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- Fireside ChatGPT: A Thermoforming Discussion
- A Novel Incremental Decoupled FEA for Sheet Sagging
COMPLETE EXTRUSION SYSTEMS WITH REDUCED LEAD-TIMES

The GENESIS™ Program is a comprehensive inventory of complete extrusion systems comprised of stock machines, parts and sub-assemblies that qualify for expedited delivery. All systems represent current model years.

Each system component of the GENESIS™ Program features the latest in PTi state-of-the-art technology and is backed by PTi’s standard warranty and service agreements. As a program featuring an inventory of standardized extrusion solutions, product availability can be attained far sooner than the customizable option or a just-in-time build and deliver method. As the GENESIS™ Program has the potential to substantially reduce ordinary deliveries by over 3 months*, the reduction in lead time would be a contributing factor in the expedition of product-to-market and pathway to financial success.

System components include extruders, roll stands, die supports, winders and pelletizers. Individual lines sized by process, sheet specifications and output are available for inline and offline applications.

**Contact us for Details!**

*Program inventory is replenished as needed and subject to change. Contact PTi for inventory availability and to determine if your project qualifies for the GENESIS™ Program.*

**APPLICATION DETAILS**

**INLINE THERMOFORMING**
- Process: Sheet Extrusion/Thermoforming
- Resins: PS, PP, HDPE & PET (...and more!)
- Gauge: 9 – 90 MILS
- Structure: Mono- and/or Co-extrusion
- Rates: 1000+, 2000+, 3000+, & 4000+ pph
- Width: 36 – 68 inch sheet widths

**ROLL STOCK**
- Process: Sheet Extrusion
- Resins: PS, PP, HDPE & PET (...and more!)
- Gauge: 9 – 60 MILS
- Structure: Mono- and/or Co-extrusion
- Winding: 1 & 2 Up
- Rates: 1000+, 2000+, 3000+, & 4000+ pph
- Width: 36 - 68 inch sheet widths
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Cover photo taken from thermoforming workshop held at PMG in September 22. Image courtesy of Plastics Machinery Group.
Nominations are open!

Who do you know that’s made the thermoforming industry better? Each advancement is always the result of one person’s idea and their efforts to make it a reality. Our Division recognizes these people and their accomplishments with the Thermoformer of the Year award.

So, who do you know that’s bootstrapped, leveraged, inspired, taught, researched, or developed a thermoforming idea or business that’s moved us forward? The Thermoforming Division wants to hear from you. Visit our website (direct link to form) and nominate the person you believe is a Thermoformer of the Year.

Registration for the Thermoforming Conference© is now open! The premier event for our industry is being held October 23-26, 2023, in Cleveland, OH. This year’s conference is being led by Jim Arnet who is organizing an exhibition and conference that can help you find answers to your industry questions:

- How do I upgrade or add to my forming or trimming capabilities?
- Where can I find a supplier of resin or sheet?
- What are the latest advances in tooling and fixtures?
- How can I solve my thermoforming problems?
- Where can productivity be improved?
- What are recent updates on trends, markets, and skills?
- Where can I meet and network with other industry professionals?

This is the one event you need to add to your 2023 calendar! More information is on page 13 with links to sponsoring and exhibiting opportunities, attendee registration, and hotel / travel information.

In this edition of the magazine, we offer our readers the first part of a two-part article from an industrial designer who delves deep into project ideation and development to give a rich perspective on how end-users select materials and processes to achieve unique industrial items. With ANTEC 2023 just around the corner, we are pleased to publish an original paper from Baden Württemburg State Cooperative University on a novel approach to measure and monitor sheet sagging. As the venerable Dr. Throne pointed out in one of his Problems I Wish I Could Solve™, “we spend inordinate hours balancing our heaters to ensure nearly the same energy input to each side of the sheet”. The mathematics are awesome, he says. Let’s see...

Speaking of mathematical concepts, the world of artificial intelligence is creeping into our lives from all angles. Our editor has a little chat with ChatGPT to see what it knows about thermoforming. Would your answers have differed? Send us an email and let us know.
GEAR UP WITH THE LATEST IN HEAVY GAUGE THERMOFORMING

JOIN US FOR THE WORLD-PREMIERE IN HEILBRONN, GERMANY
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Society of Plastics Engineers Acquires 3Dnatives, the Leading Global Media and Event Platform for Additive Manufacturing

FOR IMMEDIATE RELEASE Contact: Chris Barry, cbarry@4spe.org, +1 203-740-5414

DANBURY, CT – February 27, 2023: The Society of Plastics Engineers (SPE) has acquired 3Dnatives, a French company that produces a media platform and international events for professionals in 3D printing, additive manufacturing, and their related market applications.

Industrial 3D printing currently only accounts for about 0.1% of the $12.8 trillion global manufacturing economy, but it’s growing rapidly. The additive manufacturing market is expected to reach $107.7 billion by 2031, representing a Compound Annual Growth Rate (CAGR) of 21.9% (1).

“There is a natural similarity between the work of SPE and of 3Dnatives,” says Patrick Farrey, SPE’s CEO. “Both publish the most up-to-date technical information for professionals in the plastics and additive manufacturing industries. Joining with 3Dnatives expands SPE’s expertise in these growing markets and gives our members unprecedented access to the science and technologies they need to know.”

3Dnatives global presence will also broaden SPE’s worldwide reach, through daily industry news and distinct market-specific platforms produced in five native languages – French, German, English, Spanish, and Italian. Every month, over 1.2M professionals visit 3Dnatives for its 3D printing equipment comparison engine, original articles, technical guides, product reviews, job board, business directory and more – each in the users’ native language.

3Dnatives, under its “ADDITIV” brand, also produces online and in-person events dedicated to 3D printing and its applications. 2023 events will focus on additive manufacturing in the medical, automotive, and aerospace sectors. The company’s recent events included over 200 expert speakers from top-tier companies (such as L’Oréal, Audi, NASA, Boeing, etc.) and more than 15,000 attendees overall.

“3Dnatives has found a great partner in SPE,” explains Alexandre Martel, CEO, and founder of 3Dnatives. “SPE’s well-established leadership in producing technical information for plastics and manufacturing professionals will be a great asset, as 3Dnatives continues to serve more than six-million 3D printing and additive manufacturing professionals across the globe every year. Together, we look forward to reaching even more markets, with original content produced specifically for each country in their native language.”

The companies will maintain offices in the U.S., Brussels, and Paris. Terms of the transaction were not released.

__________________________
(1) Allied Market Research

About SPE: 84 countries and 60k+ stakeholders strong, SPE unites plastics professionals worldwide – helping them succeed and strengthening their skills through networking, events, training, and knowledge sharing. For more information, visit www.4spe.org.

About 3Dnatives: 3Dnatives is the largest international media platform focused on 3D printing and its applications. With its in-depth analysis of the market, 3Dnatives covers the latest trends of the technology and is available in English, French, Spanish, German, Italian. Our mission is to educate professionals on how additive manufacturing can transform the future of manufacturing. To learn more, visit www.3dnatives.com/en/.
Thermoforming In The News

D&W Fine Pack Boosts Recycled Content with New Equipment

Bridget Janis, Staff Writer, Plastics News

December 22, 2022 – D&W Fine Pack LLC is adding equipment to make food packaging from up to 100 percent post-consumer PET.

The Wood Dale, Ill.-based company is adding what it calls the largest extrusion line of its kind in the United States to its plant in Fort Wayne, Ind.

This new technology will be able to make FDA-certified food packaging products from 100 percent post-consumer PET and will launch in January 2023. The project will add 10-15 jobs.

The company said the equipment will use about 29 percent less energy than conventional technology because it precludes the need to crystallize and dry flake prior to extrusion. Doing away with the additional heat history should also result in a better-quality part, according to D&W Fine Pack.

The company would not identify the equipment supplier and called the project a multimillion-dollar investment.

D&W Fine Pack produces food packaging, single-use containers, tableware, cutlery, foodservice disposables and straws.

Russ Stephens, vice president of engineering, said the line will be able to handle a variety of resins.

“It was flexible to convert multiple different types of materials, so not only PET [but] the technology we chose can convert other materials as well,” Stephens said.

He added that the technology will be familiar to the company’s operators.

“When we chose our partners, we chose our partners that would allow our operators interface to machine in the same way they interface the existing machines that they have on the plant,” Stephens said.

“The [extrusion] line was sourced globally in order to bring in the best technology possible. This will be the largest output extrusion line in our portfolio,” the company said in reply to questions from Plastics News.

The company’s announcement highlighted that the new line will be able to use “a broader range of plastic flake … from plastics that would have otherwise ended up in a landfill.”

In response to questions, the company said “the technologies inherent within this extrusion unit will enable D&W Fine Pack to utilize a wide spectrum of post-industrial and post-consume flake that will extend well beyond the traditional bottle markets.”

The food applications will be used for cold food such as produce, grab and go snacks, catering trays and bakery items.

The company will primarily use PET sheet for its captive use, but officials said they expect to be able to sell sheet into the thermoforming market in the future.

“We can do it very effectively [and] energy efficiently,” Stephens said, adding that the company can develop new products with up to 100 percent post-consumer content.

D&W Fine Pack ranked No. 4 in Plastics News’ survey of North American thermoformers, with estimated thermoforming sales of $645 million. The company also ranked in a tie for No. 96 in PN’s survey of North American injection molders, with estimated molding sales of $75 million.

Why Join?

It has never been more important to be a member of your professional society than now, in the current climate of change and global growth in the plastics industry. Now, more than ever, the information you access and the personal networks you create can and will directly impact your future and your career. Active membership in SPE – keeps you current, keeps you informed, and keeps you connected. Visit www.4spe.org for details. The question really isn’t “why join” but ...

Why Not?
Bo-Mer Goes Big on Solar

Bridget Janis, Plastics News

January 20, 2023 – With an eye toward boosting its use of renewable energy, custom thermoformer Bo-Mer Plastics LLC, has installed rooftop mounted solar arrays it says will substitute for more than half its electricity.

The Auburn, N.Y. company in late 2022 completed installation of more than 1,000 bi-facial solar panels over the two buildings in its campus, producing about 750,000 kilowatt hours of energy.

The solar array, not including incentives and tax credits, cost about $900,000. Before the solar panels, the company was spending more than $150,000 a year on its electric bill, so Bo-Mer is projecting the project will pay for itself in less than four years.

“Although this is our first venture into renewable energy, it is by no means our first project focused on energy efficiency and ultimately reducing our carbon footprint,” said Brian Colella, human resources and accounting manager. Plastics

Bo-Mer, which started researching the switch about two years ago, said there are economic benefits with incentives from both the New York State Energy Research and Development Authority and from federal tax savings, as well as an environmental boost.

“After reviewing proposals from multiple vendors, we accepted a proposal to install a roof-mount, solar array which would maximize the available square footage of our two buildings,” Colella said.

The declining cost of solar panels was not a big factor for Bo-Mer when it started researching the idea, but Colella said “we were pleasantly surprised with the results of the payback analysis.”

Besides thermoforming, Bo-Mer does plastic and metal fabrication and rotational molding.

The company, which started in 1946, has worked with a wide variety of customers, including Coca-Cola and Hershey, as well as supplying sectors like mass transit and automation.

“We feel confident about how Bo-Mer Plastics is positioned within our industry today,” Colella said. “We will continue to diversify our processes and the industries we serve. Our strengths are our expertise, quality, customer service and our ‘can do’ attitude.”

Over the past 10 years, Bo-Mer has made other energy saving moves like switching to LED lights and altering the speed and run time of equipment.

“We have been in the mode of energy saving investments for several years now, and that will continue to be the case moving forward,” Colella said. “We understand that utility costs are a major driver in our cost structure, one that we need to monitor and always attempt to improve on, in order to remain competitive in the marketplace.”

Bo-Mer had an estimated $10 million in annual thermoforming sales last year, and ranked 101st in the Plastics News North American thermoformers ranking. The company has 55 thermoforming employees.

Lacerta Buys Wisconsin Thermoformer Previously Slated to Close

Jim Johnson, Plastics News

January 09, 2023 – A Wisconsin PET packaging thermoformer once slated to close is getting new life after being sold, and the new owner is a familiar name in plastics.

Portage Plastics Corp. had been under a court-ordered receivership in 2022 due to financial difficulties and previously told Wisconsin labor officials the site was going to shut down.

But fellow thermoformer Lacerta Group LLC was able to buy the assets of Portage Plastics to save the facility from closing and, in the process, keep most of the jobs.

Lacerta, owned by private equity firm SK Capital Partners, operates four thermoforming facilities in its headquarters of Mansfield, Mass., and one in Chatsworth, Calif.

After learning about Portage Plastics’ decision to close during a conversation at Pack Expo in Chicago in late October, officials from Lacerta were at the facility the next day to take a look at operations, Lacerta CEO Peter Lennox said.
“We were adequately impressed with the facility, the team, the operations, the organization and the workforce. That really prompted us to take a serious look at doing something. It was truly opportunistic. This was not a planned event. This came out of the blue for us,” he said.

Lacerta ultimately paid less than $5 million for the facility in Portage and equipment in a deal that closed Dec. 21, the company said.

Lacerta actually had been looking for a Midwest location for months, to help fill in the geographic gap between the company’s plants in Massachusetts and California, when it learned about Portage Plastics.

“It helps us get closer to our Midwest customer base. It’s an opportunity to serve our current customers with a location in the Midwest. I think that’s critical. It allows us to further expand our customer base in the Midwest, having this extended footprint,” Lennox said. “Part of our plan was to expand in the Midwest and this opportunity came along.”

Portage Plastics operates 11 thermoforming lines and now has 58 employees following the change in ownership. That’s down from an estimated 64-68 who were previously working at Portage, Lacerta said.

“This essentially was an asset sale, and we were able to save a lot of jobs, and we actually are really excited about what we paid for it relative to how much business we think we can run though it and how profitable we can get that site,” said Josh Lieberman, a principal at SK Capital Partners.

Establishing a Midwest location will allow Lacerta to better serve customers in that region and cut down on transportation costs to clients in the middle of the country.

“Part of the reason this Portage transaction is interesting for Lacerta is we think we can fill the plant with really good business on the basis on the existing customer base we have and the growing demand we are seeing in and around this prepared food, fresh food and produce categories,” Lieberman said.

SK Capital has invested more than $20 million in new equipment at Lacerta during its first two years of ownership, a move that’s helped doubled the top line, said Lennox.

“This is the first step to continue to expand our ability to serve our customers on a nationwide basis,” he said about the Portage Plastics deal.

“We’re excited by the growth we see ahead. I think Lacerta’s consumer-centric business model allows it to grow at really attractive rates and generate highly attractive margins,” Lieberman said.

Lacerta was No. 23 in the most recent Plastics News ranking of North American thermoformers with $111 million in annual sales. Portage was No. 69 with $20 million in sales.

Portage Plastics lost some customers as the company went through court proceedings in Wisconsin, but the new owners were able to retain some work and Lacerta will now build upon that base.

Prior to the sale, Portage Plastics had sought protection from creditors through what is known as Chapter 128 of the Wisconsin Circuit Court system. The State Bar Association of Wisconsin calls Chapter 128 a little-known alternative to bankruptcy that “empowers a circuit court to appoint a trustee to administer the debtor’s estate,” in an article in Wisconsin Lawyer.

Anthony Domerchie, founder of Portage Plastics, is pleased Lacerta was able to buy the assets of the Wisconsin plant and save many jobs, he said.

“It couldn’t have come at a better time,” he said about the Lacerta acquisition. “I’m pretty happy things have worked out, especially for the employees. Our 27 years of work that we built the company through survives. And I think Lacerta adds great value and I wish them nothing but the best of luck with business.”

His company entered financial difficulties with the loss of business at the company’s former location in Brownsville, Texas, about two years ago. That ultimately closed the Texas site, and the problems created by the loss of business eventually caused the Wisconsin site to falter, Domerchie explained.

“We had a major customer unexpectedly cancel a supply agreement that we had for many years. They just one day stopped buying without warning,” he said. “It forced the closure of our Texas operation. It was such a traumatic impact that we’ve never been able to recover from it.

“The legacy of that even really hurt the company going forward. We did everything we could, and we just didn’t do enough,” he said. “I guess there’s a good story for too much dependency on one customer.”
SK Capital, based in New York City, has a wide range of investments in the plastics industry aside from Lacerta. The firm’s portfolio also includes Geon Corp., Techmer PM, SI Group, Ascend, TPC Group, Valtris Specialty Chemicals, Deltech, Woodstock Sterile Solutions and iPackChem.

The investment firm has invested heavily in the sector in recent years despite a growing opposition to the use of plastics by some.

“I think while plastics have been under attack for some time, there really is a lot of science and engineering that goes into these plastics to really make our lives better each and every day and also to reduce greenhouse gas emissions in other ways,” Lieberman said.

Sustainability is a critical consideration in SK Capital’s investment decisions, he said. “I think you have to weigh some of the benefits that plastics really have in the modern world with also a focus on reducing your footprint where you can and using recycled content where you can, where appropriate.”

Portage Plastics also has a location in Plant City, Fla., which was not part of the Wisconsin purchase. Domerchie said that facility, which does heavy-gauge and light-gauge thermoforming has about 22 employees and will continue to operate.

Life Science Outsourcing Picks Up J-Pac Medical

**Posted by staff (Plastics Today)**

January 05 – 2023 Medtech contract manufacturer Life Science Outsourcing Inc. (LSO) announced today that it has acquired J-Pac Medical, a supplier of manufacturing, packaging, and sterilization services to medical device and diagnostics companies.

Headquartered in Somersworth, NH, J-Pac Medical’s experience in complex thermoplastic devices, packaging, and in-house tooling capabilities allows it to manufacture anatomically correct, Class III implantable textile assemblies, lab-on-chip reagent blisters, and sophisticated thermoformed packaging. It operates a 60,000-square-foot, ISO 13485–certified and FDA-registered facility with cleanroom capabilities in New Hampshire. It also maintains strong supplier relationships in Costa Rica’s medical manufacturing hub.

“J-Pac Medical stood out as a unique and attractive business that aligned perfectly with LSO's strategic and commercial objectives,” said LSO CEO John Nino. “The company’s capabilities in reagent blister packaging, thermoforming, and biomaterials will be additive to LSO’s existing customer base.”

“J-Pac Medical’s technical know-how and production experience around reagent blister packaging in the molecular diagnostics end-market represents an exciting growth opportunity given trends in point-of-care diagnostics, specifically as it relates to microfluidics and lab-on-chip applications,” said Jeff Barrett, President of the newly formed Diagnostics Division. “Our partnership with LSO broadens our reach within the life sciences and diagnostics end-markets we are targeting.”

Located in Brea, CA, LSO was acquired by private equity firm PPC Enterprises LLC in January 2021. This acquisition further builds on the vision of a truly national platform that provides post-manufacturing and regulated services to early stage and established medtech and diagnostics companies, commented Asif Zaman, Partner and Head of Healthcare Services at PPC.

“The combination of LSO and J-Pac Medical allow us to provide a wider array of services to our customers across an even broader geographic footprint,” added PPC Partner John Morgan. “This should allow a greater number of medical device and diagnostics organizations to accelerate their development and manufacturing capabilities.”

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Ideation in Thermoforming

Editor’s Note: This new section of the magazine will focus on selected winners of our Thermoformed Parts Competition held at our bi-annual conference. We aim to share with our readers both the technical descriptions of the parts themselves and a commentary from the judging panel illustrating why a particular part was selected.

Part Description
Hagie Sprayer Rear Engine Enclosure Assembly

Winning Category
People’s Choice Award 2023

Summary
This assembly is an engine enclosure for Hagie sprayers. Hagie Manufacturing is an Iowa-based firm that designs and develops crop spraying systems.

This is one capability. These parts had to pass many different tests including 2000 hours of Xenon Arc UV, accelerated weathering testing, high heat testing from the engine, turbos, and radiators. They also had to pass many other tests to ensure that they could pass everyday abuse, including scratches and dozens of aggressive chemicals that the sprayer applies on the crops.

The main enclosure material is custom-colored “Hagie Gray” with smooth, high gloss ABS and an acrylic cap with a starting thickness of .236”. It is bonded with fiberglass using a patented TEC (Toolless Engineered Composites) process. The fiberglass increases the rigidity, durability, and temperatures that the assembly can withstand. The grill is thermoformed from black, high temperature ABS/PC blended haircell-textured material with a low gloss acrylic film. The starting sheet thickness is .240”.

This new design and assembly solved a tricky problem for the customer related to the difficulty with servicing the enclosures on the previous design because of their huge size. The new parts also have much tighter tolerances and a better overall fit.

The design incorporates hidden mounting brackets that allow for easy, quick, and simple assembly by the OEM. Plastics Unlimited also added screens to improve airflow to reduce overheating of the engine. The parties worked together to redesign the parts for thermoforming by eliminating die locks and improving forming and trimming conditions.

One of the most impressive parts of this project was the extremely quick turnaround time from design to manufacturing. Plastics Unlimited produced about 40 parts of each one of the dozen different exterior engine enclosure panels, all of the patterns, aluminum tools, trim fixtures, and assembly fixtures in about two months.

The thermoformed parts of this assembly are formed using single-cavity cast aluminum tools with temperate control.

Benefits Realized
The assembly approach replaced a single, large fiber-reinforced plastic (FRP) component which had several drawbacks and disadvantages:

- Over-designed for the majority of the part functions.
- Bulky to handle and transport; could only ship 3 parts at one time.
- Prone to damage when shipped.
- Limited design aesthetics.
- Visible fastener heads on “A” surface.
- Field replacement required an entire new part – very costly!
- By switching to a multi-part thermoformed design, the following advantages were gained:

  Matched functionality to each part.

- “Toolless Engineered Composite” (TEC) process used for those parts requiring additional strength and heat resistance.
- Less bulky and much easier to ship.
- Reduced shipping costs and number of rejects.
- More design flexibility.
- Fasteners hidden from the “A” surface.
- Reduced cost of replacement parts.
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Building Tooling for the Plastics Industry Since 1961
Editor’s Note: Concepts like “Industry 4.0” are directly related to machine technology, interoperability, and networking across factory floors. Adoption of 4.0 is perhaps uneven across different industries and there is no denying that it has had an effect on the modern factory. But what about the latest developments in artificial intelligence and the software that powers it, notably ChatGPT? Is manufacturing immune? We sat down with ChatGPT to understand its perspective on thermoforming. Our conversation branched off in a lot of directions, so we have summarized highlights here. ChatGPT’s responses are copied in their entirety with no editing whatsoever (including ignoring Microsoft Word’s grammar prompts). Each response was delivered in less than 20 seconds.

Want to learn more or ask questions of your own? Email the editor at cpcarlin@gmail.com or visit openai.com and see for yourself.

CC: Explain how thermoforming works.

ChatGPT: Thermoforming is a manufacturing process in which a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold, and then trimmed to create a finished product. The process begins by heating a plastic sheet to a temperature at which it becomes pliable. The sheet is then placed into a mold, which is the negative of the shape that the finished product should be. Once the sheet is in the mold, it is pressed against the walls of the mold using vacuum pressure or mechanical pressure to conform to the shape of the mold. After the plastic has cooled and hardened, it is removed from the mold and trimmed to the desired shape. This process can be used to create a wide variety of products, including plastic parts for automobiles, electronic devices, and household appliances.

What is the difference between thin-gauge and heavy-gauge thermoforming?

Thin-gauge and heavy-gauge thermoforming are two different variations of the thermoforming process, which differ mainly in the thickness of the plastic sheet used to create the finished product.

Thin-gauge thermoforming typically uses plastic sheets that are between 0.010 inches and 0.060 inches thick. The process is used to create a wide range of products such as disposable cups, food packaging, clamshells, blister packs, and other consumer goods. It is a cost-effective method for producing large quantities of parts with consistent quality, as it requires less material and less energy to heat the plastic sheet. However, the finished products tend to be less precise and have a lower strength-to-weight ratio compared to heavy-gauge thermoformed parts.

Heavy-gauge thermoforming, on the other hand, typically uses plastic sheets that are between 0.060 inches and 0.500 inches thick. The process is used to create more durable products such as automotive parts, medical devices, industrial containers, and furniture components. It allows for the production of more complex and precise parts than thin-gauge thermoforming and with higher strength-to-weight ratio. However, it is a more expensive process as it requires more material, more energy to heat the plastic sheet, and specialized equipment.

In summary, thin-gauge thermoforming is used for producing large quantities of simple and less precise parts with lower cost, while heavy-gauge thermoforming is used for producing small quantities of complex and precise parts with high strength-to-weight ratio but with a higher cost.

What are some of the most common materials used in thermoforming?

Thermoforming can be used with a wide range of plastic materials, including:

1. Polyethylene (PE): This is one of the most commonly used materials in thermoforming, as it is low-cost, easy to process and has good chemical resistance. It is commonly used for creating disposable packaging and consumer goods.

2. Polypropylene (PP): This material is known for its high-strength and chemical resistance, making it suitable for creating durable products such as automotive parts and medical devices.

3. Polystyrene (PS): This material is known for its low-cost and ease of processing, making it suitable for creating disposable packaging and consumer goods.
4. Acrylonitrile butadiene styrene (ABS): This material is known for its high-impact strength, chemical resistance, and dimensional stability, making it suitable for creating automotive parts, electronic devices, and household appliances.

5. Polyvinyl chloride (PVC): This material is known for its chemical resistance, durability and flame resistance, making it suitable for creating packaging and consumer goods, as well as construction and industrial products.

6. PETG: This material is known for its high-strength, clarity and resistance to impact, making it suitable for creating packaging and consumer goods, as well as construction and industrial products.

7. Other materials such as Acetal, Polycarbonate and Nylon are also used in specific applications that require specific properties such as high strength, high temperature resistance and chemical resistance.

It's important to note that, the choice of material will depend on the application and the specific properties required for the final product, such as strength, flexibility, transparency, and chemical resistance.

**Can thermoformed parts be decorated?**

Yes, thermoformed parts can be decorated. There are several ways to decorate thermoformed parts, depending on the desired outcome and the type of plastic being used. Some common methods include:

**Painting:** The parts can be painted with a liquid paint that can be applied using a spray gun or brush. This method can be used to achieve a wide range of colors and effects, including glossy, matte, and textured finishes.

**Screen printing:** This method uses a stencil and ink to apply a design or logo onto the surface of the part. It is commonly used for applying graphics and text to packaging and other consumer goods.

**In-mold decoration:** This method involves applying a pre-printed film or sheet to the surface of the plastic sheet before it is formed into the final shape. The design becomes an integral part of the product, and the process can be used to achieve a high-quality, glossy finish.

**Hot stamping:** This method uses a heated die to transfer a metallic or pigmented foil onto the surface of the part. It can be used to create a wide range of decorative effects, including metallic and glossy finishes.

**Pad printing:** This method uses a silicone pad to transfer ink from a plate onto the surface of the part. It can be used to create intricate designs, logos and texts on the surface of the parts.

It’s important to note that, the decoration of thermoformed parts is usually done after the forming process, but it can also be done during the process in case of In-mold decoration. The choice of the method will depend on the material and size of the parts, the design, and the desired finish.

**How does the thermoforming process compare to injection molding?**

Thermoforming and injection molding are both manufacturing processes used to create plastic products, but they differ in several key ways.

Thermoforming is a process in which a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold, and then trimmed to create a finished product. The process is relatively simple and requires minimal equipment, making it a cost-effective option for producing large quantities of parts with consistent quality. However, the finished products tend to be less precise and have a lower strength-to-weight ratio compared to injection-molded parts.

Injection molding, on the other hand, is a process in which plastic material is heated and then injected into a mold under high pressure. The process allows for the production of complex, precise and high-strength parts. It is more expensive than thermoforming and require more equipment and tooling, but it allows for the creation of highly detailed and intricate parts with high precision and dimensional stability. Injection molding is also more suitable for producing small quantities of parts, and is generally considered more efficient for high volume production.

In summary, thermoforming is a simpler, less precise, and less expensive process that is well-suited for creating large quantities of parts with consistent quality, while injection molding is a more complex, precise and expensive process that is better suited for creating small quantities of highly detailed and precise parts.
What is the best way to design a tool for thermoforming?

There are several key considerations when designing a tool for thermoforming, including:

1. Material choice: The choice of material for the tool will depend on the specific properties required for the final product, as well as the type of thermoforming process being used. Common materials for thermoforming tools include aluminum, steel, and epoxy.

2. Tool geometry: The geometry of the tool should be designed to create the desired shape of the final product. This includes the shape of the cavities, the thickness of the walls, and the radius of any curves or corners.

3. Heating and cooling: The tool should be designed to allow for efficient heating and cooling of the plastic during the thermoforming process. This includes the placement of heating elements, the use of cooling channels, and the use of insulation to prevent heat loss.

4. Ejection: The tool should be designed to allow for easy and efficient ejection of the formed part from the tool. This includes the use of ejector pins, the design of the part's draft angle and the use of release agents.

5. Surface finish: The tool should be designed to create a smooth and high-quality surface finish on the final product. This includes the use of polished surfaces, the use of coatings, and the use of a high-quality tool steel.

6. Maintenance: The tool should be designed to be easy to maintain, as well as to be able to withstand the high temperatures and pressures of the thermoforming process.

It’s also important to note that working with an experienced tool maker and a professional thermoforming company to design the tool is highly recommended, as they will have the knowledge and expertise to create a tool that meets your specific requirements and optimize the thermoforming process.

What is the impact of talc as a filler in plastic applications?

Talc is a natural mineral that is often used as a filler in plastic applications. When added to plastic, talc can have a number of impacts on the material’s properties.

1. Cost reduction: Talc is a relatively inexpensive filler, and its use can reduce the overall cost of the plastic product.

2. Improved stiffness: Talc can improve the stiffness of a plastic, making it more rigid and less flexible. This can be beneficial for applications where high stiffness is required, such as automotive parts or electronic devices.

3. Improved dimensional stability: Talc can improve the dimensional stability of a plastic, making it less prone to warping or shrinking. This can be beneficial for applications where precise dimensions are required, such as packaging and consumer goods.

4. Improved flame resistance: Talc can improve the flame resistance of a plastic, making it less flammable and more suitable for applications where fire safety is a concern.

5. Improved chemical resistance: Talc can improve the chemical resistance of a plastic, making it more resistant to chemicals and suitable for applications where chemical resistance is a concern.

6. Improved UV resistance: Talc can improve the UV resistance of a plastic, making it more resistant to UV radiation and suitable for applications where UV resistance is a concern.

However, it’s also worth noting that using talc as filler also can have some negative effects on the plastic material. The addition of talc can reduce the impact resistance and toughness of the plastic, and also it can cause some issues with the surface finish and color of the final product.

How do you fix problems with webbing in thermoforming?

Webbing, or thin areas of plastic in the final product, can be caused by a number of factors in the thermoforming process. Here are a few ways to address webbing:
1. Adjusting the material temperature: Increasing the temperature of the plastic before it is formed can help to reduce webbing by making the plastic more pliable and easier to shape.

2. Adjusting the material thickness: Increasing the thickness of the plastic sheet can also help to reduce webbing, as thicker material is more resistant to stretching and thinning during the forming process.

3. Adjusting the tool design: The design of the thermoforming tool can also play a role in webbing. Adjusting the tool to provide more support for the plastic during forming can help to reduce webbing.

4. Adjusting the clamp pressure: Increasing the clamp pressure during the forming process can also help to reduce webbing. Higher clamp pressure helps to distribute the plastic more evenly and can prevent it from stretching and thinning.

5. Adjusting the vacuum level: A higher vacuum level can help to remove more air from the plastic, which can help to reduce webbing.

6. Adjusting the forming speed: Adjusting the speed at which the plastic is formed can also help to reduce webbing. A slower forming speed can help to reduce stretching and thinning of the plastic, while a faster forming speed can help to reduce the amount of time the plastic is in contact with the tool.

It’s important to note that the webbing problem can be caused by multiple factors, and it’s crucial to evaluate the entire thermoforming process, including material, tool, machine and process parameters before making any adjustments. A professional thermoforming company or a skilled engineer would be able to conduct a thorough analysis and provide recommendations to fix the problem.

What are some global trends for thermoforming?

Thermoforming is a widely used manufacturing process that has a broad range of applications across many industries. Here are a few global trends in thermoforming that are currently shaping the industry:

1. Sustainable packaging: With an increasing focus on reducing waste and environmental impact, more companies are turning to thermoforming to create sustainable packaging solutions. This includes using renewable or recycled materials for packaging, as well as designing packaging that is easy to recycle or compost.

2. Demand for high-quality and precision parts: As the demand for precision and high-quality parts in various industries, such as healthcare and automotive, continues to grow, thermoforming is becoming an increasingly popular choice for manufacturing these parts.

3. Advancement in technology: With the development of new technologies, such as automation and robotics, the process of thermoforming is becoming more efficient and accurate. This allows for faster production times and improved product consistency.

4. Increased popularity of In-mold decoration: The use of In-mold decoration is increasing, as it allows for the creation of more attractive and cost-effective packaging and consumer goods.

5. Expansion in the use of heavy-gauge thermoforming: The use of heavy-gauge thermoforming is expanding as it allows for the creation of more durable, complex and precise parts.

6. Focus on sustainability and cost-effectiveness: Companies are focusing on developing sustainable and cost-effective thermoforming solutions, as it helps to reduce the environmental impact and lower the production cost.

Overall, the trend in thermoforming industry is to produce more sustainable and cost-effective products, with improved precision and high-quality parts.
Selecting Pressure Forming and Optimizing Design Part 1

Michael Paolain, Principal, Integrated Design Systems

Product designers are chiefly interested in the materials and manufacturing processes as means to an end. In other words, we are not partial to a specific process. Designers optimize the design for a particular manufacturing process based on numerous considerations. We will explore some of these in this article.

Several years ago, my design company, Integrated Design Systems, was retained by a startup medical company called Luminetix to design an innovative new medical device, the Veinviewer. The novel medical device enabled nurses and clinicians to see subcutaneous veins during venipuncture procedures in real time. This was the first device of its kind. It operated by projecting an infrared light onto the area of interest, processing the data, and reprojecting a visible false color image of the veins onto the same skin patch. Photos of the final product are shown in pictures 1 and 2.

The product design and development journey from the beginning of this project to the end was a roller-coaster saga of disappointments, extreme mental pressure, and high risks. When I was first introduced to the project, my eyes fell upon the prototype shown in picture 3. The entire structure, including the covers, was fabricated from sheet metal. Prototypes like this are typically constructed to verify specific functional tasks and are not meant to look pretty. Although this prototype looked hideous, I was shocked that some managers were seriously considering introducing this as the final production product! Luckily, better judgment prevailed, and we began developing this breadboard into an actual medical devic

- Initial research, industrial design, and concept development
- Basic engineering layout and overall structure
- Process selection and considerations
- Pressure forming design
- Prototyping
- Production Startup and challenges
- Final production release
Initial Research, Industrial Design, and Concept Development

We began this project, like all major projects, by delving into the technology, user requirements, sales forecasts, overall functionality, and dozens of other parameters that would affect design. This information was documented in a comprehensive product design specification report accompanied by photos and videos. Every major project should include a well-organized and comprehensive set of product specifications. Industrial design-related activities were also completed during this phase focusing on patient and clinician user interface, user environments, portability, safety, storage, and safety. All these considerations would ultimately have a significant effect on overall product architecture, size, orientation, and numerous other design-related parameters. Concurrently with these activities, we began developing concepts for the new Veinviewer based on all the information accumulated and feedback from development team members. A few of the early concepts are shown in picture 4.

During this early development phase, information was pouring into the project at a feverish pace, resulting in an equally frequent number of changes in design direction. Ultimately, activity stabilized, and changes were reduced to a level sufficient for developing a realistic concept for the new device, as shown in picture 5.
Basic engineering layout and overall structure

After finally arriving at a design concept that satisfied most industrial design and marketing requirements, we now faced the challenge of translating this concept into an actual manufacturable medical device within the remaining six months of development time left in the project. Our first objective was to overlay the proposed design concept over the essential internal components and begin detailing mechanisms, performing structural analyses, and verifying overall ease of assembly. The assembly of the internal structure and optical head is shown in picture 6 below:

Process selection and considerations

As the internal details were developed, we also evaluated various manufacturing processes for the external plastic covers. Process selection is a critical decision during the design process since a significant portion of design time is dedicated to detailing parts for a specific manufacturing process. What are the most vital deciding factors affecting process selection? I’ve listed them below:

1. Projected Annual Sales

     Estimating sales is always a challenge. Marketing forecasts are optimistic, and finance is usually more conservative. Annual sales are essential to assess because they affect the rate of return on tooling investment. In this project, the forecasted sales were under 1000 units per year. This annual production quantity is attractive to most pressure formers but only appealing to some injection molders.

2. Risk

     There are different types of risk. Product introductions are
faced with risks associated with missing projected sales forecasts, missing critical launch dates, components becoming obsolete, competitors introducing a disruptive alternative device, and many other unknowns. Minimizing capital investment in tooling is one way of reducing risk. Pressure-forming tooling is an excellent choice based on the low tooling cost compared to injection molding, which lowers capital investment and reduces risk.

3. Lead time

Lead time for production tooling and startup was critical for this project. The schedule was extremely aggressive, leaving minimal time for tooling, and production startup needed to be improved. Typically, injection molds can take up to 16 weeks to complete versus pressure-forming molds, which can be completed in as little as 4 weeks. The spread in lead time between these two processes increases as the part size and complexity increase. Pressure forming, therefore, has a significant advantage over injection molding to comply with short lead times.

4. Production cost

Production costs are based on materials, processing, labor, and overhead. Although injection molding production costs are usually the lowest of all the plastics manufacturing processes, it depends on production volume. Higher production volumes allow manufacturers to amortize tooling costs much faster, justifying the increased initial capital investment. However, if the production volumes fall below a critical threshold, the part costs can be very high. One must therefore compare the breakeven point between pressure forming and injection molding to accurately determine which process is ideally suited for a given set of parts.

5. Production consistency

Injection molding production consistency is undoubtedly much better than pressure forming since labor content is virtually nil. Parts are solely dependent on tool quality and process control. Pressure-formed parts always require secondary operations such as trimming, bonding, and handling. These additional manufacturing steps introduce potential inconsistencies in part quality. Variation in part quality can occur depending on how parts are trimmed (CNC versus hand trimming), how parts are restrained during trimming, how mounting blocks are assembled, how fixtures are designed and used, etc. The part quality depends on the pressure-forming molder and its QC.

6. Tolerances

Tolerance control is one of the most challenging production criteria for any molder. Designers must understand the process, the molder’s capabilities, and material characteristics to optimize their design for the process and desired result. Novice designers typically apply little to no clearance between parts, which leads to numerous last-minute design changes or disastrous results. Injection molding tolerances are much better than pressure forming since all the part features are molded consistently with little human intervention. My experience with pressure-formed parts is that tolerances of molded surfaces are as good or sometimes better than injection molding. Still, wider tolerance variations occur with trimmed features and bonded mounting blocks. Designs must therefore account for these variations.

7. Aesthetics & Design Freedom

Although pressure-formed parts cannot precisely replicate features as fine as injection molding, the process does allow designers to design parts with complex shapes, embossed logos, and tight radii. This design freedom enables industrial designers to create beautiful complex forms which convey quality and marketing appeal to the end user. All these benefits are available to the designer at a tooling investment which can range from 20% to 50% of that of an injection mold.

8. Assembly Time

The assembly time of an injection molded part versus a pressure-formed part is equivalent. I have not experienced any significant difference in assembling parts manufactured in either process unless parts have been consolidated into more complex, highly functional components with the injection molding process.

9. Product Life

Product life should be considered during the early phases of design and process selection. This is especially true for high-technology products like medical devices, where products can quickly be obsoleted within two to three years. CoinciThisct was completely redesigned and replaced after it was on the market for less than three years. Highly capital-intensive tooling should be carefully evaluated before any commitments are made since the return on investment may never be realized. Pressure forming was highly favored as the process of choice due to the volatility of this product’s life span.
10. Tooling Investment & Amortization

Many of the previous factors indirectly referred to tooling and amortization. However, I’d like to briefly discuss amortized tooling costs. The formula is very straightforward but frequently overlooked. Tooling amortization is simply averaging the tooling cost over a set number of parts and applying this cost to the total part cost. For example, if you want to get on your tooling investment during the first year’s production, you simply the tooling cost by the number of products you expect to sell in the first year. You can use a one-year, two-year, or product life timeframe. This is typically done when comparing two processes or molders. Pressure forming will usually show the fastest ROI.

11. Part Size

Injection molding tooling and processing costs rise significantly for large parts. I define large parts as those exceeding 12 inches in two dimensions. Injection mold press sizes are determined by shot weight and the projected surface area of the part. Injection molding machine press size is classified by clamp tonnage and shot capacity. Typically, 3 to 5 tons of clamp force is required for every square inch of the projected area of a part. For example, a part with a projected area of 144 square inches (a 12-inch square) will require a 450-ton press which is a medium-sized molding machine. There are many other details, such as platen size, daylight opening, and injection pressure, but this simple formula is a reasonably good estimate. Molders with large presses desire high production volumes due to the costs associated with handling large molds and starting production. Therefore, pressure forming has a significant advantage over injection molding for production runs under 2000 parts per year.

12. Structural Requirements

Structural integrity is critical to any design. Injection molding offers superior structural advantages in part design compared to pressure forming because reinforcing ribs can be added to parts to increase part strength. In addition, injection molding offers a broader material selection and includes glass-reinforced materials to optimize strength and rigidity. Pressure forming is limited to producing surfaces that can only be strengthened by bonding internal ribs are attaching the cover to a more rigid substrate such as a sheet metal frame. The latter method was applied to the design of the Luminetix Veinviewer, as illustrated in the CAD file images shown in picture 6. If appropriately designed, combining an inner sheet metal structure with pressure-formed covers is a cost-effective and structurally viable method to impart rigidity to flimsy plastic pressure-formed covers.

Part 2 of this article will be published in the next issue of Thermoforming Quarterly.

About the author:

Michael Paolain is a product designer with more than 40 years’ experience in virtually every commercial manufacturing process available. With an undergraduate degree in plastics engineering, Michael has designed products in every plastics manufacturing process and material. He has also designed products in sheet metal, die casting, sand casting, and many other manufacturing processes.
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- Numerous quick change features
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- LR5 Shown - 45 Ton
- Side Loading of Tool
- Numerous quick change features
- Precise tolerances via linear rails

TECHNOLOGY
- Flat Bed Formers
- Form-Trim Models
- Linear Trim Presses
- Linear Vertical Press
- Heavy Duty Presses
- Tilt Bed (IML)
- Linear Pre-Punch
- Linear Scoring Station
- Rotary Drum Former

PROCESSES
- PP, PET, HIPS, OPS
- PLA, HDPE, PS Foam
- In line/Roll Fed
- Cups, Car Cups, Lids
- Retort Products
- Tamper Evident
- Hinged Trays
- Storage containers
- TIML

VALUE
- Energy Efficient
- Production Rates
- Move Times
- Ease of Access
- Reliability

SERVICE
- Training Classes
- On line help
- Process Training
- After hours help
- Included start up service
A Novel Incremental Decoupled Finite Element Approach for Sheet Sagging During Heating in Thermoforming Process

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Abstract

In order to make a semi-finished plastic product formable in the thermoforming process, it must first be heated to its processing temperature. The reason for this is that the constitutive behaviour of polymers strongly depends on temperature, in addition to elongation and strain rate. Companies that thermoform components seek the best possible temperature distribution in the heating process to achieve a high-quality plastic part with an economical process. Radiant heating is widely used to heat the plate. However, the heating process is very complex because the heat transfer rate varies with more than just temperature. When the sheet sags, the relative position between a material point on the sheet and the heater changes with time. It follows, that dynamic structural-thermal simulation, in this article using a finite element method (FEM), is suitable to solve this type of problem. Coupled dynamic structural-thermal simulations are not supported by the commercial software ABAQUS/Standard. Therefore, a dedicated Fortran subroutine (UTEMP) is introduced to calculate the thermal part incrementally and decoupled from the structural method.

1. Introduction

Since sagging affects the position and orientation of a material point on the sheet to the radiant heaters, it causes the distribution of the heat flux and influences the subsequent forming process due to the temperature-dependent constitutive behaviour. There are several studies that provide analytical solutions for sheet sagging under certain assumptions [4, 11, 21, 22]. Stephenson et al. [21] modelled sheet sagging using Timoshenko beam theory and the upper convected Maxwell model. Giacomin et al. [11] and Baek et al. [4] assume a nearly cylindrical shape during sagging to develop an analytical solution for sagging using transport phenomena. Thermoforming processes are usually simulated isothermal throughout the whole process (e.g. [1, 2, 5–10, 12–14, 16–20, 23]). In some cases, there exist combined heating forming approaches. Labeas et al. [15] decoupled the heating and forming simulation for diaphragm forming. Aus der Wiesche [3] simulated the forming process of an automotive fuel tank including heating and sagging. In finite element simulation, there exist two fundamental different integration methods called implicit and explicit. Explicit analysis provides good results in dynamic analysis and allows coupled structural-thermal simulations. Although, the calculation for the next timestep is computationally less expensive than with the implicit solver, the analysis is not conditionally stable, requiring a small stable time increment, resulting in a computationally inefficient analysis for long duration processes. The dynamic implicit solver is conditionally stable and therefore more suitable for sheet heating simulation, while the explicit solver might be better suited for forming simulations. However, there is another drawback in using the ABAQUS dynamic implicit solver, which is the lack of structural-thermal analysis. This problem is solved in this work, resulting in a decoupled-implicit-structural-explicit-thermal finite element analysis (DISET-FEA).

2. Heat Transfer

The general equation for heat transfer is

\[ \rho c(T) \frac{\partial T(\vec{x}, t)}{\partial t} = \frac{\partial}{\partial x_j} \left( k_{ij}(T) \frac{\partial T(\vec{x}, t)}{\partial x_j} \right) + Q(\vec{x}, t), \]  

(1a)

\[ \rho c(T) \frac{\partial T(\vec{x}, t)}{\partial t} = \nabla \cdot (k \nabla T(\vec{x}, t)) + Q(\vec{x}, t), \]  

(1b)

where \( \rho \) is the density, \( c \) is the specific heat, \( k \) is the conductivity matrix and \( Q \) is any heat source term, e.g. radiation or convection. The convective heat flux is modelled by means of Newton’s condition

\[ Q_{conv} = A \cdot h(T - T_a) \]  

(2)

where \( A \) is the area, \( h \) is the convective heat transfer coefficient and \( T_a \) is the ambient temperature. To model the radiation heat transfer between heater and sheet, diffuse gray opaque radiation between all bodies is assumed. Therefore, the incoming radiation \( G \) is either absorbed or reflected. The overall radiation send by a surface to the environment is called the radiosity \( J \), and is the sum of the emitted radiation \( \epsilon_i \) and the reflected radiation \( (1 - \epsilon)G \). This is valid because the emissivity \( \epsilon \) (fraction of emitting radiation) and the absorptivity \( \alpha \) (fraction of absorbing incoming radiation) are the same for diffuse gray body’s. Diffuse means that there is no preferred direction of the rays. So, the transferred energy to surface \( i \) is given as

\[ Q_{rad} = \epsilon_i J + \alpha_i G. \]
\[ Q_i(\vec{x}, t) = A_i(J_i - G_i) = A_i(J_i - \frac{\epsilon_i \rho \Delta T}{1 - \epsilon_i}) = \frac{A_i \epsilon_i}{1 - \epsilon_i} (E_{bi} - J_i). \quad (3) \]

\[ E_b = \sigma T^4, \quad (4) \]

where \( \sigma \) is the Stefan Boltzmann’s constant. The evaluation of the radiant heat flux between two surfaces \( i \) and \( j \) leads to

\[ Q_{ij}(\vec{x}, t) = A_i F_{ij}(J_i - J_j), \quad (5) \]

where the viewfactor

\[ F_{ij} = \frac{1}{dA_j} \iint \frac{\cos(\theta_i) \cos(\theta_j)}{\pi r^2} dA_i dA_j \quad (6) \]

considers the orientation of surface \( i \) to \( j \). If every ray originating from surface \( i \) hits surface \( j \) regardless of direction, the viewfactor is one. If, on the other hand surface \( j \) is completely turned away from surface \( i \), the viewfactor is zero. Equation (3), (4) and (5) results in a complex thermal network. The objective is to find an exchange factor \( F \) between the sheet and the heater in the manner

\[ Q_{rad}(\vec{x}, t) = A F \sigma (T_h^4 - T^4). \quad (7) \]

However, applying some algebra to such a network leads to the following expression for an enclosure

\[ F = \epsilon \left( \frac{1}{1 - F(1 - \epsilon)} \right)^{-1} (1 - F), \quad (8) \]

where \( \epsilon \) is the diagonal emissivity matrix, \( 1 \) is a diagonal matrix with only ones, \( F \) is the matrix of all view factors and \( A \) the corresponding matrix of all exchange factors. The exchange factors of interest are given by the related submatrix. Since the exchange factor varies over the sheet dimension, it should be calculated for each finite element. In particular equation (8) appears to be computationally expensive and in addition, it is necessary to create an enclosure (e.g. an additional environment). Therefore, the question arises, whether the exchange factor can be calculated by a time-varying viewfactor multiplied with a time-constant gray factor. To verify this assumption, a setup similar to Weinand [24] is proposed. The sheet sag is assumed to be parabolic

\[ z = 16 \cdot z_0 \left( \frac{x}{l_x} - \frac{x}{l_x} \right)^2 \left( \frac{y}{l_y} - \frac{y}{l_y} \right)^2. \quad (9) \]

with \( z_0 < 0 \) and \( l_x \) and \( l_y \) are the length in the planar area. Figure 1 shows from left to right the exchange factor, the gray factor and the view factor given \( l_x = l_y \). The distance from the sheet to the heater is 0.2 \( l_x \) with same planar dimensions. The emissivity of the sheet is 0.85 and that of the heater is 0.95. As expected, the gray factor varies only weakly from sagging. Even with excessive sag (0.6\( l_x \)), the maximum error compared to no sag is only about 9%, while the view factor strongly depends on the orientation.

**Figure 1:** exchange, gray and view factor for different sagging extent

3. Finite element approach

Since the heating of the sheet takes several minutes, the temperature changes slowly and there is low acceleration in changing position and temperature. Therefore, it seems appropriate to model the heating and structural analysis in a decoupled manner, such that first the deformation (implicit structural analysis) of the current time step is calculated by holding the temperature constant and then the temperature for the next timestep is calculated explicitly with the structural constitution at the end of the current timestep (see figure 2). The author calls this incrementally decoupled.

**Figure 2:** concept of DISET-FEA

Since the dynamic implicit analysis is well explained in the ABAQUS documentation, only the designed explicit thermal analysis (UTEEMP) is described in this chapter.
Introducing a test function \( \nu \) together with (1) yields the functional

\[
\int (-Q - \nabla^T (k \nabla T) + \rho c_\nu T) \nu dV = 0. \tag{10}
\]

By applying some algebraic transformations, one can show that

\[
\int (k \nabla^2 \nu \nabla T) dV + \int \nu \rho c_\nu T dV - \int \nu Q dV + \int \nu q dA = 0 \tag{11}
\]

is the weak form of the heat transfer problem. In finite element heat transfer, test function and temperature are approximated by the shape function and nodal values, and with \( T(\xi, t) = \bar{N}^T(\xi) \bar{T}_e(t), \nu = \bar{N}^T(\xi) \bar{\nu}_e \) quation (11) can be redefined as

\[
\bar{\nu}_e \left[ \left( \bar{N}^T \right)^T k \left( \bar{N}^T \right) \bar{T}_e \right] \bar{\nu}_e + \bar{\nu}_e \left[ \int \rho \bar{c}_\nu \bar{T} \bar{\nu}_e \right] - \int \bar{\nu}_e Q dV + \int \bar{\nu}_e q dA = 0 \tag{12a}
\]

\[
\left( \int \bar{N}^T \right)^T k \left( \int \bar{N}^T \right) \bar{T}_e + \int \rho \bar{c}_\nu \bar{T} \bar{\nu}_e = \int \bar{\nu}_e Q dV + \int \bar{\nu}_e q dA = \bar{\theta} \tag{12b}
\]

\[
\int \bar{N}^T \bar{b} \bar{a}^e \bar{\nu}_e \int + \int \rho \bar{c}_\nu \bar{T} \bar{\nu}_e = \int \bar{\nu}_e Q dV + \int \bar{\nu}_e q dA = \bar{\theta} \tag{12c}
\]

where \( B = \nabla N^T \). To map (12c) to the nodal values \( X_e(t) \) and \( \bar{T}_e(t) \) to those of the undeformed configuration with element coordinates \( \xi \), an additional transformation \( \bar{X}^T(\xi, t) = \bar{N}^T(\xi) X_e(t) \) respectively \( \bar{T}(\xi, t) = \bar{N}^T(\xi) T_e(t) \) is necessary, such that

\[
\int J^T x^T \bar{c} \left( x \right) x dx d\gamma = 0 \tag{13}
\]

where \( J = dx^T d\xi \gamma \) is the jacobian and \( B_o = J B \). From (13) we find

\[
K_e = \int J^T \bar{b}_e J \left( x \right) \left| \left( x \right) \right| dV_o \tag{14a}
\]

\[
C_e = \int \rho \bar{c}_\nu \bar{T} \left( x \right) \left| \left( x \right) \right| dV_o \tag{14b}
\]

\[
\bar{Q}_e = \int \bar{N}_o \bar{N}^T \bar{N} \bar{a}_e + \int \bar{N}_o \bar{N}^T \bar{q} dV_o \tag{14c}
\]

and therefore

\[
K_e \bar{T}_e + C_e \bar{T}_e - \bar{Q}_e = \bar{\theta} \tag{15}
\]

for one element. After assembling the global stiffness matrix \( K \), mass matrix \( C \) and last vector \( \bar{Q} \) from there elementary counterparts, one obtains

\[
K \bar{T} + C \bar{T} - \bar{Q} = \bar{\theta}. \tag{16}
\]

To solve (16) explicit, the temperature rate \( \dot{T} \) is approximated in an explicit euler manner, such that (16) can be rearranged to calculate the temperature field of the next timestep \( t + \Delta t \)

\[
\bar{T}_{t+\Delta t} = \Delta t C^{-1} \left( -K \bar{T}_t + \bar{Q}_t \right) + \bar{T}_t \tag{17}
\]

from the current timestep \( t \), where \( \Delta t \) is the time increment. Since the inversion of large matrices is computationally expensive, it is widely accepted to replace this matrix by a lumped one

\[
L_{elem} = \sum_{k=1}^{N} C_{ik} \quad \text{für} \quad i = j, \tag{18}
\]

Finally, with the equation

\[
\bar{T}_{t+\Delta t} = \Delta t C^{-1} \left( -K \bar{T}_t + \bar{Q}_t \right) + \bar{T}_t \tag{19}
\]

the temperature of any node of the next time step is calculated from the temperatures of the current timestep directly. To ensure, the analysis is stable, the equation

\[
(KC^{-1} - \lambda I) \bar{\phi} = \bar{\theta} \tag{20}
\]

has to be solved to get the stable time increment

\[
\Delta t_{stable} = c/\lambda_{max}. \tag{21}
\]

form the maximum eigenvalue \( \lambda \). In this analysis we set \( c = 1 \).

It is assumed that the sheet does not deform too much, so the stable time increment is calculated at the first timestep and kept constant for the entire analysis. If the given timestep of the implicit analysis is larger than the stable explicit timestep, the temperature analysis is done multiple times until it reaches the value of the implicit step.

4. Results

The procedures described in chapter 2 and 3 are implemented in a user-defined temperature field (UTEMP) in Fortran code. While the gray factor is kept constant throughout the analysis, the view factor is calculated using the galerkin method. The constitutive behaviour is assumed to be linear viscoelastic and modelled with a four-element Maxwell (storage modulus \( G \), relaxation time \( \tau_{rel} \), poison ratio \( v \), WLF-parameters \( C_a, C_b \) and \( T_a \)). These parameters are fitted from rheological measurements on a Polystyrene. The C3D8I-ABAQUS element is used for simulation. The setup given in table 1 contains the physical modelling parameter. The resulting temperature distribution at different time steps is given in figure 3.
Figure 4 shows the temperature and displacement through the centerline of the sheet and the maximum values as a function of time. Figure 5 shows the displacement of the whole sheet. The temperature reaches about 493K at the top and 476K at the bottom of the sheet, while the maximum displacement is about 16mm at the end of the simulation. Since radiation occurs only on the top surface, the temperature rises about ten degrees Kelvin higher compared to the bottom surface of the sheet. In addition, the top surface heats up directly at t=0, while the temperature at the bottom surface starts to rise with a delay of some seconds due to the low conductivity.

The results suggest that there are two ways to achieve a more uniform temperature distribution: first changing the radiator geometry to obtain more uniform view factor and second compensating the lower view factor at the edges by a non-uniform temperature distribution on the radiator. The first approach could result in increasing the heater area or decreasing the view factor from sheet to heater through shielding. The second approach leads to zonal or pattern heating (e.g. [22]).

<table>
<thead>
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<th>parameter</th>
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<tr>
<td>$l_x$</td>
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<tr>
<td>$l_y$</td>
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</tr>
<tr>
<td>s</td>
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<tr>
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<td>0.1m</td>
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<tr>
<td>$T_{h}$</td>
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</tr>
<tr>
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<td>293.15K</td>
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<tr>
<td>$F_g$</td>
<td>0.814</td>
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<tr>
<td>$k$</td>
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</tr>
<tr>
<td>$c$</td>
<td>1800 $\text{J/(kg·K)}$</td>
</tr>
<tr>
<td>$\rho$</td>
<td>1040 $\text{kg/m}^3$</td>
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<tr>
<td>$h$</td>
<td>15 $\text{W/(m}^2\cdot\text{K)}$</td>
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<tr>
<td>$G_i$</td>
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<tr>
<td>$\nu$</td>
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<tr>
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<tr>
<td>$C_2$</td>
<td>82.1298K</td>
</tr>
<tr>
<td>$T_R$</td>
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Table 1: simulation setup

Since the maximum deflection is only about 16% of the initial distance between heater and sheet, the actual change in the gray factor is negligible, as proposed in chapter 2 and shown in figure 1. While the temperature in the center of the planar sheet is almost uniform, at the edge areas the temperature drops several degrees.

**Figure 3:** temperature distribution of the top of the sheet in Kelvin vs. time

**Figure 4:** temperature through the centerline of the sheet in Kelvin vs. position at different time steps

**Figure 5:** sagging in millimetre vs time
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5. Concluding remarks

The proposed DISET-FEA approach is an incrementally decoupled finite element solution for structural-thermal-analysis and is therefore suitable for simulating the sheet sagging process. The setup in this work involves heating the sheet on one side with a rectangular heating element with the same dimensions as the sheet and uniform temperature. With the modelling approach presented, a zoned heating setup or a complex shaped heater configuration is also possible, but not presented in this article. The next step should be to analyse a real industrial process and create a more realistic heater design to verify the simulation results with experimental data. The result of the sagging simulation could be used as input in a subsequent forming simulation. As proposed in the introduction chapter, the ability to estimate heating and forming results allows the operator to improve the production process. A very interesting question to be answered is what should be the temperature distribution of the sheet to achieve optimal results for an individual product. Doing this in a virtual process flow could lead to better process reliability and thus improve the quality of thermoformed product and product quality as well as lead to more efficient, faster and more economical processes.

References

Excerpt from PI Circularity

**Editor’s Note:** With sections reprinted with permission here, Plastic Ingenuity’s 2023 Thermoform Circularity Report is the culmination of a year-long effort to discover the drivers, goals, and challenges associated with the transition to a circular economy for thermoforms. Stakeholders with diverse sustainability and packaging expertise were interviewed from consumer-packaged goods (CPGs), food retailers, and healthcare organizations. In our 2023 Thermoform Circularity Report, we highlight the many ways we are doing our part and some of the results we are already seeing. This section of the 2023 Thermoform Circularity Report highlights data-driven organizational insights throughout the industry driving the change happening today. To view the entire report, please visit PlasticIngenuity.com

**SPOTLIGHT**

**PET Recycling Landscape**

The demand for the use of post-consumer recycled (PCR) PET material in packaging is accelerating, fueled by brand commitments and legislative mandates. The leading global beverage brands have made significant commitments to add PCR PET material to their bottles. These PCR commitments are shown in the chart below, courtesy of NAPCOR1. PCR targets are shown in the dark blue bars of the chart, with current level in light blue. Overall volume is shown in orange with the scale on the right-hand side.

**THE DEMAND FOR PCR FUELS THE ECONOMIC INCENTIVES OUR RECYCLING INDUSTRY NEEDS TO OPERATE.**

Introducing PCR into packaging keeps valuable material out of our landfills so it can recirculate in our economy. The demand for PCR fuels the economic incentives our recycling industry needs to operate. Outside of the economic benefits, using PCR significantly lowers the carbon footprint of a package and reduces the use of virgin materials. Brands are also discovering that using PCR can enhance brand equity with sustainability-minded consumers.

PCR PET is in high demand and packaging applications are competing with other industries over the limited supply. Recycled PET material is used in a variety of end markets. In addition to packaging, a significant amount of recycled PET is consumed in the fiber and strapping industries. These applications can use lower grade PCR PET since they tend to be more forgiving than packaging, and there is significant pressure to increase the amount of PCR in fiber and strapping products. In positive news for packaging end markets, packaging surpassed fibers as the largest consumer of PCR PET in 2020 for the first time ever1. Also, it’s estimated that thermoforms are the largest consumer of recycled PET material recovered from California’s container redemption system.
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SPOTLIGHT

The existing supply of PCR PET is insufficient. In 2021, recycling rates for PET beverage containers were around 28.6%1. That can be seen in the dashed line of the chart below1. Target PCR content amounts are shown on the x-axis. This model estimates that a recycling rate of 45% would be needed to achieve 25% PCR in all beverage containers, shown in the dark blue line. This would require an investment of nearly $1 billion in reclamation capacity, shown in the light blue line. That does not include investments needed for increased collection and sorting.

Thermoformed packaging made from PET is recyclable when design for recycling guidelines are applied. However, thermoform recovery rates significantly lag behind beverage containers. A total of 142 million pounds of PET thermoforms were collected in U.S. and Canada in 2021 1. This equates to a recovery rate of 7.6%, assuming total generation of 1,871 MM lbs. This is much lower than the 28.6% recovery rate for beverage containers. The PET thermoform recovery rate is a conservative estimate, given difficulties quantifying the inputs to the rate calculation. The following chart shows the steadily increasing recovery of PET thermoforms 1:

Although 142 million pounds sounds like a lot of material (and it is!), capturing unrecovered thermoforms has the power to transform the PCR market. On a positive note, domestic reclamation of PET thermoforms has increased by 60% since 2017 1. This is evidence of a rapidly emerging market for recovered thermoforms.
**SPOTLIGHT**

**PET Reclaimer Survey**

Plastic Ingenuity surveyed nine of the leading PET reclaimers in North America to get a better understanding of the PCR PET market dynamics. PCR demand in thermoforms is expected to increase significantly over the coming years for the reasons highlighted above. The reclaimers surveyed account for nearly 950,000 U.S. tons of rPET capacity. The reclaimers were asked a series of questions regarding their perspective on the market and current bottlenecks they face. The following sections highlight key learnings discovered during the conversations.

**Capacity and Utilization**

Reclaimers are operating well below their installed capacity. The utilization is calculated to be 67% by dividing the amount of bottles collected (1,928 MM lbs.) by the estimated industry capacity (2,890 MM lbs.) in 2021. Several reclaimers are expanding capacity aggressively despite the bottleneck in bottle supply, while others are taking a “wait and see” approach to expansion. They expressed willingness to invest in new capacity if recovered bottle supplies increase.

**Feedstock Sourcing**

Most of the reclaimers source post-consumer PET bottle bales from localities near their production facilities. The bottle bales collected from curbside sources do have some percentage of thermoforms. The reclaimers did not list an allowable percentage, but research indicates thermoforms comprise on average 8.1% of a PET curbside bale. Some reclaimers stated they prefer zero thermoforms in their bales since they primarily sell to bottlers who do not allow them. The reclaimers purchase flake on the open market to supplement their operations when bottle bales are limited.

**Feedstock Market**

PET bale prices had a volatile year in 2022, as evidenced in the chart below, courtesy of RecyclingMarkets.net. Bale prices spiked to near-record levels in the beginning half of the year with a peak national average around $0.40 per pound. Pricing fell significantly at the end of summer with national average pricing dipping below $0.10 per pound. Consensus opinion is the decline was due to a combination of factors. Supply of recovered beverage containers is highest in the summer months as consumption increases. At the same time, recession-ary fears softened demand for PCR in fiber and construction markets. The combination of excess supply and tapering demand shifted the market into a correction. This is worth monitoring since bale pricing has significant implications on the recovery of PET items and PCR adoption in the market.

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SPOTLIGHT

End Markets

As discussed above, end markets for PCR PET include packaging, such as bottles and sheet for thermoforms, fibers, and strapping. Bottles are viewed as the highest value end market due to the high purity level and physical properties required for bottle-to-bottle recycling. Strapping and fibers are commonly viewed as the lowest value markets.

Equipment Considerations

All reclaimers surveyed deploy solid state polycondensation (SSP) units to increase the Intrinsic Viscosity (IV) of their outputs. It is the IV that determines the physical properties of the PET, with a higher IV being preferred for more demanding applications. The position of the SSP unit in the process does vary from reclaimer to reclaimer. Some are using it after the wash/rinse/dry process while others are using it after pelletizing. The later it is used in the process, the higher the IV that can be achieved with the pellet.

The wash/rinse lines also appear to be areas where reclaimers attempt to differentiate themselves. The effectiveness of the washing process correlates to the level of purity that can be achieved in the final product. Several reclaimers stated they build their own wash lines.

Quality & Certifications

All reclaimers surveyed provide PCR PET with a letter of no objection (LNO) from the FDA for use in food containers. Only one reclaimer surveyed offers certified PCR. This PCR is certified by a third party to be from post-consumer sources. The other reclaimers are self-certifying and audited by their customers for compliance.

Recycled Thermoforms

PET thermoforms are recycled in practice by inclusion in low percentages with PET bottles collected curb-side. Material Recovery Facilities (MRFs) typically cap the level of thermoforms included in bottle bales at 10-20% depending on agreements they have in place with their customers, the PET reclaimers. Unfortunately, many of these agreements do not allow thermoforms at any level 1.

MRFs are starting to sort and market thermoform-only bales on the West Coast. This signals that a market is emerging for PCR material from recovered thermoforms, known as thermoform clean wash flake (TCWF). Although the market is just starting to emerge, this demonstrates recovered thermoforms have value.

None of the reclaimers surveyed are marketing TCWF. However, most reclaimers accept thermo-forms in their bottle bales.

Conclusion

The reclaimers listed a variety of issues with thermoforms in their process:

- Their equipment was not designed to denest or separate thermoforms.
- Residue from labels and food causes issues.
- The shape of the flake (flat, instead of curly) presents conveying challenges.
- Thermoform cracking in hot wash process causes fines that result in yield loss.
- Barrier layers impact efficiency and produce fines.
- Variation in intrinsic viscosity causes issues with the final product.
- Lack of availability of thermoform-only bales hinders ability to experiment.

Several reclaimers expressed a desire to do more work with TCWF as the market develops. Reclaimers expressed that equipment can be optimized to process a higher level of thermoforms in bales.

A market is emerging for PCR material from recovered thermoforms, known as thermoform clean wash flake

We need to design for recovery to increase the likelihood of plastic being recycled.
Conclusion

Escalating demand for PCR PET in packaging markets is expected to incentivize efforts to recover additional PET items, like thermoforms, for recycling. These efforts will be catalyzed by initiatives such as the PET Recycling Coalition. PI will continue to support these initiatives, striving to unlock a more circular future for thermoformed packaging.

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<td>2022 Comet 6’ x 10’ Single Station Thermoformer</td>
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<td>NEW MAAC 6’ x 10’ Twinsheet 4 Station Rotary</td>
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To see how the GN915 form-cut-stack thermoformer can help your business grow, reach out today.

**Mantis**

Revolutionary Robotic Product Handling for Lids, Cups, Containers & More
The Mantis™ Robotic Trim Press Handler is compatible with all trim presses and dramatically reduces the need for manual labor on the back of your trim press. Front and back product containment keeps the integrity of your counted stacks “from trim press to palletizer”. System highlights include intuitive controls, VeriTool™ RFID tool verification, QC and reject isolation, plus quick and easy tool changeovers. The Mantis™ Robotic Trim Press Handler is the most innovative and successful solution in the industry for trim press automation.

Work smarter, faster, better
› Infinite, compact & flexible configurations
› 100% compatibility on all OEM trim presses
› 4x faster tool changeover: <30 minutes
› 75% labor reduction
› Reduced jams & product scrap

NAS is the leading food service packaging automation designer and manufacturer for full line material handling and packaging. NAS can support your forming automation needs from the trim press to the palletizer, offering industry-leading counting, wrapping, case erecting, case packing and palletizing solutions designed specifically for the thermoforming industry.

To see how the Mantis™ robotic trim press handler can improve your productivity, reach out today.
SEE YOU THERE.
2023 SPE Thermoforming Conference
October 23-26, 2023
Cleveland, OH

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