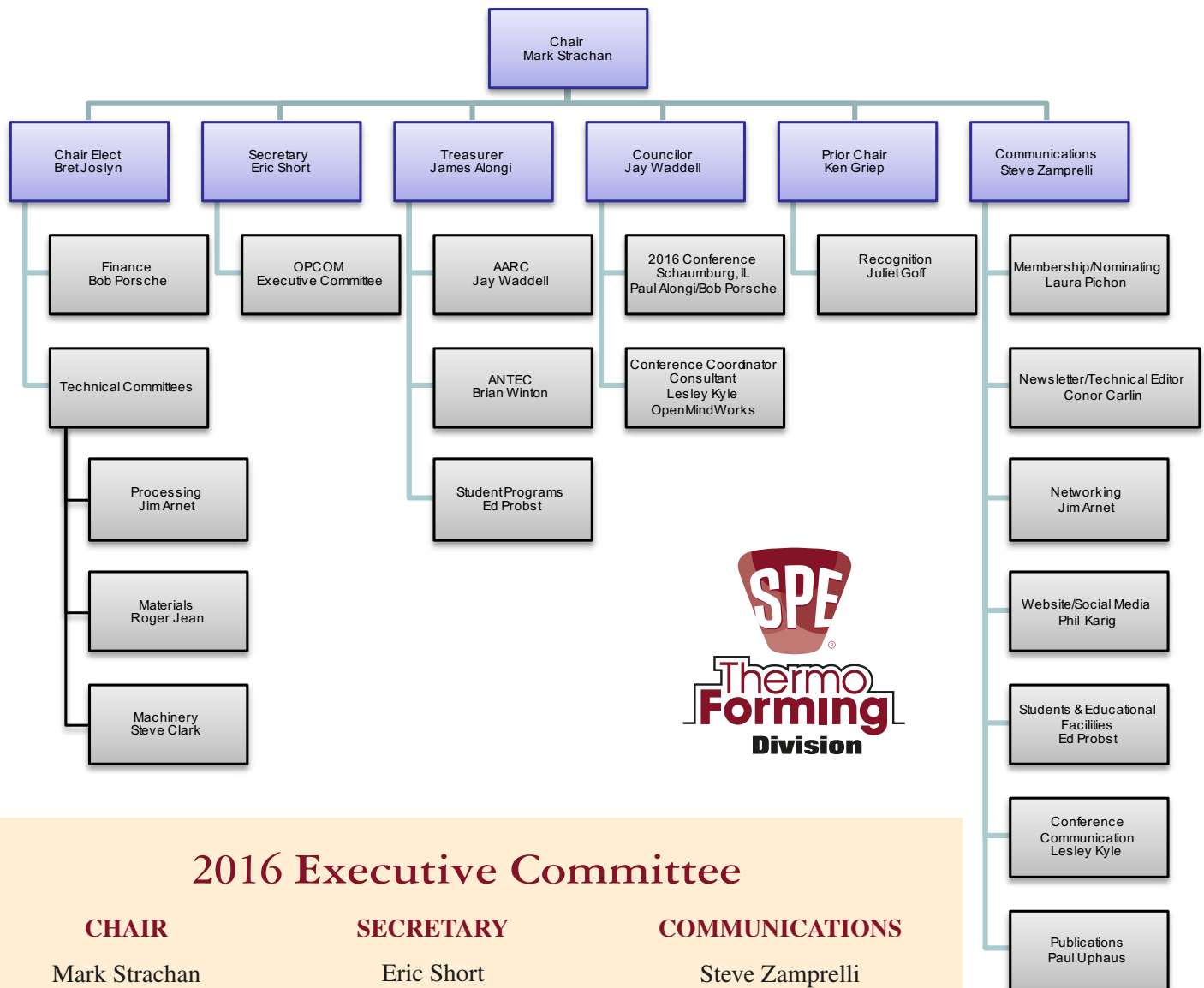
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Questions?

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TQ Magazine's Advertising Sizes Changed in Third Quarter 2015

In an effort to provide more advertising value to our sponsors, *Thermoforming Quarterly* changed its advertising sizes. The new sizes give sponsors more square inches. For example, the previous Silver Ad was 4.75" x 3" or 14.25 square inches. Now the Silver Ad size is 3.65" x 4" or 14.6 square inches. Gold sponsors now have a choice of two ad sizes. Platinum sponsors saw no change and still received a cover position (inside front, inside back or back cover) measuring 8.75" x 11.25" which includes the necessary page bleed. There was also no change in the Titanium Ad size which is 8" x 10.5" with no bleed.

New Ad Sizes in a Nutshell

Platinum	Cover	8.75 x 11.25" (includes bleed)
Titanium	Full Pg	8 x 10.5" (no bleed)
Gold		7.5 x 4" or 3.65 x 8"
Silver		3.65 x 4"
Bronze		3.65 x 1"

25th Anniversary Conference

The SPE Thermoforming Division invites you to attend its 25th Annual Conference created exclusively by and for the Thermoforming Industry. The Conference will be held at the Renaissance Schaumburg Convention Center Hotel, located at 1551 Thoreau Dr. N, Schaumburg, IL 60173.

Network with clients, vendors and industry leaders in one convenient location! Our exhibit hall will provide you with opportunities to meet with equipment, material, tooling and service providers. The SPE Thermoforming Conference® is the most convenient and cost-effective way to learn about the Industry.

Full-day workshops focusing on fundamentals and troubleshooting will help your technical staff gain practical insight into the thermoforming process. Our comprehensive conference program includes technical presentations by recognized industry experts, featuring new and exciting developments in our industry. Attend your choice of presentations delivered by your peers!

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APPLICATION // LIGHT TOWER ACCESS PANEL

OPPORTUNITY

- Make it rustproof
- Reduce noise and weight
- Eliminate need for paint
- Improve serviceability

PMC SOLUTION

- TPO thermoformed "mold-in color access panels," replacing powder-coated metal

ADVANTAGES

- Recyclable materials
- Weatherable with no secondary coating
- Sleek aerodynamic design



APPLICATION // WATERCRAFT DASH/GLOVE BOX

OPPORTUNITY

- Eliminate secondary application
- Seamless product integration
- Custom design

PMC SOLUTION

- Vinyl clad ABS sheet product
- Indian Burl decorative laminate

ADVANTAGES

- Soft touch "feel"
- Luxury appearance
- Custom thermoformed design
- Sustainable thermoplastic product



APPLICATION // COMMERCIAL SALES CASE

OPPORTUNITY

- Reduce time and material to "dial-in" the thermoforming process
- Screen printable
- Lightweight

PMC SOLUTION

- Thermoformed Carbon Fiber Black sheet laminate

ADVANTAGES

- Simplifies the thermoforming process to meet specifications
- Reduces cost for production (time and material)



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