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Developed by the SPE Thermoforming Division R&D Committee

spe Thermoforming Quarterly®

Fourth Quarter 2025 | Volume 46 | Number 4

A Journal of the Thermoforming Division of SPE

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IN THIS ISSUE:

- Thermoforming Material Constants
- SPE Merger Announcement
- Polymer Tool Friction Coefficient
- K2025 Review

Thermoforming Quarterly®
Fourth Quarter 2025 | Volume 46 | Number 4

Departments

Features

In This Issue

Cover image courtesy of SAY Plastics

A JOURNAL PUBLISHED EACH CALENDAR QUARTER BY THE THERMOFORMING DIVISION OF THE SOCIETY OF PLASTICS ENGINEERS
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Every three years the plastic industry comes together at the K-Fair in Dusseldorf Germany. This year was no exception but what seemed to be missing was the US presence. China, India, Italy, Germany and most of the European Union was present and in force. Although the numbers were about the same as three years previous the absence of US-based companies was palatable. There was a large focus on sustainability both in products and in process. Recycling and recapturing material streams was in the forefront. See in-depth round-up on p . 48.

Paul G Uphaus

AI was also on display, with many companies promoting this emerging technology as the new frontier. **Plastics.com** launched a new platform that features an AI agent for suggesting plastics materials. **PolyID** was created by the National Renewable Energy Lab (NREL), a tool to help engineers balance performance with sustainability by screening millions of potential polymers and designs. MattterGen, a new tool from Microsoft Research, can create novel materials based on specific design requirements instead of just screening and existing option.

Automation was another key focus at K. Even in extrusion,where old school operators are the norm, it is becoming increasingly more difficult to maintain skilled labor due to the lack of interest in younger employees to work on dies that are manual without touch screens. Companies like Reifenhauser displayed their PAM (precise, autonomous, mechatronic) system which enables autonomous adjustments of the flex lip, and therefore of the thickness profile. In addition, depending on the configuration, adjustments of the restrictor bar, width adjustments and lip opening can be achieved. All adjustments are controlled by a gauge scanner on the takeoff.

The SPE Thermoforming Division made a lot of changes at our recent Board meeting held in Chattanooga, TN. We focused on our succession plan with Erich Kaintz voted in as Incoming Chair-Elect. Owen Dow will become Communications Committee Chair at the end of ToddHarrell's term in June 2026. Owen will step in as Promotions Committee Chair effective immediately until he joins ExCom. Gabriel Knee has accepted the position of Vice Chair of Promotions. Travis Kieffer is stepping in as Secretary of ExCom. Sam Owings accepted the position of Vice Chair of R&D Committee. Robert Browning will become Education Committee Chair, with Matt Hawkins as Vice Chair. Ned Moore will step in as ANTEC Technical Program Committee Chair and handle student activities. Both Stacy Ware and Chris Alongi were voted onto the board for one-year terms. See the new org chart on p. 57 for a summary of these changes.

During the meeting, three committees focused on two new workshops for 2026. Our goal is to hold a heavy gauge event in the spring and a thin gauge event in the fall. We also plan on holding 4 webinars to continue our mission. In fact, earlier this year, Primex Plastics hosted a workshop at their Technology & Innovation

Center in Richmond, IN. There were 18 total sponsors including 14 table tops which netted the division just over $15,000. We believe this will be the first of many more workshops in the "off-years" from the conference.

Finally, Pat Farrey, CEO of SPE, was kind enough to take some time during our board meeting and provide some clarity on the merger between Plastics Industry Association (PLASTICS) and the Society of Plastics Engineers (SPE). It made perfect sense, and we were all excited about the potential future benefits for both organizations and all the divisions,including ours.

You can read the complete press release on pp. 51-52. And check the SPE Communities online to register for future roundtable discussions about this momentous event.

SPE THERMOFORMING

Thermoforming Quarterly Goes 100% Digital – Starting Q3 2025!

An exciting new chapter for the only publication dedicated exclusively to thermoforming

Dear Sponsors, Partners, and Industry Colleagues,

We're excited to announce that Thermoforming Quarterly is transitioning to a fully digital format beginning in Q3 2025!

For over three decades, TQ has been the trusted source of technical insights, market updates, and innovations for thermoforming professionals. Since introducing a digital replica of our print edition in 2011—and expanding circulation by 10x in 2018—our digital audience now spans over 5,000 industry professionals across North America and Europe.

With this move, we are retiring the printed version and embracing a new, mobile-friendly digital platform. This upgrade offers several benefits:

- **Interactive content** with embedded video and audio files (YouTube, Vimeo)
- **Real-time metrics** including clicks, open rates, and reader engagement
- **Expanded reach** beyond Division members to a broader international audience

Importantly, **sponsorship pricing remains unchanged for 2025–26**. Sponsors can now elevate their messaging through enhanced ads, embedded multimedia, and exclusive issue sponsorship opportunities.

We deeply appreciate the support of our long-standing sponsors whose commitment has helped make TQ an award-winning publication and an essential industry resource.

For details on digital sponsorship enhancements or to secure space in an upcoming issue, refer to the supporting documentation or reach out to our editor, Conor Carlin, directly.

Thank you for joining us on this exciting next step in TQ's evolution!

Warm regards,

The Editorial Team
SPE Thermoforming Quarterly
An official publication of the SPE Thermoforming Division

New Sponsorship Opportunities

With our new digital platform, we are now able to offer analytics and metrics on most new sponsorship formats. In addition to the standard full page / half page / quarter page sponsorships, we are offering a suite of new options that can added or substituted for existing sponsorships / artwork.

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- Article body: 50-500 words, call to action link, and/or phone number

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- Audio must be uploaded in MP3 audio format.

Video

- MP4 (The maximum file size for a video is 100MB)
- YouTube Streaming Video (Hosted URL)**
    - **analytics not offered through our platform but via YouTube or other service
- Price: 1x $1250 / 4x $5000 (new category)

Slideshows

- No set dimensions. However, we recommend all images provided are the same size for the best experience.
- Price: 1x $1250 / 4x $5000 (4x – new category)

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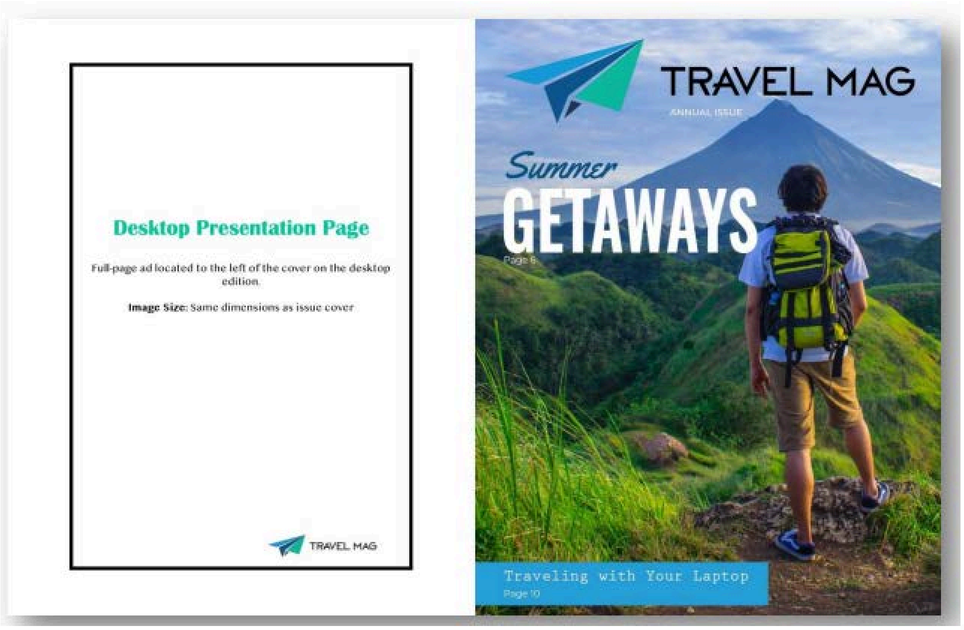

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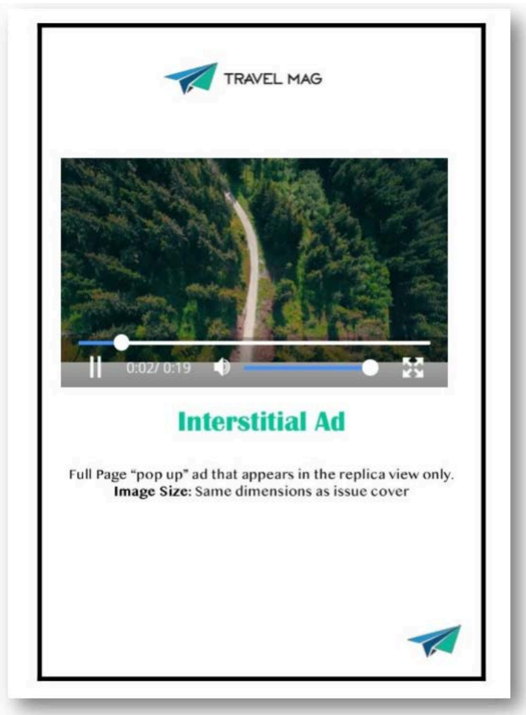

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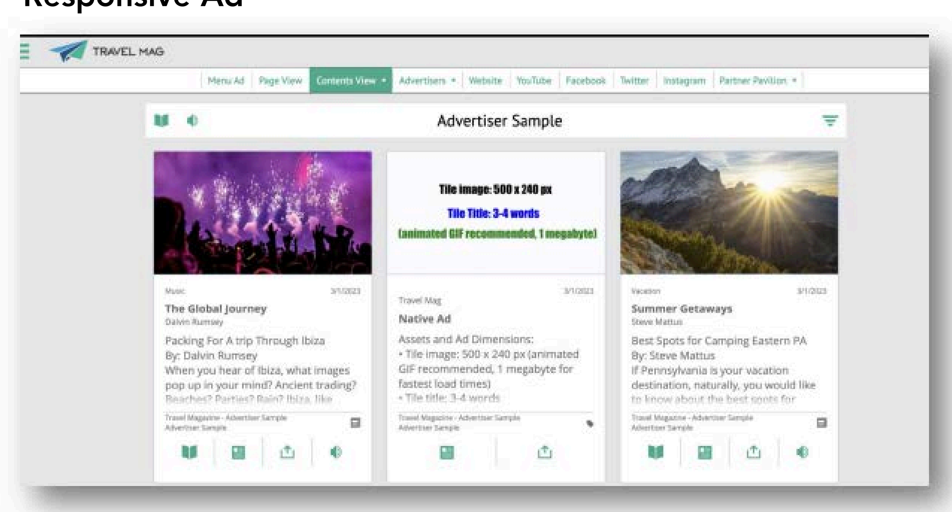

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Thermoform.ai Brings Decades of Training to Shop Floors Through AI

October 14, 2025
By Don Loepp, Editor, Plastics News (edited)

Düsseldorf, Germany — A new artificial intelligence tool introduced at K 2025 aims to solve one of thermoforming's most persistent challenges: how to preserve deep expertise and make it accessible to a new generation of operators — instantly, and at scale.

The platform, Thermoform.ai, is the brainchild of Conor Carlin, a longtime industry veteran and president of Clefs Advisory LLC.

Built on an industrial AI platform called Sprocket AI, Thermoform.ai is designed to act as a digital copilot on the shop floor—diagnosing problems, suggesting solutions and standardizing best practices across teams and shifts. Users will have the option to upgrade to SprocketAI for full network and manufacturing systems integration.

"It's been labeled a 'black art' for too long," Carlin said. "This is about bringing structure, clarity and confidence to a process that's traditionally relied on tribal knowledge and feel."

To build the platform's technical foundation, Carlin turned to Mark Strachan, a well-known trainer and consultant behind Global Thermoform Training Inc. (GTTI). Strachan's training materials — developed over more than three decades — form the initial knowledge base powering the AI's responses.

AI trained on real-world thermoforming problems

Thermoform.ai accepts natural language queries — typed or spoken — from users. Questions like "Why am I getting angel hair on PET?" or "How should I adjust my plug assist for this tool?" trigger answers based on a curated library of real-world training content, not generic web data.

"This isn't ChatGPT with a plastics vocabulary," Carlin said. "It's a domain-specific tool trained on actual thermoforming problems and how to solve them."

The system is designed for practical, line-side use. It helps with troubleshooting, setup optimization, and shift-to-shift knowledge retention. It can also evolve over time: customer scan upload machine manuals, part drawings or maintenance logs to build out their own private, plant-specific knowledge base.

"The base library is shared," Carlin said, "but the customer's own documents stay secure and separate. Each plant builds its own legacy over time."

Addressing labor gaps and generational change

One of the core motivations behind the tool is the industry's aging workforce and the shortage of young technicians entering thermoforming roles. Strachan, who still conducts hands-on training and speaks at industry events, said he's seen a growing gap in experience on the floor.

"There are a lot of operators who are retiring, and not a lot of people lining up to take their place," Strachan said. "This tool is about capturing what we know—and making it usable by people who are just getting started."

He also sees it as a better fit for the way younger technicians want to learn."They're not flipping through manuals," he said.

"They're on phones or tablets. This gives them the answers in a format that makes sense to them."

From concept to pilot launch

Carlin and Strachan are currently working with several early beta customers, and full pilot trials are expected to begin by the end of the year. The team plans to formally launch the platform in 2026.

While the initial focus is on thin-gauge and cut-sheet thermoforming, the training materials already include content relevant to heavy-gauge forming as well.

Staying focused on what they know

While AI hype is sweeping across the manufacturing world, Carlin is quick to emphasize that Thermoform.ai is a content package focused solely on thermoforming.

"There are a lot of bigger companies chasing injection molding or extrusion," he said. "We're not trying to be everything to everyone. We're staying in our lane and building a tool that speaks the language of thermoformers."


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Strachan sees Thermoform.ai as a bridge between the generation that built the industry and the one now learning to run it.

"This is the culmination of 30 years of my work," Strachan said."I've spent decades helping people troubleshoot on the shop floor. Now they'll have access to that knowledge whenever they need it—and that's pretty exciting."

Rumpke using AI to improve thermoform recycling

October 1, 2025
By Jim Johnson, Senior Reporter, Plastics News

Cincinnati — For the largest privately held solid waste and recycling company in the United States, improving plastics recycling is a case of enlightened self-interest.

Rumpke Waste & Recycling of Cincinnati has grown into a $1.3 billion company with operations in Ohio, Kentucky, West Virginia, Indiana and Illinois. With 16 recycling plants,4,300 employees and 2,800 vehicles of all types on the road, the company's impact on recycling continues to grow in the Midwest.

The company recently added PET thermoform packaging to its recycling stream collected from residential curbside collection, thanks to improvements in artificial intelligence that now helps the company better identify and segregate that material.

Jeff Snyder, recycling director at Rumpke, said investing in technology not only allows customers to recycle more but also gives Rumpke the opportunity increase recycling and divert more material from the network of 16 landfills the company operates.

Building and maintaining landfills is an expensive proposition for solid waste management companies, so diverting more collected material away from disposal through recycling is ultimately a financial win for firms.

"For me, it's about getting material out of the landfills, right? We want to save space on these landfills. We don't want recyclables in these landfills," Snyder said at the recent Baerlocher Recycling Summit held in Cincinnati.

While thermoforms can be made from PET, the resin formula is different for that packaging compared with PET bottles. There can be some tolerance for PET thermoforms in PET bottle-to-bottle applications, but not a lot.

"Thermoforms have to be segregated from water bottles," Snyder said during the summit organized by Baerlocher, a maker of additives for plastics. "And the only way that I can do that is with AI. AI was incorporated in Ohio over the last year and a half in our material recovery facilities."

Rumpke has two significant MRFs in Columbus and Cincinnati, where the company has invested millions of dollars to manage single-stream curbside collected recyclables that can also include glass, metal and paper.

"Now I can take a picture of a thermoform and send it in a different direction than a waterbottle," he said about the use of artificial intelligence while calling the technology a "game-changer."

"I can now sort it. I can now tell the public to put the recyclables in because all that material is going to Eastman Chemical down in Kingsport, Tenn.," he said

Eastman opened a chemical recycling plant in Kingsport in March 2024 that has the capacity to recycle 110,000 metric tons of plastic each year through methanolysis, a process that breaks down resin into its molecular constituents that can then be reformulated.

Snyder also talked about ongoing work to recycle toothpaste tubes, which have undergone redesign in recent years to become a monomaterial container that allows for recycling.Colgate-Palmolive pioneered the switch from the use of multimaterial structures that rendered such tubes essentially unrecyclable to a high-density polyethylene approach that helps open the door to recyclability. The problem remains, however, that the tubes are smaller than what is typically managed by MRF sorting equipment and are more difficult to recapture.

Rumpke recently hosted representatives from both Colgate-Palmolive and Procter &Gamble Co., another major toothpaste maker, for tube sortation trials. "We and hundreds and hundreds of toothpaste tubes," he said. "We wanted to see what happened to them [as they went through the sortation process].

"When a brand wants to understand how their material or their package can flow through a material recovery facility, I give them access to our plants," he said, and use tracking technology such as RFID tags to gain an understanding on how material flows through the maze of sortation equipment.

"Very excited about being able to add new different commodities, new different packaging things to the recycling stream. The tube didn't go as well as I thought it would. We only recovered about 15 percent of them," Snyder said. "So, there's still some work to be done there. But I just wanted to tell you the energy around packaging and trying to get it recycled."

Thermoformer PolyFlex Spending $8.3M to Expand in Tennessee

September 24, 2025
By Jim Johnson, Senior Reporter, Plastics News

PolyFlex Products LLC is spending $8.3 million to expand in Tennessee, a move that will create 58 new jobs.

The project in McMinnville "will assist the company's Morrison thermoform packaging operations by adding material extrusion capabilities and reuse of end-of-life industrial packaging," according to a project announcement.

PolyFlex, a unit of Nefab Group AB of Sweden, will employ 85 in Warren County when the expansion is complete.

"We are not only investing in the economic growth of Warren County but also enhancing our technological capabilities in advanced thermoforming and sustainable plastics for the road ahead," said Darrell Tiedeman, vice president of plastics solutions America for Nefab Group,in a statement.

Nefab's growth in Tennessee through PolyFlex comes at a time of growth for Nefab, which acquired Plastiform Inc. of Irving, Texas, a maker of thermoformed cushioning products, last year.

And about a year ago, Nefab opened a location in Grand Blanc, Mich., for the design, prototype and manufacture of injection molding tooling as part of a "larger expansion strategy to bring injection molded parts to market more efficiently while prioritizing sustainability and cost effectiveness," the company said at the time.

Nefab Group also completed a new 58,000-square-foot location in Zapopan, Mexico, specializing in thin-gauge thermforming to serve the data communications, electronics and automotive industries.

Nefab, headquartered in Jönjöping, Sweden, acquired PolyFlex in 2023.

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PLASTICS M&A UPDATE

SEPTEMBER 2025

Plastics Industry M&A Activity Tracking

Global Packaging M&A announced 25 deals in September, coming in below year-to-date monthly averages but exceeding August volumes by one transaction. Both Platform and Add-on activity saw upticks relative to August, which was offset by weaker activity from Strategic buyers, who posted less than 10 deals in a month for only the second time this year. Deals involving an acquirer and target based in the United States accounted for the majority of monthly deal flow for the first time in 2025, underscoring strong demand within the domestic Packaging M&A market. Overall, Global Packaging M&A remains elevated compared to prior year levels heading into the fourth quarter.

- In September, the Printing/Labels subsector led all subsectors for the first time since February 2025. Meanwhile, all other subsectors recorded deal flow in-line with or below year-to-date averages.
- Strategic buyer activity slowed in September. Strategic buyers accounted for nine transactions, which marked the second-lowest monthly total for this buyer type in 2025. Financial buyers accounted for 64% of the deals in the month, a significant increase from 42% in August. This uptick was primarily driven by add-on acquisitions, which recorded 10 deals in the month, the highest level since April.
- No cross-border transactions were announced in September involving companies based in the United States. Meanwhile, Domestic activity drove transaction levels and accounted for 56% of volume. This marks only the second month in 2025 that domestic deal volumes outpaced foreign transaction activity.
- 11 Food & Beverage transactions were recorded in the month, marking the highest level of deal activity this end market has experienced since April. Meanwhile, the Industrial end market had its least active month of the year with only four transactions, a decline of six deals from August.

PACKAGING M&A BY SUBSECTOR

	Month-to-Date			Year-to-Date		
Subsector	2024	2025	Change	2024	2025	Change
Rigid Packaging	7	6	-1	47	58	11
Flexible Plastic	1	1	0	29	35	6
Paper	6	4	-2	54	56	2
Printing/Labels	1	8	7	26	39	13
Protective Packaging	0	1	1	17	24	7
Machinery & Distribution	6	5	-1	54	47	-7
Total	**21**	**25**	**4**	**227**	**259**	**32**

PACKAGING M&A BY BUYER TYPE

Type	MTD	% of Total	YTD	% of Total
Strategic	9	36%	129	50%
Add-On (PE)	10	40%	78	30%
Platform (PE)	6	24%	52	20%

PACKAGING M&A BY GEOGRAPHY

Type	MTD	% of Total	YTD	% of Total
US-to-US	14	56%	98	38%
US-to-Foreign	0	0%	25	10%
Foreign-to-US	0	0%	7	3%
Foreign	11	44%	129	50%

PACKAGING M&A BY END MARKET

End Market	MTD	%	YTD	%
Food & Beverage	11	44%	82	32%
Industrial	4	16%	83	32%
Consumer	8	32%	74	29%
Medical	2	8%	20	8%

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If you are a plastics company considering a merger, acquisition, sale, or recapitalization in the short or longer term please consider leveraging PMCF's transaction planning and execution expertise to best position your company in a transaction.

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

Plastics M&A Update — September 2025

Industry Multiples and Trends

Mean EV/EBITDA multiplesexperienced mixed performance in September. Plastic Fabricating maintained strong growth, while Resin and Color & Compounding and Plastic Packaging saw modest declines. Despite this pullback, all three remain well above early-year levels, with Plastic Fabricating expanding more than 2.25x compared to the first month of the year

Public Stock Performance

Plastic publicentities experienced a mix of gains and losses for the month. 2025 continues to show wide disparity among the three subsectors, with Resin and Color & Compounding on one end posting significant losses year-to-date, while Plastic Fabricating has recorded similar sized gains over the same period

Company Name	Stock Performance Year-to-Date	Stock Performance Month-to-Date	Enterprise Value / LTM1	
			Revenue	EBITDA
Resin and Color & Compounding				
Avient Corporation	-17.9%	-11.9%	1.41x	8.42x
Dow Inc.	-41.9%	-6.9%	0.79x	6.38x
LyondellBasell Industries N.V.	-33.0%	-13.0%	0.71x	8.76x
Solvay SA	-12.4%	-3.8%	0.96x	5.81x
Trinseo PLC	-54.0%	-2.1%	0.77x	13.58x
Westlake Chemical Corporation	-32.1%	-12.3%	1.16x	9.40x
Mean	**-31.9%**	**-8.3%**	**0.97x**	**8.73x**
Median	**-32.5%**	**-9.4%**	**0.88x**	**8.59x**
Plastic Packaging				
Amcor plc	-12.4%	-5.2%	2.22x	14.94x
Aptar Group, Inc.	-14.7%	-4.0%	2.72x	11.63x
Essentra plc	-17.4%	7.0%	1.37x	10.03x
Huhtamaki Oyj	-13.8%	-2.9%	1.10x	8.60x
Karat Packaging Inc.	-15.7%	-0.3%	1.25x	7.93x
Nampak Limted	11.7%	-4.0%	0.77x	5.66x
Sealed Air Corporation	5.1%	8.9%	1.74x	8.59x
Silgan Holdings Inc.	-16.9%	-8.3%	1.52x	8.87x
Sonoco Products Company	-11.3%	-8.8%	1.52x	8.04x
Transcontinental Inc.	7.3%	-3.4%	0.89x	5.60x
TriMas Corporation	57.9%	-0.1%	2.09x	14.01x
Winpak Ltd.	-14.7%	-2.5%	1.34x	6.37x
Mean	**-2.9%**	**-2.0%**	**1.54x**	**9.19x**
Median	**-13.1%**	**-3.1%**	**1.44x**	**8.59x**
Plastic Fabricating				
Core Molding Technologies, Inc.	25.2%	7.0%	0.57x	5.03x
Proto Labs, Inc.	27.4%	0.4%	2.11x	18.00x
Myers Industries, Inc.	55.0%	1.2%	1.22x	8.17x
Mean	**35.9%**	**2.9%**	**1.30x**	**10.40x**
Median	**27.4%**	**1.2%**	**1.22x**	**8.17x**

[1]LTM as of latest available financials

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

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Notable M&A Activity

Date	Acquirer	Target	Category
9/29/2025	Resonetics	Eden Manufacturing	Medical Injection Molding
9/23/2025	Advanced Drainage Systems (NYSE: WMS)	National Diversified Sales, Inc.	Extrusion
9/22/2025	Freudenberg Sealing Technologies	DMH Group	Seals
9/19/2025	Sheridan Capital Partners	Currier Plastics	Rigid Packaging
9/17/2025	I Squared Capital Advisors	ENTEK International	Machinery
9/15/2025	Inteplast Group	Reef Industries, Inc.	Film
9/9/2025	Polycorp	Burke Industries	Color & Compounding
9/8/2025	Georgia-Pacific	Anchor Packaging	Thermoforming

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

Major News & Insights

- Federal Agencies Retain 'Keen Interest' in Microplastics Research (Plastics News)
- US Imposes Full Tariffs on PET, Recycled PET Imports from Asia (Plastics News)
- California Names Companies Expected to Report Emissions, Climate Risks (Packaging Dive)
- Industry Report: The Good, the Bad, and the Uncertain? (PlasticsToday)
- Trump's Team Explores Government-Backed Manufacturing Boost (The Wall Street Journal)
- Powell Describes Rates as 'Modestly Restrictive,' Keeping Door Open to Cuts (The Wall Street Journal)

PMCF's Plastics & Packaging Group

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Recent PMCF Plastics & Packaging Transactions

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COMPOUNDING

SUNAMERICA a portfolio company of HUNTER VALLEY COMPANY LLC / VITRUVIAN GROUP has been acquired by MPE PARTNERS and completed a simultaneous merger with Central Coated™

THERMOFORMING

CMG PLASTICS has been acquired by Berry

INJECTION & BLOW MOLDED PACKAGING

ENVIRO PLAS INC. ENGINEERING RESIN SOLUTIONS has completed its merger with AURORA PLASTICS a portfolio company of NAUTIC

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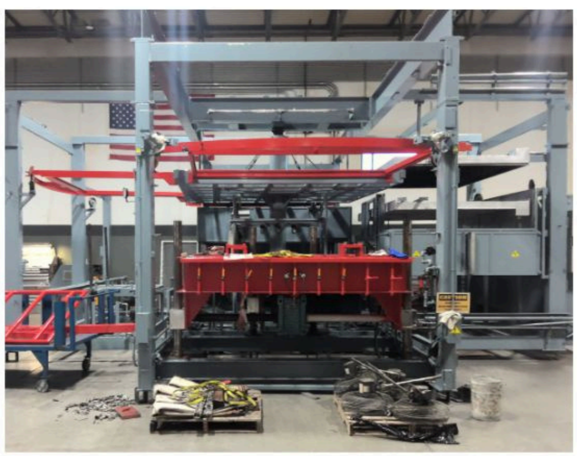
New Chillers In Stock



Rebuilt Maac 5' x 8' Twin Sheet

New Temperature Control Units

spe THERMOFORMING

Blow Molding Thermoforming Injection Extrusion Size Reduction

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PACKAGING M&A UPDATE

SEPTEMBER 2025

Packaging Industry M&A Activity Tracking

Global Packaging M&A announced 25 deals in September, coming in below year-to-date monthly averages but exceeding August volumes by one transaction. Both Platform and Add-on activity saw upticks relative to August, which was offset by weaker activity from Strategic buyers, who posted less than 10 deals in a month for only the second time this year. Deals involving an acquirer and target based in the United States accounted for the majority of monthly deal flow for the first time in 2025, underscoring strong demand within the domestic Packaging M&A market. Overall, Global Packaging M&A remains elevated compared to prior year levels heading into the fourth quarter.

- In September, the Printing/Labels subsector led all subsectors for the first time since February 2025. Meanwhile, all other subsectors recorded deal flow in-line with or below year-to-date averages
- Strategic buyer activity slowed in September. Strategic buyers accounted for nine transactions, which marked the second lowest monthly total for this buyer type in 2025. Financial buyers accounted for 64% of the deals in the month, a significant increase from 42% in August. This uptick was primarily driven by add-on acquisitions, which recorded 10 deals in the month, the highest level since April
- No cross-border transactions were announced in September involving companies based in the United States. Meanwhile, Domestic activity drove transaction levels and accounted for 56% of volume. This marks only the second month in 2025 that domestic deal volumes outpaced foreign transaction activity
- 11 Food & Beverage transactions were recorded in the month, marking the highest level of deal activity this end market has experienced since April. Meanwhile, the Industrial end market had its least active month of the year with only four transactions, a decline of six deals from August

PACKAGING M&A BY SUBSECTOR

	Month-to-Date			Year-to-Date		
Subsector	2024	2025	Change	2024	2025	Change
Rigid Packaging	7	6	-1	47	58	11
Flexible Plastic	1	1	0	29	35	6
Paper	6	4	-2	54	56	2
Printing/Labels	1	8	7	26	39	13
Protective Packaging	0	1	1	17	24	7
Machinery & Distribution	6	5	-1	54	47	-7
Total	21	25	4	227	259	32

PACKAGING M&A BY BUYER TYPE

Type	MTD	% of Total	YTD	% of Total
Strategic	9	36%	129	50%
Add-On (PE)	10	40%	78	30%
Platform (PE)	6	24%	52	20%

PACKAGING M&A BY GEOGRAPHY

Type	MTD	% of Total	YTD	% of Total
US-to-US	14	56%	98	38%
US-to-Foreign	0	0%	25	10%
Foreign-to-US	0	0%	7	3%
Foreign	11	44%	129	50%

PACKAGING M&A BY END MARKET

End Market	MTD	%	YTD	%
Food & Beverage	11	44%	82	32%
Industrial	4	16%	83	32%
Consumer	8	32%	74	29%
Medical	2	8%	20	8%

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If you are a packaging company considering a merger, acquisition, sale, or recapitalization in the short or longer term please consider leveraging PMCF's transaction planning and execution expertise to best position your company in a transaction.

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

Packaging M&A Update — September 2025

Industry Multiples and Trends

Multiples for public packaging entities held relatively steady compared to stock performance. Rigid Plastic was the only subsector to see meaningful expansion, with its mean EV/EBITDA multiple increasing by more than 0.6x, while the other three subsectors posted slight contractions

Public Stock Performance

Publicpackaging stocksextended their decline in September, with all four subsectors posting single-digit losses. Other Packaging remains the only segment showing gains for the year, supported by strong performance from select companies. Meanwhile, Paper Packaging closed the month with cumulative losses exceeding the double-digit mark for the sixth time this year, reinforcing ongoing challenges in the segment

Company Name	Stock Performance Year-to-Date	Stock Performance Month-to-Date	Enterprise Value / LTM[1]	
			Revenue	EBITDA
Rigid Plastic				
AptarGroup, Inc.	-14.7%	-4.0%	2.72x	11.63x
Essentra plc	-17.4%	7.0%	1.37x	10.03x
Karat Packaging Inc.	-15.7%	-0.3%	1.25x	7.93x
Nampak Limited	11.7%	-4.0%	0.77x	5.66x
Silgan Holdings Inc.	-16.9%	-8.3%	1.52x	8.87x
Sonoco Products Company	-11.3%	-8.8%	1.53x	8.10x
TriMas Corporation	57.9%	-0.1%	2.09x	14.01x
Mean	**-0.9%**	**-2.6%**	**1.61x**	**9.46x**
Median	**-14.7%**	**-4.0%**	**1.52x**	**8.87x**
Flexible Plastic				
Amcor plc	-12.4%	-5.2%	2.22x	14.94x
Huhtamaki Oyj	-13.8%	-2.9%	1.10x	8.60x
Sealed Air Corporation	5.1%	8.9%	1.74x	8.59x
Transcontinental Inc.	7.3%	-3.4%	0.89x	5.60x
Winpak Ltd.	-14.7%	-2.5%	1.34x	6.37x
Mean	**-5.7%**	**-1.0%**	**1.46x**	**8.82x**
Median	**-12.4%**	**-2.9%**	**1.34x**	**8.59x**
Paper Packaging				
Cascades Inc.	-18.7%	-1.9%	0.65x	5.72x
Graphic Packaging Holding Co.	-27.8%	-12.1%	1.34x	6.81x
Greif, Inc.	-1.6%	-8.5%	1.04x	6.79x
International Paper Company	-13.5%	-6.6%	1.55x	11.81x
Packaging Corporation of America	-3.1%	0.0%	2.47x	10.90x
Smurfit Westrock Plc	-20.6%	-10.1%	1.16x	7.59x
Mean	**-14.2%**	**-6.5%**	**1.37x**	**8.27x**
Median	**-16.1%**	**-7.6%**	**1.25x**	**7.20x**
Other Packaging				
Ardagh Metal Packaging S.A.	34.8%	8.1%	1.18x	8.22x
Avery Dennison Corporation	-13.4%	-5.5%	1.82x	10.60x
Ball Corporation	-8.3%	-4.2%	1.68x	10.04x
CCL Industries Inc.	6.8%	-4.7%	2.05x	9.82x
Crown Holdings	18.0%	-2.8%	1.45x	8.18x
Gerresheimer AG	-50.3%	-18.1%	1.55x	7.84x
O-I Glass, Inc.	24.4%	-0.2%	1.05x	6.46x
Toyo Seikan Group Holdings, Ltd.	40.2%	-6.0%	0.69x	6.76x
Mean	**6.5%**	**-4.2%**	**1.43x**	**8.49x**
Median	**12.4%**	**-4.4%**	**1.50x**	**8.20x**

[1] *LTM as of latest available financials*

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

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Notable M&A Activity

Date	Acquirer	Target	Category
9/29/2025	Welch Packaging	Elite Packaging	Corrugated
9/25/2025	Handgards	Albany Packaging USA	Packaging Distribution
9/19/2025	Sheridan Capital Partners	Currier Plastics	Rigid Packaging
9/19/2025	Portrait Capital	AAi Labels & Decal & Sticker Ranch	Printing/Labels
9/16/2025	Momentum Packaging	Superior Lithographics, Inc.	Folding Cartons
9/8/2025	Arsenal Capital Management	ThermoSafe Business Unit of Sonoco	Protective Packaging
9/8/2025	Georgia-Pacific	Anchor Packaging	Rigid Packaging
9/2/2025	Veritiv	S. Walter Packaging Corporation	Packaging Distribution

Sources: S&P Capital IQ, Company Websites, Pitchbook, Company Reports, PMCF

Major News & Insights

- 2025 Packaging State of the Industry: U.S. Expands, Canada Maintains (Packaging World)
- 5 Ways AI is Shaping Packaging Today (Packaging Dive)
- California Names Companies Expected to Report Emissions, Climate Risks (Packaging Dive)
- PRS 2025 Captures Pivotal Moment in Circularity (Packaging World)
- Trump's Team Explores Government-Backed Manufacturing Boost (The Wall Street Journal)
- Powell Describes Rates as 'Modestly Restrictive,' Keeping Door Open to Cuts (The Wall Street Journal)

PMCF's Plastics & Packaging Group

PMCF's Plastics and Packaging investment bankers are dedicated solely to serving the needs of middle-market transactions within the plastics and packaging industries. Our exclusive focus on plastics and packaging sale, merger, and acquisition advisory provides significant advantages to our clients and the opportunity to maximize value in a transaction. PMCF's extensive coverage of these industries has provided us with specialized, in- depth knowledge of the sector dynamics and relationships with key strategic and financial industry players. Our firm has been serving the plastics and packaging industries for over 20 years and has a long track record of successful transactions involving specialty, niche players in these industries.

Recent PMCF Plastics & Packaging Transactions

SUNAMERICA
a portfolio company of
Hunter Valley Company LLC | Vitruvian Group
has been acquired by
MPE Partners
and completed a simultaneous merger with
Central Coated

THERMOFORMED & PAPER PACKAGING

CMG Plastics
has been acquired by
Berry

INJECTION & BLOW MOLDED PACKAGING

Progress Container & Display
has been acquired by
TRG The Royal Group

CORRUGATED PACKAGING

kpc
has been acquired by
Hood Container Corporation

CORRUGATED PACKAGING

Two-time winner, Boutique Investment Banking Firm of the Year by M&A Advisor

Awarded, Cross Border Corporate and Strategic Acquisition of the Year by M&A Advisor

Awarded, Cross Border M&A Deal of the Year by M&A Advisor

Awarded, Dealmaker of the Year by ACG Detroit

Development of Low Environmental Impact Technological Solutions Based on PLA, PBS, PBAT and Talc Blends for Multilayer Food Packaging Manufacturing

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Keywords: *Plastic and Composite Material Processes, Extrusion, Environmental Impact*

Abstract. This research focuses on manufacturing of innovative multilayer food packaging solutions employing PLA, PBS and PBAT to investigate the use of bio-based, biodegradable and compostable polymeric materials to replace fossil-based plastics. To meet the final product technological and functional requirements, three material formulations were investigated. Corotating twin-screw extrusion was used to produce the compounds for the single layers. A multilayer sheet extrusion process was then used to create a multilayer film made of an inner core and two equal outer layers with the aim to meet varying property requirements across the film thickness. Finally, thermoforming of the films was carried out to produce prototype food containers that were tested to evaluate their thermo-mechanical properties. The integration of material, process and product design allowed to develop biodegradable and compostable food packaging solutions, notably reducing the environmental footprint of these products.

1. Introduction

Food packaging plays a central role in food manufacturing, as it preserves the quality of food products for storage, transportation and end use [1]. In rigid food packaging, polyolefins are often used as they offer a good compromise among cost, ease of molding and performance [2]. For multilayer packaging, the most employed materials include low-density polyethylene (LDPE), polypropylene (PP), high-density polyethylene (HDPE) and polyethylene terephthalate (PET) [3]. The production of fossil-based plastics represents a global concern as it disrupts the global carbon cycle [4]. The end of life of these products is an issue, as they are often improperly managed. As a matter of fact, open air incineration or disposal in landfills can harm the ecosystem via contamination of air, soil and water [5]. Millions of tons of plastics are annually dumped into landfills, occupying large volumes and contributing to capacity shortage [6].

Various research efforts have been carried out to develop bio-based blends suitable for manufacturing thermoformed products. Compostable blends specifically designed for thermoforming, including those based on PLA, have been extensively explored in the literature [7]. However bioplastics are much more expensive than traditional petroleum-based polymers.

This study aims to validate the feasibility and processability of new low cost, bio-based and biodegradable polymer compounds to manufacture multilayer sheets to be thermoformed with the aim of producing food trays with performances comparable to those of traditional fossil-based products. Three compound formulations were designed to produce three different materials. Two alternative configurations of a three-layer sheet were designed to explore the best solution providing a structural inner core layer with high impermeability properties and low material cost, and two identical outer surfaces with high flexibility. The three materials were produced by twin screw extrusion process while the three-layer sheets were fabricated by multilayer cast extrusion. The semifinished products were then thermoformed to manufacture a food tray prototype made of bio-based, bio-degradable and compostable polymeric materials.

2. Materials and methods

The initial material formulations are presented in Table 1. The first (INN) is intended as the core layer of the sheet while OUT_T1p and OUT_T2p are designed to serve as the outer surface layers.

Table 1. Initial formulations.

Sample ID	INN (Inner layer)	OUT_T1p (Outer layer Type 1)	OUT_T2p (Outer layer Type 2)
Components	*wt.%*	*wt.%*	*wt.%*
PLA Luminy L175	48%	20%	0%
PBS A200 MF	12%	80%	80%
PLA Luminy D120	2%	0%	0%
Talc CHX05L	36,9%	0%	0%
EBS EVIWAX	1%	0%	0%
Joncryl ADR 4400	0,1%	0%	0%
PBAT KB100	0%	0%	20%

APLA Luminy L175 and PLA Luminy D120 from Total Corbion PLA (TotalEnergies Corbion, Stadhuisplein, NL) were selected to produce a bio-based and compostable polymeric phase. PBS A200 MF and PBAT KB100 from Kingfa (Guangzhou, CN) were used as compostable polymeric phases. A large amount of talc (from IMI Fabi S.p.A., Milan, Italy) was used as mineral filler to reduce production costs and improve the properties of the inner layer compound, such as rigidity, strength, hardness, flexural modulus, dimensional stability and thermal conductivity; it was also used as nucleating agent [8]. EBS (Ethylene bis stearamide) waxy lubricant was used as process aid. Joncryl ADR 4400 (Basf, Ludwigshafen, Germany) was used as chain extender. Each material was chosen for its compliance with food contact regulations, as stated in the technical data sheets.

During cast extrusion, the outer layer materials in both formulations exhibited processability issues, as the film surfaces were excessively sticky on the calenders, leading to delamination of the multilayer sheet. Thus, OUT_T1p and OUT_T2p were redesigned by adding 10% of talc to both formulations. Actually, a preliminary compound can often highlight, during processing, the need for mineral fillers and rheological additives to enhance its processability [7]. A mineral additive such as talc is affordable and can be used as an anti-blocking agent, reducing moisture absorption and increasing scratch resistance [3]. OUT_T1p and OUT_T2p were then re-extruded with the optimized formulations presented in Table 2 to produce OUT_T1 and OUT_T2 surface materials.

Table 2. Optimized formulations.

Sample ID	INN (Inner layer)	OUT_T1 (Outer layer Type 1)	OUT_T2 (Outer layer Type 2)
Components	*wt.%*	*wt.%*	*wt.%*
PLA Luminy L175	48%	18%	0%
PBS A200 MF	12%	72%	72%
PLA Luminy D120	2%	0%	0%
Talc CHX05L	36,9%	10%	10%
EBS EVIWAX	1%	0%	0%
Joncryl ADR 4400	0,1%	0%	0%
PBAT KB100	0%	0%	18%

2.1 Compounding, cast extrusion and thermoforming.

The processes were carried out in sequential phases with different extruders for each film component. The inner layer (INN) material of the film was produced via twin screw extrusion on a Leistritz ZSE MAXX 27 I extruder (Leistritz AG, Nuremberg, Germany) with 27 mm screws and length to diameter ratio of 40. Table 3 shows the process parameters and temperature profile.

A hump-back temperature profile with a maximum temperature of 180°C was set to ease the processability of PLA. The set screw speed was relatively low (250 - 270 rpm) to avoid any excessive torque or pressure increase due to the presence of talc which, when compounded with polylactic acid, tends to increase the viscosity of the melt [9]. Increasing screw speeds can enhance material mixing and plasticization; however, they also raise the risk of elevated torque and pressure. Hence, it is crucial to carefully regulate screws speed to optimize material properties while minimizing excessive mechanical stress [10].

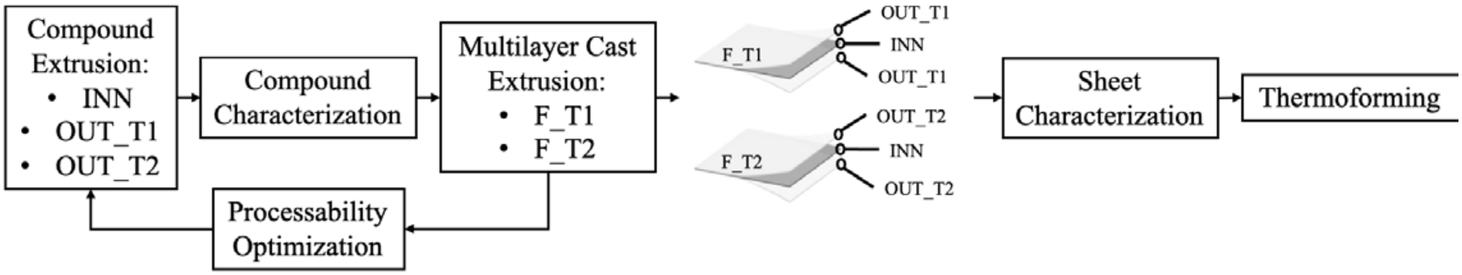

Figure 1: Overall process scheme

Table 3. Temperature profile and processing parameters for INN inner layer material extrusion.

Temperature profile [°C]									
T1	T2	T3	T4	T5	T6	T7	T8	T9	Die
170	172	175	177	180	180	180	175	175	173

Processing parameters							
Screws speed [rpm]	Feeder speed [rpm]	Granules flow [%]	Powders flow [kg/h]	Melting temperature [°C]	Pressure [bar]	Torque [%]	Cutting speed [%]
250	256	15	8,77	182	62	30	80

The mineral filler was fed into the extrusion cylinder in its 4th zone, just before reaching the maximum temperature value, to facilitate the mixing of the powder with the polymer matrix. Also, a low screw speed allows a longer stay of the melt in the extruder cylinder, giving the talc more time to mix with the other components.

The extrusion of the outer layer materials required two consecutive stages because of the above mentioned issue. They were produced with the same technology as the inner layer but using, for the first stage, a Thermo Scientific HAAKE PolyLab 24/40-MC OS machine (Thermo Fisher Scientific, Karlsruhe, Germany). The latter was selected for the outer layer materials without mineral powders because, with 24 mm-screws and a length to diameter ratio of 40, it is smaller and easier to manage when no additional powders or liquid additives are needed. Table 4 presents the process parameters and temperature profile for the outer layer material Type 1 (OUT_T1p).

Table 4. Temperature profile and processing parameters for OUT_T1p.

Temperature profile [°C]									
T1	T2	T3	T4	T5	T6	T7	T8	T9	Die
150	152	153	155	160	160	160	160	155	153

Processing parameters				
Screws speed [rpm]	Granules flow [%]	Pressure [bar]	Torque [%]	Cutting speed [%]
270	35	14,1	81	3,5

Also in this case, a hump-back temperature profile was chosen. The formulated blend was prepared by mixing the raw materials in a CABO Mix Space 490 planetary mixer for 10 min and the mixture was fed via volumetric feeder in the first feed zone of the extruder. For the extrusion of the outer layer material Type 2 (OUT_T2p), the blend blend preparation process was the same, and the process parameters and temperature profile presented in Table 5 were adopted.

The process parameters for the extrusion of OUT_T1p and OUT_T2p were almost the same except for the granules flow: it was observed that, even with a lower granules feed rate, the presence of PLA instead of PBAT caused an increase of pressure and torque.

Table 5. Temperature profile and processing parameters for OUT_T2p.

Temperature profile [°C]									
T1	T2	T3	T4	T5	T6	T7	T8	T9	Die
150	152	153	155	160	160	160	160	155	153
Processing parameters									
Screws speed [rpm]		Granules flow [%]		Pressure [bar]		Torque [%]		Cutting speed [%]	
270		50		9,4		78		3,5	

In a first attempt, the three extruded compounds were cast extruded to produce the two multilayer sheet configurations. The films were produced using a MiniCast Coex 5 machine (Eurotech Extrusion Machinery - Eurexma, Tradate (VA), Italy), which allows to produce multilayer sheets up to five layers.

The study involves the production of two multilayer sheets with different configurations. Type 1 film F_T1 consists of an inner layer of INN material and two identical outer layers of OUT_T1p on both external sides. Type 2 sheet F_T2 has the same inner layer and two outer surfaces of OUT_T2p. The cast extrusion process parameters are the same for both F_T1 and F_T2 (Table 6).

Table 6. Temperature profile and processing parameters for cast extrusion of F_T1 and F_T2.

	Rotational speed [m/min]	Screw speed [rpm]	Temperature profile [°C] Zone 1	Zone 2	Zone 3	Central back zone	Central front zone	Left lateral zone	Right lateral zone
Drive	1,1								
Calender 1	0,6								
Calender 2	0,8								
Extruder A (outer layer)		71	140	145	145				
Extruder C (inner layer)		73	200	200	200				
Extruder B (outer layer)		71	140	145	145				
Die						150	165	155	155

The screw rotational speed for the inner layer was slightly higher than the screw speed chosen for the extrusion of the outer sides of the sheet in order to reduce the thickness of the surfaces compared to the core layer. The temperature profile for the outer layers was set to slightly lower values compared to the relative twin screw extrusion profile to reach a lower flow of the melt with an already processed material. For the inner layer, it is important to at least reach the activation temperature between 190°C and 200°C for the chain extender Joncryl ADR 4400 and then reduce the temperature to decrease the melt flow through the die. The die temperature profile was chosen considering the different heat transfer of the external surfaces of the die.

For each sheet configuration, the cast extrusion process showed that the outer layers were too sticky on the calenders and the process could not be completed. The design of the surface layers was consequently modified to optimize the processability in cast extrusion. 10% of talc was added to the original design as a solid lubricant to mitigate the adhesion phenomenon on the calenders. The final design configuration is shown in Table 2. The issue was successfully solved, and the cast extrusion process was completed for both configurations, producing the two multilayer sheets, F_T1 and F_T2, with the MiniCast Coex 5 and the processing parameters of Table 6. In Figure 2 it is possible to see the cast extrusion process, in calender mode, with a focus on the die and the extruded sheet during the fabrication of the semifinished products.

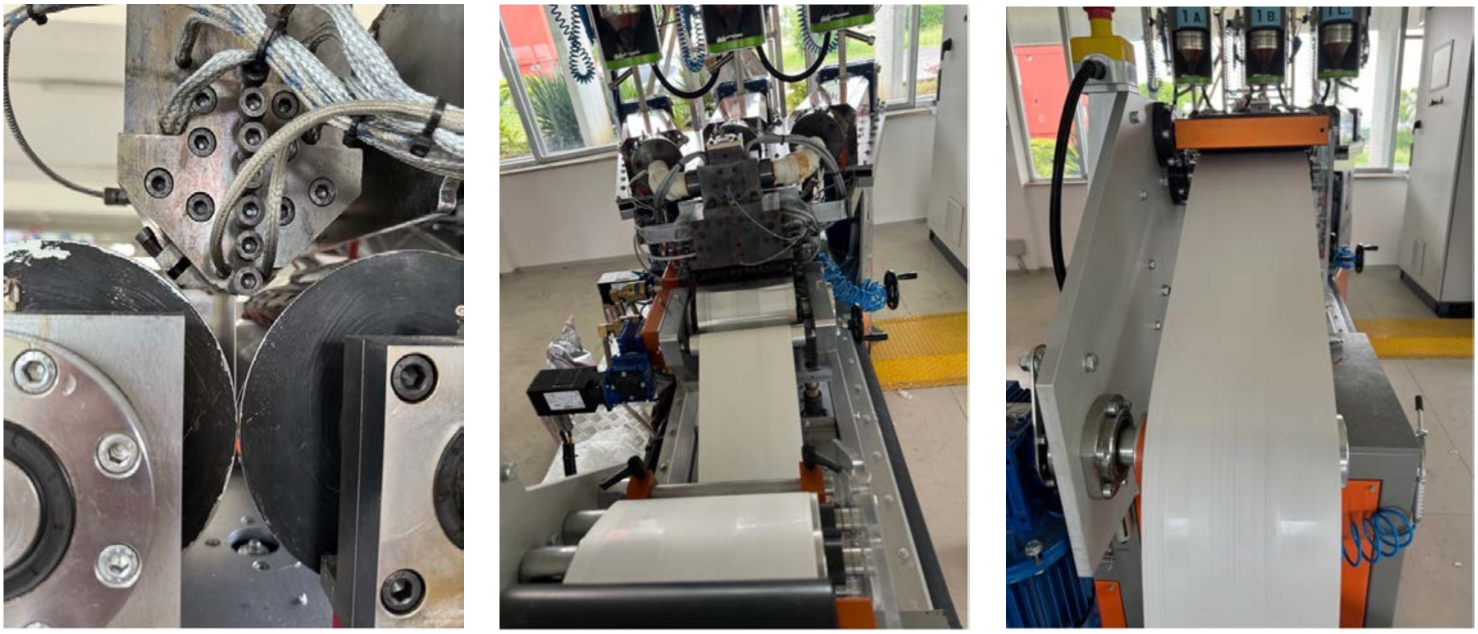

Figure 2: Cast extrusion process on EUR.EX.MA MiniCast Coex 5.

The thermoforming process was performed using a Formech 450DT (Formech International Limited, Thrales End, UK), a pilot device equipped with a single cavity mold with vacuum. The final products thermoformed from F_T1 and F_T2 semifinished products are shown in Figure 3. Injection molded samples used for material characterization were produced using a manual test sample injection molding apparatus Ray-Ran (Kelsey, UK).

Figure 3: Food trays thermoformed from F_T1 sheet (left) and F_T2 sheet (right)

2.2 Characterization.

The mechanical characterization of the film was made according to ISO 527 on both dogbone injection molded samples and cast extruded sheets in Machine Direction (MD) and Transverse Direction (TD) using a Shimadzu AGS-X tensile tester (Shimadzu Corporation, Kyoto, Japan).

The cast extruded films were tested imposing a strain rate of 10 mm/min for F_T1 and F_T2 sheets for both machine direction (MD) and transversal direction (TD) specimens. The impact resistance of the film was evaluated using a IZOD XJUD series pendulum (AMSE S.r.l., Turin, Italy). The selected load was 2.75 J for the INN specimens. An increasing load, from 2.75 J to 11 J, was chosen for both the outer layers. In fact, OUT_T1 and OUT_T2 resisted to the increasing impact load till the highest one. A DSC (Differential Scanning Calorimetry Analysis) was performed on the produced pellets using a DSC3 (Mettler Toledo, Columbus, Ohio). The samples were put in aluminum crucibles and a flow of 50 ml/min of Nitrogen was used as purge gas, according to ISO 11357. Three thermal ramps were applied to the samples: a first heating ramp at 10°C/min from -70°C to 250°C, a cooling ramp at -10°C/min from 250°C to -70°C and a second heating ramp at 10°C/min from -70°C to 250°C.

The Heat Deflection Temperature (HDT) was measured according to ASTM-D648 using a HDT/V-1113 tester (AMSE s.r.l., Turin, Italy). The samples were submerged in silicone oil at constant temperature for 5 min before starting the test. The oil heating rate was set at 120°C/h.

3. Results and discussion

3.1 Processability.

The processing parameters adopted for twin screw extrusion of the initial formulations are presented in Table 3, Table 4 and Table 5. The produced materials were then cast extruded to fabricate the two multilayer sheets, using processing parameters specified in Table 6. The first one, F_T1, has a total thickness of 566 ± 17 μm, the second one, F_T2, has a total thickness of 703 ± 42 μm. Both the semifinished products were suitable to thermoform a solid bio-based food tray.

3.2 Mechanical properties.

A tensile test was conducted on specimens of F_T1 and F_T2 sheets in both machine and transversal directions. The analysis was conducted with 10 mm/min strain rate using pneumatic brackets. The results are reported in Table 7.

Table 7: Tensile test results

Sample ID	Max Stress [N/mm^2]	Max Strain [%]	Young Module [N/mm^2]	Yield Stress [N/mm^2]
F_T1 MD	46,2 ± 2,7	13,3 ± 2,8	837,5 ± 235,4	42,2 ± 3,5
F_T2 MD	45,9 ± 2,5	35,4 ± 1,7	726,2 ± 116,9	15,2 ± 2,1
F_T1 TD	34,3 ± 1,5	4,3 ± 0,2	977,8 ± 120,5	15,7 ± 4,5
F_T2 TD	37,2 ± 1,7	20,9 ± 12,2	953,8 ± 374,7	27,1 ± 7,5

The strain values recorded for F_T1 sheet are lower than the F_T2 values for both machine and transversal direction. This is due to the use of PBAT instead of PLA in blend with PBS for the outer layers of the F_T2 sheet. In fact, PBAT can increase the material elongation and toughness when blended with other biopolymers [11, 12]. The maximum stress values are mostly alike.

The IZOD impact test was led on the specimens of each material to examine their behavior when subjected to an impact stress. The test results are indicated in Table 8.

The considerable amount of mineral filler used in the core layer made it significantly brittle. Otherwise, it is necessary to reduce moisture, water vapor and oxygen transmission rate of the layer improving barrier performances [13].

Table 8. IZOD Test results.

Material	Load [J]	Impact energy [J]	Strength [kJ/m2]
INN	2,75	0,444 ± 0,079	11,10 ± 1,98
OUT_T1	11	Resist	Resist
OUT_T2	11	Resist	Resist

The considerable amount of mineral filler used in the core layer made it significantly brittle. Otherwise, it is necessary to reduce moisture, water vapor and oxygen transmission rate of the layer improving barrier performances [13].

3.4 Thermal properties.

A heat deflection temperature analysis was done for each material and the relative test results are shown in Table 9.

Table 9. HDT Test results.

Material	Deflection [mm]	Temperature [°C]
INN	0,34	91,5 ± 0,8
OUT_T1	0,34	64,6 ± 11,8
OUT_T2	0,34	83,2 ± 2,1

A differential scanning calorimetry was conducted on a pellet of each material in order to analyze its thermal properties. The relevant temperatures of the three materiales are presented in Table 10. From the inner layer DSC analysis, it was possible to notice a glass transition at -32,8°C for PBS and, at 61,8°C for PLA phase. An endothermic peak at 115,5°C could be associated to the melting point of PBS and another endothermic peak at 177,3°C is ascribable to PLA. There are two other endothermic peaks of the second heating curve for the INN material. One of them was detected at 148,2°C while the second one at 216,0°C. These two peaks can be attributed to the presence of more stable crystalline regions of PBS and PLA that melt at higher temperatures. These structures could be generated by the presence of talc, acting as nucleating agent, during the twin screw extrusion process. For the PBS – PBAT blend it is difficult to distinguish the respective peaks because of their strong similarity in thermal characteristics.

Table 10: DSC analysis for INN, OUT_T1 and OUT_T2

Material	Component	wt%	T_g [°C]	T_m [°C]
INN	PLA	48%	61,8	177,3
	PBS	12%	-32,8	115,5
OUT_T1	PLA	20%	61,7	174,0
	PBS	80%	-33,8	116,5
OUT_T2	PBS	80%	-31,5	114,8
	PBAT	20%	-31,5	114,8

A last empirical stress test was conducted on food trays prototypes fabricated with F_T1 and F_T2 semifinished products. For both of them, no relevant damage was observed when subjected to a typical use. In a 25°C environment, they were full filled with water at 100°C for 1h, making the fluid and the trays free to exchange heat with surrounding environment. For both the trays was noted just a slight hazing on the internal surface, in the fluid first contact zone.

4. Conclusions

This paper investigated the manufacturing of innovative multilayer food packaging using biobased, iodegradable and compostable polymeric materials such as PLA, PBS and PBAT as alternatives to conventional fossil-based plastics. Two configurations of a three-layer sheet were designed to study the best solution providing a structural inner core layer with high impermeability and low cost, and two identical outer surfaces with high flexibility. The mechanical, thermal and rheological analyses confirmed that the designed materials exhibit properties comparable to those of traditional polymers and can be processed using established industrial technologies. The three materials were produced by twin screw extrusion process while the three-layer sheets were fabricated by multilayer cast extrusion. Proper tuning and optimization of the manufacturing processes and material formulations were required to deal with processability issues of the new materials. The cast extrusion process revealed the need to optimize the initial material formulations to improve their processability and prevent delamination of the multilayer sheets. The redesigned formulations, with the addition of 10% of talc as an anti-blocking agent, made the outer surfaces more brittle but less vulnerable to scratches and prone to moisture and water vapor transmission. The semifinished products were then thermoformed to manufacture a food tray prototype. A final thermal empirical test demonstrated that the prototypes of the final products were not prone to hot water damage. The developed solutions, based on PLA, PBS, PBAT and talc blends, enable a significant reduction in the overall environmental footprint of the products at the end of their life cycle as all the materials used for the main polymeric phases of the compounds are biodegradable and compatible with composting processes, allowing for disposal alongside organic waste. With advancements in waste management infrastructure, this product has the potential to reduce the burden on landfills and contribute to the mitigation of environmental plastic pollution. Future developments of this research will focus on conducting a comprehensive life cycle assessment (LCA) of the final product to validate its overall environmental impact in more detail. In addition, further studies may investigate the feasibility and cost-effectiveness of industrial-scale production.

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Toward Standardized Material Constants for Predictive Thermoforming

Editor's Note: *This paper was developed in collaboration with Dr. Erhan Turan of Simularge (Turkiye) and Dr. Amit Dharia (ret.). We also invite readers to explore our Lead Technical Article which delves deeper into the topic of numerical simulation in thermoforming.*

Executive Summary

This white paper explores the concept of 'material constants' in thermoforming, highlighting efforts by researchers and industry to create standardized parameters for predictive modeling. Unlike metals, polymers are viscoelastic, making it difficult to define universal constants. However, through indices, constitutive models, and digital twins,the thermoforming sector is moving closer to data-driven prediction. The comparative landscape of approaches, global efforts, and the potential application in industry are presented here, with the ultimate goal of creating a unified, simulation-ready database of thermoforming constants.

Introduction

Thermoforming, unlike metals processing, uses polymers whose properties are not fixed but instead are time-and temperature-dependent. Whereas metals can often be described by a handful of universal constants—elastic modulus, yield strength, thermal conductivity—polymers are inherently viscoelastic. Their behavior during sheet heating and forming varies with temperature, strain rate, and material history.

This presents a challenge: can we define 'material constants' for polymers in thermoforming? Not in the classical sense. Instead, thermoforming engineers and researchers have sought to identify quasi-constants or standardized parameters that, within defined conditions, enable prediction, comparison, and simulation.

Material Constants in Polymer Science

In polymer science, a 'material constant' is usually defined under strict conditions. Examples include:

- Glass transition temperature (Tg) and melting point (Tm)
- Density (ρ)
- Characteristic relaxation times fitted by WLF or Arrhenius equations
- Zero-shear viscosity (η_0) at a reference temperature

For polymers, these values shift with temperature and time, so they are better viewed as reference constants for specific regimes. In thermoforming, where the sheet is heated near Tg or Tm and subjected to biaxial strain, apparent constants such as WLF coefficients, plateau modulus, and thermal diffusivity are often used in simulations.

One available option is rheological testing, which involves four different experiments and thermal testing, all under very controlled conditions. However, this overall method is costly, and there are limitations on the applied strain rate and deformation. Additionally, even a slight change in material composition requires retesting, as the zero-shear viscosity changes. Again, anytime you use standard rheometers, you are doing experiments in uni-direction straining in linear elasticity region. There are strain rate and deformation limitations.

Thermoforming-Specific 'Constants'

Thermoforming is dominated by the interplay of heating, viscoelastic deformation, and cooling. Several properties have been used as practical constants within simulation and process models:

- Rubbery Plateau Modul us (G_N^0)
- K-BKZ model
- Williams–Landel–Ferry (WLF) Constants (C1, C2)
- Zero-shear viscosity $\eta_0(T)$
- Thermal diffusivity ($\alpha = k / \rho C_p$)

These are not universal constants, but within a defined forming window they function as reliable inputs for predictive models. Complicating matters, however, is the temperature-dependent nature of material properties.

We also note that the K-BKZ model does not account for friction, which needs to be handled separately. If you ignore friction and thermal transport between the tool and the material, simulation predictions become less accurate. Including them, however, significantly increases computation time. Average simulations can run for over 4 hours using a 16 core processor on PC, not including the time needed to prepare CAD files, FEM meshes, etc.

The Permutation Challenge

A common question is whether it is possible to build a comprehensive database of thermoforming-relevant constants. Theoretically, yes—but the combinatorial explosion is enormous.

A full-factorial design considering temperature, strain rate, sheet thickness, deformation mode, heating profile, plug type, sheet color (or transparency), and mold temperature results in hundreds of thousands of permutations per polymer family. When polymer-specific factors (IV, crystallinity, additives, moisture) are included, the total expands to millions of permutations for PET, PP, PS, and PLA.

The practical solution is to use designed experiments (DOE) and time–temperature superposition to collapse variables into representative datasets. Instead of millions of permutations, 120–250 runs per polymer can define a master database that is both experimentally feasible and simulation-ready.

Efforts to Define Material Constants in Thermoforming

A number of individuals, companies, and institutes have attempted to systematize thermoforming behavior by proposing indices, empirical metrics, or simulation-ready constants. These efforts can be placed on a continuum from empirical indices to digital twins. The following is a non-exhaustive list of notable work in this field:

Don Hylton—Thermoforming Index
A dimensionless index derived from biaxial bubble inflation tests, useful for benchmarking.

Accuform /T-SIM
A finite element simulation tool using stress–strain curves, WLF constants, and thermal properties.

Amit Dharia—Technoform
A semi-empirical platform that defines indices such as Formability Ratio and Critical Draw Ratio. It's the only lab setup that allows biaxial stretching in contact with the plug, accounting for friction and shrinkage.

Fraunhofer IVV / ICT
Rigorous biaxial testing and constitutive models for FEM codes.

Simularge
AI-enhanced, real-time parameter adaptation/estimation from plant-floor data in corporation with Digital Twins

Technoform is reported to be the only lab setup that allows biaxial stretching in contact with the plug, accounting for friction and shrinkage. In contrast, bubble stretching methods do not involve interaction between the membrane and plug. The IKP method allows for high-speed testing (up to 2 m/s) but only at a constant temperature.

Other Global Efforts

Beyond these named initiatives, additional work has come from:

- UMass Lowell, Penn State, Akron (USA): biaxial testing and sag analysis.
- NIST (USA): rheological standards and master curves.
- Brunel & Queen’s Belfast (UK): PET crystallization kinetics during thermoforming.
- IKV Aachen (Germany): thermoforming test rigs and simulation.
- INSA Lyon & CEMEF (France): biaxial stretching models for PET and PLA.
- Resin suppliers and OEMs (ILLIG, Kiefel, WM, Eastman, Indorama, NatureWorks): in-house forming datasets.
- Japan (Tokyo Tech, Kyoto): optical heating models and emissivity constants.

The Ideal Outcome

The ideal outcome of these efforts would be a global, standardized database of thermoforming-relevant material constants, incorporating:

- Thermal and optical properties (k, Cp, α, emissivity, IR absorption–possibly with temperature dependency)
- Rheology and viscoelastic parameters (η_0(T), WLF constants, DMTA mastercurves)
- Biaxial stress–strain surfaces and failure envelopes
- Plug–sheet friction data
- Sag and heating data under standardized conditions

This database would be simulation-ready, interoperable with FE packages and digital twins, and structured with confidence intervals and metadata.

Application in Thermoforming Companies

How would converters and OEMs use such a resource?

- Material selection: Rank candidate resins by formability indices before trialing.
- Virtual trials: Run FE simulations with pre-certified material cards.
- Set up efficiency: Access oven zone and plug speed presets.
- Quality assurance: Benchmark rPET or PLA, for example, against PET using common indices.
- Adaptive optimization: Feed plant-floor data into digital twins.

This would shift thermoforming from an empirical, trial-and-error process to a predictive,data-driven practice.

For context, to run two simulations using Accuform, costs have been quoted at $5,000 ($2500 per run). Generating data via IKP costs $3,300 per material, while Data Point Lab charges $6,500 per material for rheology and thermal testing. Such tests can only be justified once the material is finalized and one is in process of making tools or purchasing equipment. Most small-to medium-sized thermoformers cannot justify the expenditure measured against an unclear return or competitive advantage.

When it comes to deriving material constants, there are both easier and more complex (and expensive) methods. The choice depends on your objective. Is the part drawn to more than300% or less? Is it amorphous or semi-crystalline (shrinkage)? Does it exhibit slow or fast relaxation (elastic recovery after forming)? And is it thin or thick gauge (heat transfer)? If you're not concerned with time-dependent phenomena like shrinkage or orientation, viscoelastic models can suffice.

A more accessible alternative is to determine force-temperature-time curves at three different temperatures and six plug speeds, then reverse-engineer the material constants using Accuform or Simularge software. This is the most cost-effective and efficient approach. Both IKP and Technoform can provide such data. Other methods involve directly measuring the constants via physical property measurements. Reverse engineering is the most cost-effective route. All it requires is curve fitting routines

Conclusion

The search for 'material constants' in thermoforming reflects a broader effort to make polymers as predictable as metals in processing. While true universal constants do not exist, researchers and industry players have converged on sets of indices, empirical parameters, constitutive constants, and adaptive digital twin models that increasingly enable prediction.

From Don Hylton's Thermoforming Index to Simularge's digital twin, the field has evolved along a continuum of sophistication. The next logical step is to unify these efforts into a shared, global, simulation-ready database of thermoforming constants. Such a resource would reduce cost and waste, accelerate innovation, and empower converters to meet the demands of circular economy packaging with confidence.

Approach / Group	Core Concept	Inputs Required	Nature of 'Constants' Produced	Outputs / Applications	Strengths	Limitations
Don Hylton – Thermoforming Index (TI)	Dimensionless index to compare thermoformability across polymers	Bubble inflation biaxial test data, sheet stiffness at forming T	Single index (TI value per material/condition)	Resin selection, material ranking	Simple, quick comparative tool; useful for benchmarking	Oversimplifies behavior; not simulation-ready
T-SIM (Simcon / Moldex3D module)	Finite element forming simulation	Stress–strain curves (uniaxial/biaxial), WLF shift constants, thermal properties, plug friction	Parameterized constitutive models (WLF C1/C2, viscosity $\eta(T,\dot{\gamma})$, k, Cp, α)	Predict sag, wall-thickness distribution, cycle optimization	Simulation accuracy, detailed design support	Needs extensive lab characterization; license cost
Amit Dharia – Technoform	Semi-empirical formability assessment platform	Proprietary biaxial tests, strain–energy absorption, draw ratio to failure	Empirical indices (Formability Ratio, Critical Draw Ratio, Energy Index)	Resin selection, forming window definition, troubleshooting	Practical, industry-friendly; correlates well with line trials	Not a full CAE model; limited generalizability
Fraunhofer IVV / ICT	Fundamental material modeling for FEM	Biaxial test rigs, DMTA, creep/relaxation, fracture strain	Constitutive constants (Prony series, Arruda–Boyce, Bergström–Boyce, failure strain energy)	ABAQUS/PAM-FORM digital twins, scientific models	Physics-based, transferable across platforms, academically rigorous	High cost/time for data generation; overkill for converters without CAE teams
Simularge – AI-based Digital Twin	Physics Informed Machine-learning-enhanced thermoforming digital twin	Live process data (sensor streams: temps, pressures, sag, plug force) + initial material characterization	Dynamic, adaptive 'constants' → ML-refined parameters that evolve with process	Predictive maintenance, real-time forming optimization, 'what-if' simulations	Leverages AI to reduce reliance on exhaustive lab tests; closes loop between lab, CAE, and plant floor	Requires integration with sensors + cloud/edge infra; adoption curve in conservative plants

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How Plastics Processors Can Become the Provider of Choice

Editor's note: *The following article is adapted from a story originally published in PlasticsNews by Don Loepp, Editor. The story appeared on September 26, 2025.*

SAY Plastics, a 40-employee thermoformer in McSherrystown, Pa., has made responsiveness its signature. The company specializes in heavy-gauge thermoforming and tooling for markets from transportation to medical, and it uses technology to give customers faster answers.

One standout tool is its virtual first article inspection (FAI) process. "We can take the first part off the line, scan it, and send the customer a 3D model that shows the variances against their CAD drawing," explained Bobby May, IT Director. "They don't have to wait for shipping and review. They can hit the go button that same day."

That capability has been especially useful for large replacement projects, where each piece must be customized. "We can fit every part virtually before it ships," May said. The company also relies on Delmiaworks dashboards to manage quality and production. ISO audits that once took weeks of prep now take minutes.

"When an auditor walks in today, we just open the dashboard," May said. "Everything they ask for is one click away."

The dashboards also flag problems in real time, whether it's downtime on a line or a cost variance. That lets SAY reschedule instantly and keep customers informed.

"One of the biggest compliments we get is how fast we can turn around quotes," Erich Kaintz, Vice President said. "Customers want to feel like their project is important. You show that by being responsive."

Beyond systems, Kaintz stressed continuous improvement and education. SAY partners with schools and brings in interns to work on robotics, collaborative robots (cobot) programming and project management.

"Just meeting expectations doesn't drive innovation," Kaintz said. "The goal is to prepare for the future, where change is coming whether you're ready or not."

Investment in What Matters Most: People and Production

Automation is growing. Examples include robotic loading, CNC trimming, and in-line inspection. But the company says people remain the foundation.

Upgrades to the facility over the past three years include expanded CNC capacity for throughput and precision, advanced metrology and camera inspection systems, and digital scheduling and demand forecasting to eliminate downtime.

SAY partners with schools and brings in interns to work on robotics, collaborative robots (cobot) programming and project management.

“Visibility used to mean hindsight. Now, with intelligent systems and connected technologies, it means insight and foresight,” says Louis Smith, President.

Polymer-Tool Friction Coefficient in Temperature for Thermoforming Numerical Simulation

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Keywords: Thermoforming, Friction Coefficient, Numerical Simulation, Thickness Distribution, T-SIM®, Polycarbonate

Abstract.
In this work, friction coefficient between Polycarbonate and Aluminum was measured over the entire thermoforming temperature range by using a rotational rheometer with a specific geometry, following the B. Hegemann et al.[1]method. The effects of velocity, pressure and surface roughness were investigated. Then, numerical simulation were performed using a finite element code package for thermoforming (T-SIM®)with K-BKZ viscoelastic model. The objective of this work is to find which friction coefficient use in T-SIM simulation to be as close as possible to reality. For this, numerical simulation results for different friction coefficient were compared with experimental values to evaluate the predictive capacity. It was shown that friction coefficient is temperature dependent and rapidly increase above glass transition of polycarbonate. At room temperature, friction coefficient increases with an increase in roughness, but after glass transition,trend is reversed. Simulations with measured friction coefficients shows good agreement with experiment data.

Introduction
Thermoforming is a manufacturing process widely used in the industry for making 3D complexparts. An extruded polymer sheet is heated to be easily deformable and then vacuum formed on a cold mold. Despite the apparent simplicity of this process, it is actually a technical process, difficult to optimize, in which the material undergoes very large deformations in an anisotherm environment. Uneven thickness distribution is caused by localized variable deformations during vacuum forming. However, for manufacturers, a uniform thickness distribution and a high average thickness are very important parameters for the manufacture of high-quality parts. This thickness distribution is mainly affected by the viscoelastic behavior of the extruded polymer sheet [2,3,4] but previous work show that contact friction also has a huge impact on thickness distribution[2,5-8]. In the literature, the majority of authors study the effect of friction in the context of plug assist thermoforming. In this work, we will focus on conventional thermoforming, where the slip rate between the polymer and the mold is lower. Some studies claim that the friction coefficient does not depend on the sliding speed[1,5] but others show the opposite[9]. Several friction models exist but in this study we consider that the friction behavior between mold and polymer sheet can be simply represented using Coulomb friction law. This law defines friction coefficient as the ratio between the friction force and the normal force (Eq. 1):

$$\mu = \frac{F}{F_N}$$

Two friction coefficients can be defined: a static coefficient which corresponds to the minimum tangential force necessary to prime the slide and a dynamic coefficient which corresponds to the tangential force necessary to maintain this slide. In this study, only the dynamic coefficient will be taken into account. The purpose of this work is to measure the impact of different parameters on the coefficient of friction between poly carbonate sheet and aluminum mold. The effects of velocity, pressure and surface roughness were investigated using a rotational rheometer with a specific geometry, following the method developed by B. Hegeman net al[1]. Measured friction values will be used in a numerical simulation of the thermoforming process and simulation results were compared with experimental data to evaluate the predictive capacity.

Materials and Methods

Polycarbonate is a technical polymer with excellent mechanical properties and good temperature resistance. It is easily thermoformable thanks to its good flow resistance and is used in many fields such as automotive, aeronautic or medical. For this study a commercial polycarbonate LEXAN9030 from SABIC was used. The initial sheet thickness was 2,94 ± 0,05 mm. Temperature shrinkage is negligible (< 2%) in the extrusion or transverse direction. The glass transition temperature measured by DSC (rate: 10°C/mn) is around Tg = 149°C. Thermoforming molds and friction coefficient samples used for this study were made with Aluminum 5083 (AW-AlMg4,5Mn0,7). Aluminum 5083 is a common aluminum-magnesium alloy with 4,5% magnesium.

Torsional Rheometer Test Method.

The friction coefficient measuring device used in this study is based on the B. Hegemann et al. [1] method. developed at the IPK-Stuttgart.An Anton Paar MCR302 rotational rheometer is used in parallel configuration. The upper moving plate is replaced by the mold material sample and the polymer is fixed on the bottom. The test arrangement is shown in Fig. 1a.After contact, the torque required to rotate both parts is measured and converted into a coefficient of friction. Applied normal force and rotation speed are easily adjustable over a wide range of values representative of the thermoforming process. The device is placed in a temperature-regulated chamber, suitable for making measurements from room temperature until forming temperature. Between each measurement, the upper plate is cleaned with acetone to remove any residual traces of polymer. In order to reproduce as much as possible a linear sliding during the test and minimize the velocity gradient, the contact surface is limited to one ring (Fig. 1b). Inner and outer radii are respectively 9 mm and 12.5 mm. As a result, the maximum speed rotation varies only about 15% around the mean value. The tested polymer sample is a 25 mm disc, glued on a disposable plate with a two-component epoxy adhesive resistant up to 180°C. Special attention is paid to the flatness of the experimental setup to ensure optimal contact.

Thus, assuming that the normal force is evenly distributed over the contact surface, and taking into account the geometry used, the average friction coefficient can be calculated from the following relation [Eq. 2] :

$$\mu = \frac{3}{2} \times \frac{\tau}{F_N} \times \frac{R_o^2 - R_i^2}{R_o^3 - R_i^3}.$$

where Γ is the measured torque, FN the normal force and Ri and Ro are respectively the inner and outer radius of the ring.

Test settings.

With this method, friction coefficients were measured over a wide range of temperature, from room temperature to 180°C. First every 40°C up to 140°C, then, every 10°C from the glass transition temperature of polycarbonate samples (Tg = 149°C). Beyond 180°C, the epoxy adhesive fail and does not maintain the sample properly. This temperature range does not cover the entire forming range (up to 220°C for polycarbonate) but in reality, due to the low thermal effusivity of polycarbonate compared to aluminium, interface temperature is much lower and probably no more than 180°C. Some previous studies[1, 9]show that there is no significant influence of normal force on friction coefficient. In order to verify this hypothesis, friction coefficients were measured at room temperature for several values of normal force (2, 5 and 10N). For higher temperatures, the normal force was limited to 2N because of MCR302 torque measurement limitation but also to limit compression deformations beyond glass transition temperature.

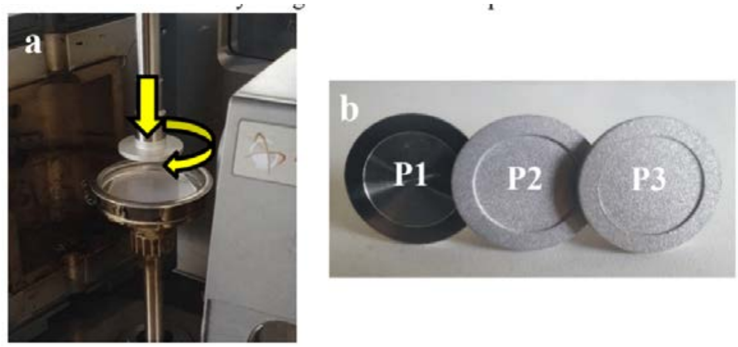

Fig.1. (a) Modified rotational rheometer with aluminum upper plate and polymer sample on the lower plate. (b) P1, P2 and P3 aluminum plate with roughness of respectively Ra = 0,38 µm, Ra =2,80 µm and Ra = 8,12 µm. Contact surface is limited to a crown of 9 mm inner radius and 12.5mm outer radius.

In order to measure the impact of the sliding speed on the friction coefficient, different rotational speeds were investigated. In industry, the mold rising speed is typically within the range 25-100 mm/s. However, glide speed can be considerably less due to the frictional force and the sheet deformation resistance[5, 9]. Thus, for the sake of covering a representative sliding speeds range of the thermoforming process, friction coefficients were measured for three different rotational speeds of 4.4rpm, 11.1 rpm and 22.2 rpm corresponding respectively to an average sliding speed of 5 mm/s, 12.5 mm/s and 25 mm/s. In addition, all these measurements were carried out for three different aluminium upper plates surface roughness, corresponding to different surface states of industrial moulds (Fig. 1b). The plate 1 (P1) corresponds to a smooth mold with Ra = 0,38 μm while plate 2 (P2) and 3 (P3) have been sanded with roughnesses of Ra = 2,80 μmand Ra = 8,12 μm respectively. The various tested parameters are summarized in Table 1. This experimental design allows the coverage of a wide range of friction coefficients values on all the thermoforming process parameter range.

Friction Measurement Results and Discussions

Fig. 2 shows the evolution of the coefficient of friction at room temperature as a function of the normal force for applied values of 2 N, 5 N, and 10 N. For the P1 plate with the smoothest surface, normal force does not affect the friction coefficient in the measurement range. For P2 and P3 plates, with a rougher surface, the friction coefficient increases slightly with normal force. Increase in the normal force must increase the penetration of the roughnesses into the polymer and therefore the friction.

Table1. Friction coefficient measurement parameters.

	Roughness (μm)	Temperature range (°C)	Normal Force (N)	Rotation speed (mm/s)
Plate 1 (P1)	0,38	20	2 - 5 - 10	5 - 12,5 - 25
		60-180	2	
Plate 2 (P2)	2,80	20	2 - 5 - 10	5 - 12,5 - 25
		60-180	2	
Plate 3 (P3)	8,12	20	2 - 5 - 10	5 - 12,5 - 25
		60-180	2	

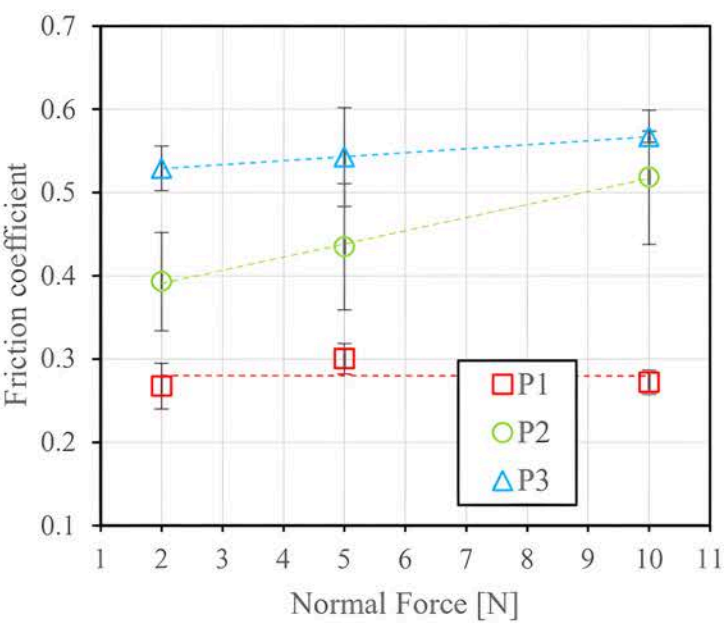

Fig. 2. Friction coefficient at room temperature for an applied normal force of 2N, 5N and 10N(Speed test =12,5mm/sec).

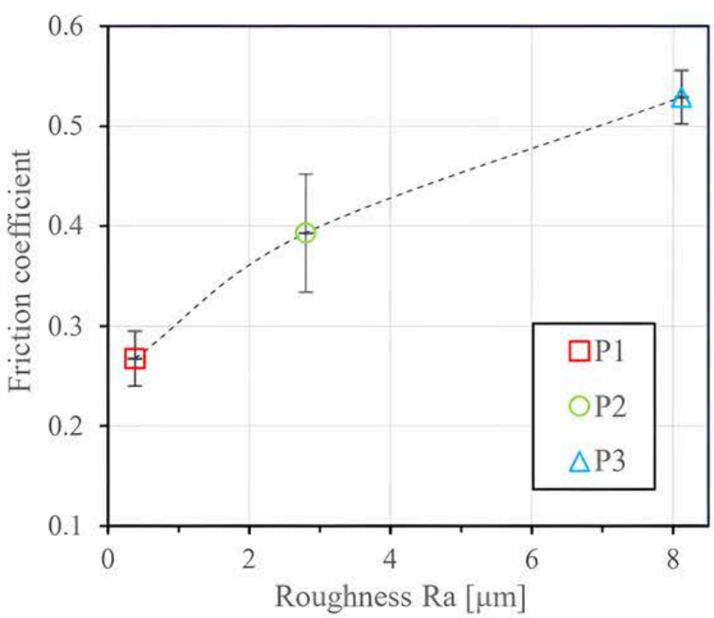

Fig. 3. Friction coefficient in function of roughness (Normal force = 2N, Speed test =12,5 mm/sec).

Friction coefficient evolution with surface roughness at room temperature is reported in Fig. 3. Contrary to expectation the coefficient of friction increases with the surface roughness by almost following a linear relationship. This result contradicts previous studies [10, 11] assuming that the apparent surface contact reduction due to the roughness decreased friction. One possible explanation is that, in reality, the friction force can be divided into two independent contributions: an adhesive term representing the adhesion phenomena at the real contact level and a deformation term representing volumic deformations by "ploughing". This deformation term is sometimes not negligible at room temperature[12]. It is possible that in the case of the roughness profile of the P2 and P3 plates, the deformation term is important and increases the friction coefficient.

In temperature, for a 2N applied force, Fig. 4 shows that the friction coefficient is stable up to the glassy transition temperature (~150°C) and then increases more or less significantly with roughness. This results is consistent with literature [1, 2, 9]. However, there is a decrease of friction coefficient in temperature as a function of the surface roughness. It is deduced that, unlike to ambient temperature, the drop in mechanical properties due to temperature increase reduces the deformation term effect on friction in favor of the adhesion term. Friction coefficient decline from 180°C can be explained by a totally sticky contact, the measured torque being linked to pure shear of the sample[1]. Fig. 5 shows the effect of the sliding speed on the friction coefficient for P1 plate. The decrease in the sliding speed increases friction. This sensitivity to speed and temperature relates the viscoelastic behavior of polymers and Time Temperature Superposition (TTS) principle. This behavior has already been observed in the case of elastomers[12]as well as on impact PS and PP[9]. The behavior is the same with the P2 and P3 plates.

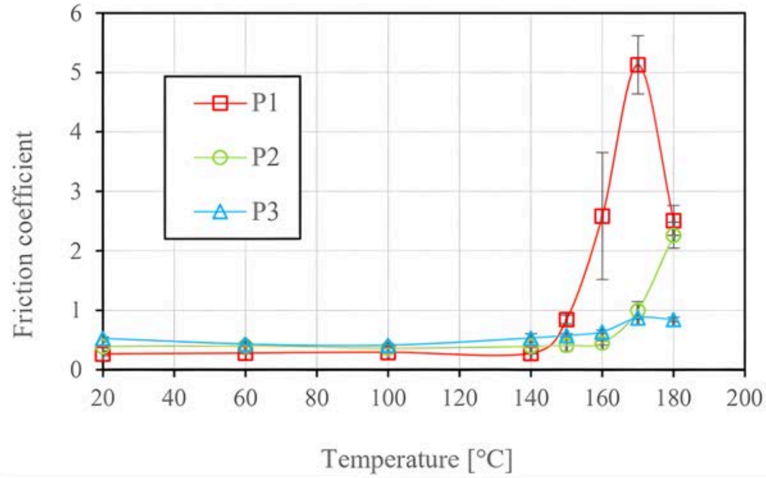

Fig. 4. Effect of temperature on friction coefficient forthe three plates (Normal force = 2N, Speed test=12,5mm/sec).

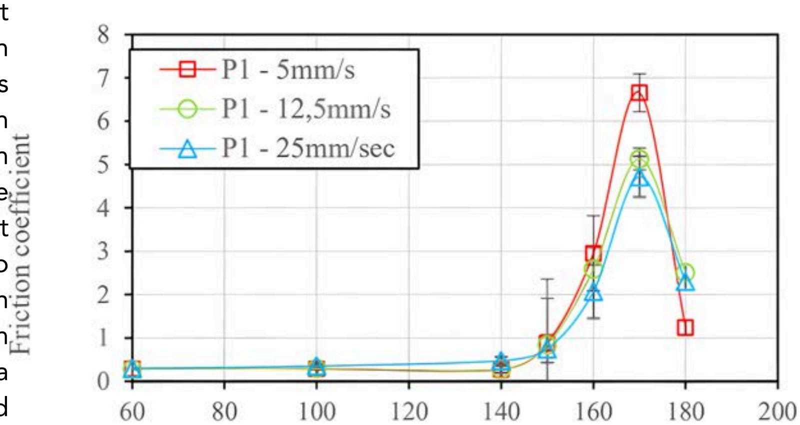

Fig. 5. Effect of speed sliding on friction coefficient intemperature for smoothplate P1 (Normal force = 2N).

Numerical Simulation and Experimental Comparison

T-SIM software. The 3D numerical simulations were carried out using the commercial package code T-SIM®version 4.9 (Accuform) based on the finite element method and specially designed for the simulation of the thermoforming process. This software use a K-BKZ[13] type nonlinear viscoelastic constitutive model to describe large polymer deformations during forming. Friction Coulomb's law was applied on contact areas between sheet and mold, and the heat equation allows the calculation of thermal transfers during the process. The thickness distribution and polymer stretching were numerically investigated for the different experimentally measured friction coefficient values. Next, numerical results were compared with experimental thermoforming data obtained with two representative moulds presented in Fig. 8. The mold A has the same surface roughness as plate P1 (Ra = 0,41 μm) and the mold B has the same as plate P3 (Ra = 8,06 μm).

Viscoelastic model parameters.

During thermoforming, polymer materials exhibit nonlinear viscoelastic behavior due to large deformations and high strain rates over a wide range of temperatures. To describe this particular behavior, T-SIM use the K-BKZ type viscoelastic Wagner

Model. This model shows good results for the simulation of the thermoforming process for ABS[2, 4], PS[14], or HDPE[15]. TheWagner model is expressed as follows (3):

$$\sigma(t) = \int_{-\infty}^{t} m(t-t')h(I_1, I_2)C^{-1}(t,t')$$

• $C^{-1}(t,t')$ is the finger strain tensor.I1andI2are invariants and depend on the solicitation type.

• $m(t-t')$ is the time dependent Memory function used to explain the linear viscoelasticity. The memory function is calculated from the discrete relaxation spectra obtained by small amplitude oscillatory shear (SAOS) experiment. Several experiments were carried out at different temperatures and the master curve was reconstructed thanks to the time-temperature equivalence principle and the Williams-Landel-Ferry (WLF) equation.

• $h(I_1, I_2)$ is the Damping of the two strain invariants used to describe the nonlinear viscoelasticity. T-SIM software uses the following damping function Wagner (4):

$$h(I_1, I_2) = \frac{1}{1 + A\sqrt{(I_1-3)(I_2-3)}}$$

K-BKZ Wagner damping function was numerically determined using T-SIMFIT® v1.41 software from uniaxial tensile test data. Tensile test were carried out at 170, 180 and 190°C and for four different speeds of 1.25, 2.5 and 12.5 mm/sec corresponding to an initial elongation rate of 0.1, 0.5 and 1 s-1 respectively. Fig. 6 shows the prediction from Wagner model for A = 0,095in comparison with experimental data at 170°C.

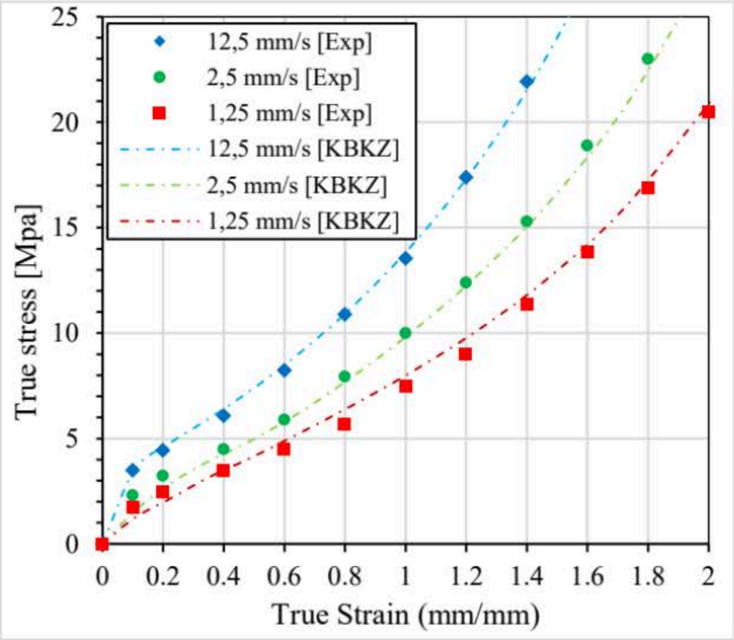

Fig. 6. Lexan 9030 stress/strain curve at 170°C.Experimental data are represented by symbols and KBKZ prediction by dashed lines for A = 0,095.

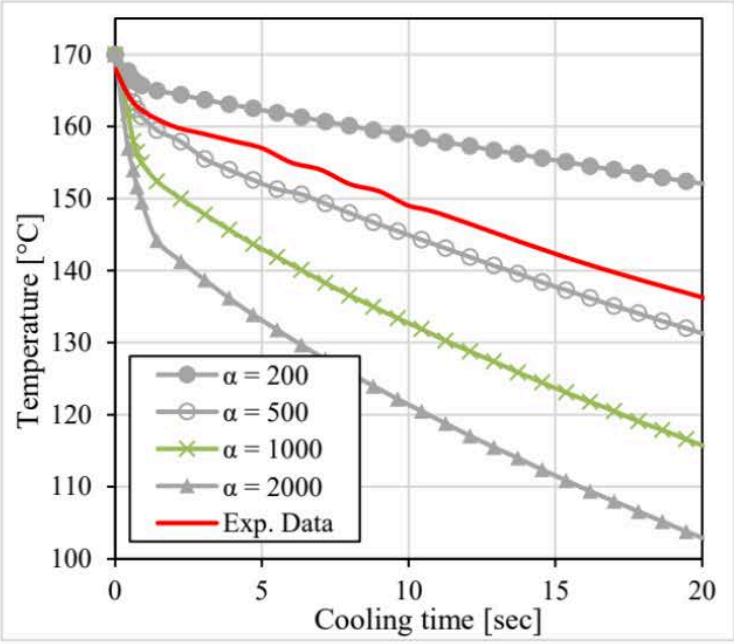

Fig. 7. Cooling of a Lexan 9030 sheet at 170°Cduring 20sec. Red line correspond to experimental cooling measured by thermal camera and gray lines are simulated cooling for different conductive exchange coefficient.

Heat transfer.

As shown above, the viscoelastic behaviour of polymers is highly temperature dependent. Therefore, it is necessary to well know the temperature throughout the forming cycle. For this purpose, a heat equation makes it possible to account for heat exchanges during the process. The polycarbonate thermal capacity and thermal conductivity were determined on a large temperature range by measurement in modulated DSC and HOT DISK device. The measured values are respectively Cp = 2.140 J/(Kg.K) and λ = 0.22 W/(m.K) at 180°C. In T-SIM, thermal properties are constant but in reality, they are temperature dependent, particularly around the Tg. For mold and sheet heat exchanges, the mold is only represented by its external surface and is assumed to be isothermal throughout the operation. The mold's thermal properties are not involved in it, and it is considered that the sheet-mold heat flow is monitored by a conductive exchange coefficient called "α". It may not hold a tangible sense, but it may however be experimentally determined: the cooling of a Lexan 9030 sheet at a temperature of 170°C, in contact with an aluminum mold at room temperature could be measured and then compared to simulated cooling for different αvalues (Fig 7). As a result, conductive exchange coefficients were found to be close to 500W/m²/K, which is similar to a value obtained by Marotta and Fletcher[16]. Likewise, the convection exchange coefficient between polymer and ambient air is 8 W/m²/K.

Friction coefficient.

At the areas of contact between sheet and mold, sliding is managed by the Coulomb frictionl aw. As with thermal properties, the friction coefficient is considered constant throughout the forming cycle. This study showed that in reality, the friction coefficient depends on several parameters and is largely temperature dependent for polymers. Several friction coefficients corresponding to the previously measured coefficients have been tested and the simulation will be compared with the experimental results.

Process parameters.

T-SIM software makes it possible to easily manage the various process parameters to best match the experimental parameters (see Experimental thermoforming). The initial sheet temperature is215°C. The mold rising speeds are respectively 20 cm/s and 10 cm/s for mold A and mold B. Nopre-stretching were performed and a vacuum of-0.2 bar is applied for 5s. A 60,000 polygons mesh permit to have an optimal compromise between precision and calculation time. Different process parameters are summarized in Table 2.

Experimental thermoforming.

Experimental thermoforming was performed on a laboratory scale thermoforming machine Formech 450DT. A thermal camera placed above the device allows sheet temperature profile recording in real time. The pressure during the forming cycle is measured by a manometer. Fig. 9shows the experimental setup. The polymer sheet is heated with ceramic radiants until reaching a temperature of 215°C. In order to achieve the most uniform temperature distribution possible, the power of the external radiants is slightly increased to compensate heat losses by convection with ambient air. The rise of the mold is manually controlled. The average mold speed is around 20cm/sec for mold A and 10 cm/sec for mold B, in order to avoid tearing the sheet on sharp angle. Then, a vacuum of - 0.2 bar is applied for 5 to 7 sec to form the sheet on the mold.

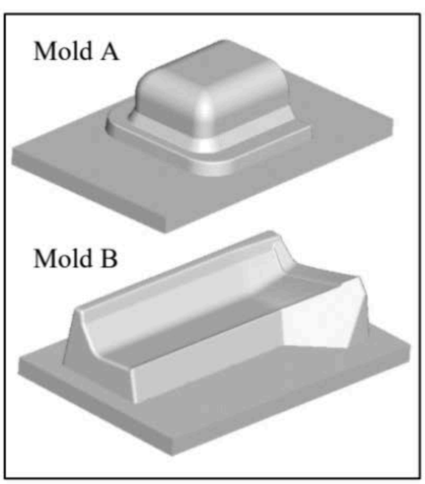

Fig. 8. Molds used for experimental thermoforming and simulation. Mold A has a surface rugosity of R = 0,41µmcorresponding to plate P1 and Mold B, Ra=8,06 µm corresponding to plate P3

Fig. 9. Experimental thermoforming setupwith Formech 450DT thermoformingmachine andthermal camera.

Table2. Process parameter for numerical simulation with T-SIM®.

Process parameters	Mold roughness	Mold temp.	Sheet temp.	Mold speed	Convection coefficient	Conduction coefficient	Vacuum pressure
Mold A	0,41 µm	70°C	215°C	20 cm/s	8	500	0,2 bar during 5 sec
Mold B	8,06 µm	95°C		10 cm/s			

Simulation and Experimental Comparison Results

Several simulations were carried out with process parameters presented in Table 2. Four coefficients of friction were simulated as a function of the two molds: µ = 0.3 (minimum coefficient of friction for the polycarbonate-plate couple P1), µ = 0.75, µ = 1.5 and µ = 5 (corresponding to total stick) for the mold A and µ = 0.5 (minimum friction coefficient for polycarbonate-plate P3) µ = 0.75, µ = 1.5 and µ = 5 for mold B. For each mold and friction coefficient, the simulated thickness distribution along the transverse (A-A) and longitudinal (B-B)axis is represented by a continuous line in Fig. 10 and Fig. 11. Experimental thicknesses has been measured on at least two different thermoformed parts using a digital micrometer is represented by diamond symbols. The thickness distribution can be divided in two regions: the upper part and the side parts. For mold A, uppers parts are located from 150 mm to 250 mm for transversal cut and from 225 mm to 375 mm for longitudinal cut. For mold B, uppers parts are located from 150mm to 275 mm for transversal cut and from 75 mm to 425 mm for longitudinal cut. Other parts are considered as side parts.

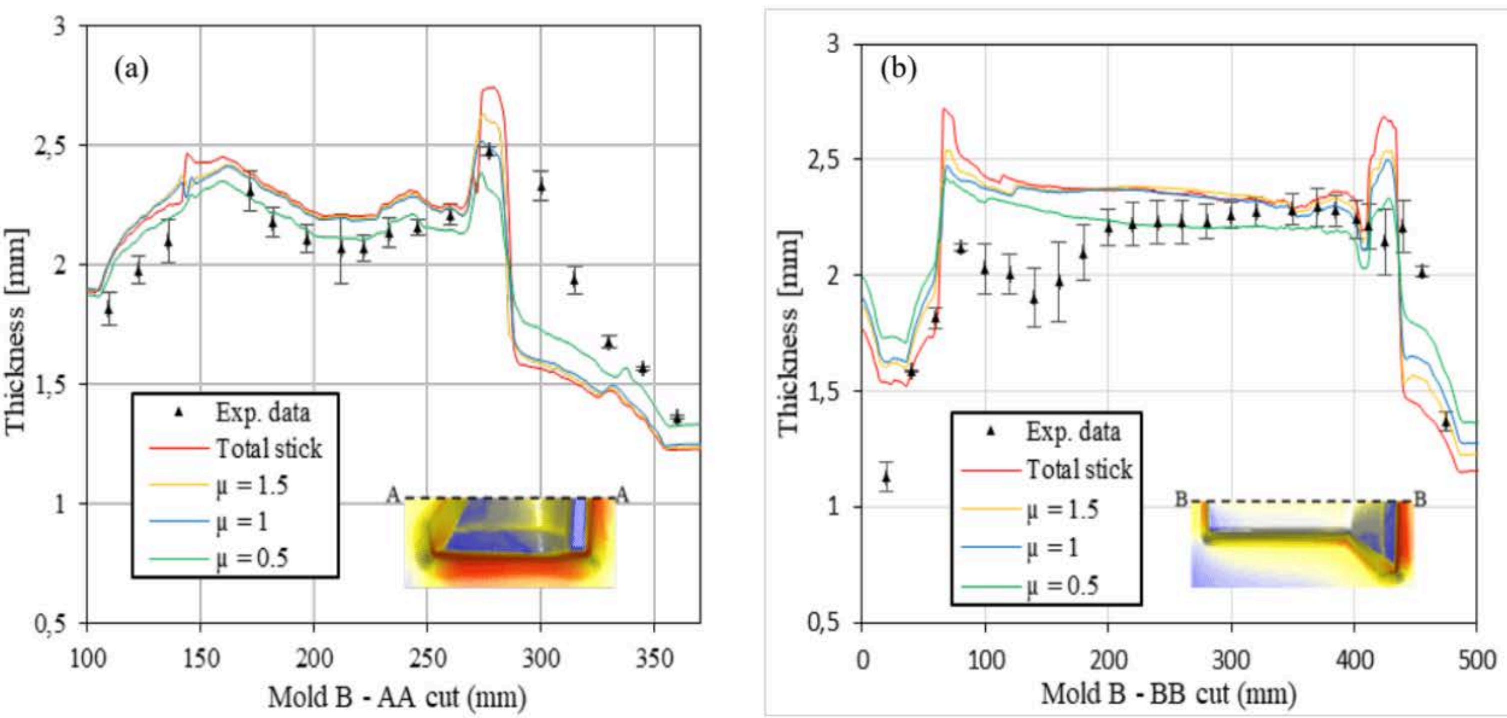

Fig. 11. Mold B thickness distribution along transversal (A-A) axis (a) and longitudinal (B-B)axis (b). Simulated data are in continuous line and experimental data are represented by diamond symbols.

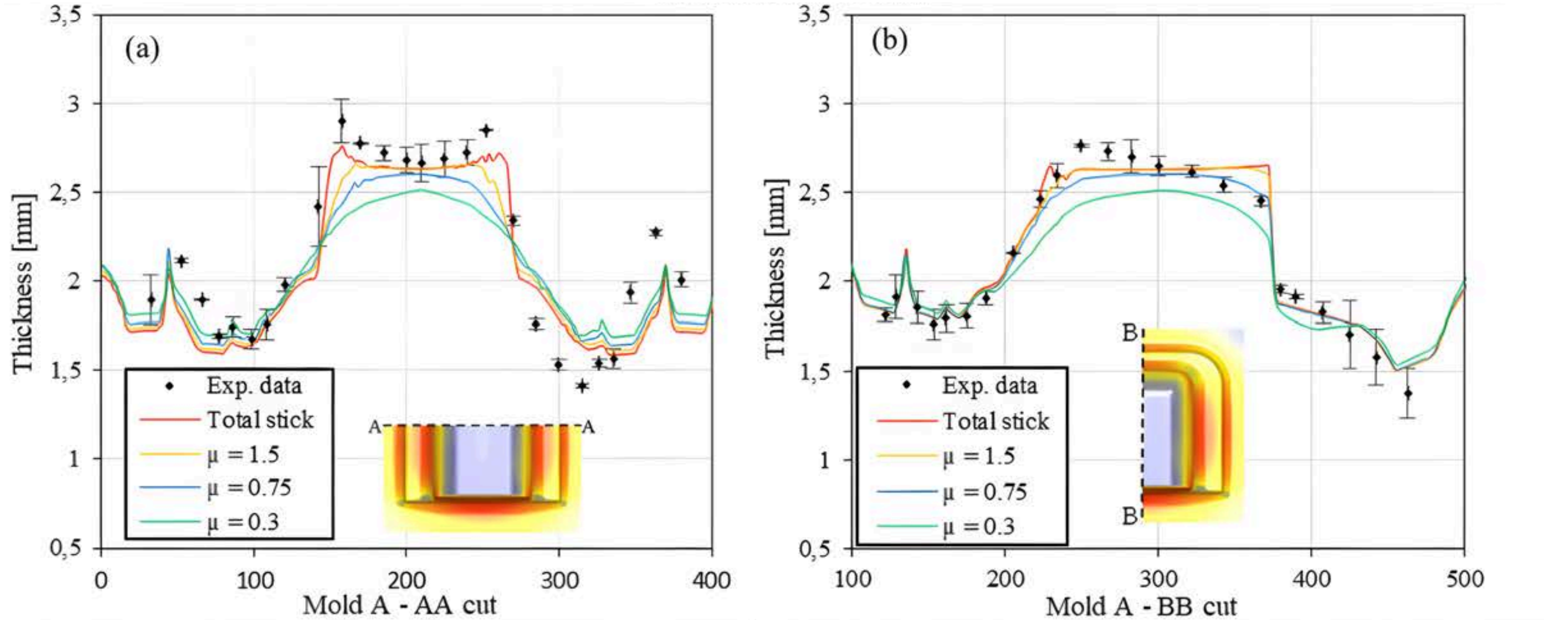

Fig. 10. Mold A thickness distribution along transversal (A-A) axis (a) and longitudinal (B-B)axis (b). Simulated data are in continuous line and experimental data are represented by diamond symbols.

The effect of friction coefficient variation is particularly visible on mold upper parts, the first in contact with polymer sheet during forming. The higher the friction coefficient, the greater the simulated thickness. Indeed, when the friction coefficient is important or when the contact is completely sticky, the sheet cannot slide on the surface of the mold. Thus, the deformations are mainly concentrated on the side parts and in the corners. This phenomenon is amplified by the sheet cooling in contact with mold, witch limit the polymer ability to deform under stress. We can deduct from its results that a lower friction coefficient promote a more uniform thickness distribution especially when the mold geometry have a large upper planar surface.

Overall, for the two mold, simulated thickness distribution shows good agreements with experimental data. For mold A [Fig. 10a and 10b], average measured thickness on the upper part correspond to simulated thickness for high friction coefficient, see even, for total stick behavior on [Fig. 10a].

Its results confirm the friction coefficients measured previously: since the polymer sheet is still close to 215°C when in contact with the mold, P1 plate friction coefficient measurements predicts ticky contact for this temperature. For mold B [Fig. 11a and 11b], average measured thickness on the upper part gets closer to simulated thickness for a friction coefficient between μ = 0.5 and 1. Again, this correspond to friction coefficient value measured for plate P3 at this temperature. Based on this results, the sanding of the thermoforming tools makes it possible to limit the friction with sheet polymer in temperature and thus greatly improve the average thickness distribution.

Summary

A rotational rheometer with a specific geometry allowed us to measure the coefficient of friction from the ambient temperature up to the forming temperature for different speed of rotation and normal force. Effect of surface roughness were explored. It was shown that friction coefficient is temperature dependent and rapidly increase above glass transition. At room temperature, contrary to expectation, friction coefficient increases with an increase in roughness. One possible explanation is that, for this couple of materials, the friction deformation term is not negligible at room temperature and result in an increase of friction for rough plate. After glass transition, this trend is reversed and the smooth plate (P1) exhibit sticky behavior beyond 180°C. Simulation swith T-SIM® shows good agreement with experiment data and confirms the friction coefficient values in temperature for the different roughnesses. For mold A (smooth surface corresponding to plate P1), best match is reached for a very high friction coefficient. For sand mold B (corresponding to plate P3), friction coefficients between 0.5 and 1 show best results. Based on this results, the sanding of the thermoforming tools makes it possible to limit the friction with sheet polymer in temperature and thus greatly improve the average thickness distribution.

Acknowledgments
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K2025: Big Shifts in Equipment; New Innovations in Product Design

By Conor Carlin, Editor

K2025 is in the books, and it delivered a wealth of knowledge in an economy of time. What this event reveals is that the size, scale, and sheer diversity of the plastics industry make it difficult to find a uniform narrative. The mood was therefore mixed, with plastics recyclers continuing to struggle with price and regulatory pressures, and machinery builders still pushing the boundaries of AI-enhanced technologies. Material (resin) suppliers are both contributing to and navigating through a glut of supply in commodity markets while engineered or specialty resins still command premiums in highly-diversified and segmented sectors, from aerospace to automotive to medical to chip manufacturing. Bio-based materials continue to evolve, though slowly, with scale-up and prices posing challenges to wider market adoption.

In the thermoforming sector, visitors from North America would have been hard-pressed not to notice both the glaring absence of any US equipment and the significant presence of Turkish and Chinese suppliers in machinery and molds. This seems to confirm a shift from west to east in quantity, if not quality, of machines produced. Several thermoforming deals were completed at the show, which is always cause for celebration, though to put things in perspective, one of the major European injection molding machine suppliers sold almost 50 machines at the event–tariffs be damned-to their North American customers.

And though K is primarily a machinery/technology show, two significant developments in product design stood out in Hall 3: the Origin thermoformed PET bottle cap and the clear, heat-resistant CPET tray from Thermapet. In both cases, the thermoforming process enableda breakthrough in recycling: in the case of Origin (see TQ3 2025 for detailed story), a PETclosure now means, among other things, that PET and PE don't have to be separated; forThermapet (see cover story on TQ4 2024), the creation of a clear CPET trays eliminates theproblems associated with black trays in recycling streams.OMG of Italy is the exclusive technology partner of Thermapet.

The following is a summary of the technological developments promoted and displayed in Dusseldorf.

Kiefel (kiefel.com)

Kiefel's KTR 6.2 Speed was the flagship introduction and ran live on Day 1. The company positions it as a higher-throughput cup system for polymer and rPET substrates, backed by a suite of automation modules (Speedstacker, Cuppacker) and integrated scrap handling(Speedgrinder). Published specs at Kshowed speedsup to 45 cycles/min, 900 kNpunchingforce, max formed part height 250 mm, max film thickness 3.5 mm, and a claimed ~10%energy saving from heating and motion optimizations. Kiefel attributes the gains to a new film handling concept (SpeedGuard™), ProSpacing™ material feed, improved forming air system (shorter fill times), and "intelligent cooling" for faster energy dissipation in the tool. The stacker and boxing modules are designed for full-auto transfer and high-rate, stable discharge, aiming to sustain cycle speed at the end-of-line.

Beyond speed, Kiefel's K 2025 content reinforced rPET processing and"circular PET" positioning, including a hot-fill-capable PET cup/tub demonstrator developed with Perstorp's Akestra™copolyester. Kiefel reported heat resistance up to 95 °C (on Kiefelthermoforming lines) in joint testing, intended to open shelf-stable beverages and ready-meal segments to recycled-PET containers without switching to PP or CPET.

WM Thermoforming Machines(wm-thermoforming.com)

WM's K 2025 booth expanded by ~50% versus the last K, hosting two running lines:

- FX780 IM2 (steel-rule-die thermoformer) featuring an automatic in-line AI vision inspection module and the new DLifter in-line elevator for product discharge. The demo formed XPP (expanded PP) menu boxes, pitched for insulation and stiffness at low density with branding latitude.
- TWIST700 (tilting, "electrical cams")paired with MSvS (new stacker design) producing PET juice cups, with MSvS highlighted for speed, precision, and flexible handling.

WM explicitly targeted software and HMI upgrades, describing usability improvements that shorten operator onboarding and embed real-time decision support/AI on the machine. The company also claimed tool-compatibility advantages for converters switching to WM without replacing legacy tools.

Gabler (gabler-thermoform.com) The Lubeck-based firm presented the latest iteration of their M100 EVO tilt-mold thermoformer, reportedly the largest tilt-former in the world. With outputs of up to 250,000cups per hour on forming table that measures 1140mm x 570mm, the M100 EVO features a fixed upper yoke and swiveling lower table. The redesigned EVO drive consumes up to 45%less energy than previous versions. The stacking station is now built with a new linear guide with an electric drive to handle parts up to 210mm deep.

ILLIG (illig.de)
Following a corporate restart and ownership change in 2024, ILLIG arrived at K 2025 with renewed messaging and a sustainability/automation focus. While the company's K-specific press materials were less spec-heavy than in past K Fairs, its exhibitor profile and event listings reaffirmed a broad thermoforming and packaging system portfolio (plastics and fiber) and a heavy sustainability narrative. The German trade press framed ILLIG's 2025 strategy as re-earning market confidence through realigned product development and innovation cadence, under new leadership and with"plastics DNA" blended with new material platforms.

Güven Teknik/GT Form (guventeknikmakina.com)
Türkiye-based Güven Teknik Makina (GT Form) exhibited in Hall 3/B10 and showcased 2 machines, both tilt-mold (GT8565M) and multi-station form/trim/stack (GTS 900). For Kvisitors, the takeaway is continued development of in-mold cutting/stacking layouts across GT's range, positioned as cost-effective options relative to Western European tilting/punch-and-die lines.

INPAK Makina (inpakmakina.com)
Also from Türkiye, INPAK used K 2025 to reconfirm its multi-station lineup for trays, clam shells, lids, and microwave-capable PP containers. Public spec sheets emphasize TS-series forming windows (e.g., TS-800: 800×580 mm; TS-850: 850×650 mm; TS-1000:1000×750 mm) and TSR-800 in-mold cutting capability for shorter footprint cells. The company's K events page tied these models to a global installed base of 500+ machines in 50+ countries, and positioned INPAK as an alternative for high-speed standardized packaging SKUs.

Cannon (cannon.com)
Cannon entered the thermoforming arena at K with a compact machine range branded e-Forming. Press releases focused on AI-driven automatic parameter setting,"intelligent power management," and geometry optimizations aimed at lower energy use and faster changeovers. Media coverage repeatedly emphasized the AI angle("when the thermoformer thinks along") suggesting embedded models that recommend or auto-populated recipes based on material/tooling. For thermoformers, this means reducing ramp-up time, cutting scrap during setup, and operator-independent repeatability.

Geiss (geiss-ttt.com)
GEISS'T11/Ts1 thermoforming systems emphasize servo drive technology and a custom energy concept with the company claiming ~60% shorter cycle times and >50% lower energy consumption compared with conventional pneumatic systems, important deltas in thick-gauge where heating and cooling times dominate takt-time.GEISS typically pairs forming with integrated CNC trimming/5-axis routers, precise heater zoning, and robust platen accuracy, things that show up in lower trim waste and consistent bead detail on deep draws.

Machinecraft (machinecraft.org)
India-based Machinecraft showcased their universal automatic vacuum/pressure forming machines for medium to very large sheets, with 3rd-party/own routers. The company has been operating now for 40+ years with machines delivered to ~35 countries. They offer large bed sizes (e.g., 4.25 × 2.5 m vacuum forming machine), confirming capability for oversized parts (wind energy housings, vehicle panels, industrial covers). Materials formed span ABS, PMMA, PC, PP, PS, PET, PVC, TPO, TPU, and more.

Sunwell Global (sunwellglobal.com.tw)
Taiwan-based Sunwell Global, long-time partner of TSL (now Davis-Standard), displayed its model MCS800 form/cut/stack machine. Out puts can reach up to 60 cycles/min, covering abroad material window (PP, PS, OPS, PE, PVC, APET, CPET, PLA)without changing platforms. Updated controls include precise temperature management, a full-servo motion package, and a robust toggle drive to stabilize repeatability across faster cycles. Commercially, Sunwell's emphasis on quick, low-cost mold exchange targets small-to-medium production runs and frequent changeovers rather than high-output cup speeds. In the broader OEM narrative, MC sits as a versatile form-cut-stack alternative to US or European multi-station lines and as a counterpoint to tilting, in-mold-cut systems.

Other Notes from Dusseldorf

- **Industry veterans, Conor Carlin and Mark Strachan, announced the launch of thermoform.ai,** the first domain-specific AI tool designed to address the shortage of skilled technicians. A partnership with CognitionWorks will start with a limited number of pilot projects this year.
- **Multiple tool suppliers vied for the time and attention of converters**, with a notable increase in the number of suppliers from Türkiyebuilding tools for a wider variety of machines.
- **Expanded-PP (XPP)** on tilting and steel-rule die platforms was visible at WM; the XPP menu box run is notable for thermal insulation/stiffness at low density, pointing to hot/cold chain applications where PS/PP foams traditionally play.

Tooling and downstream automation were quiet but present—Kiefel's full-auto Speedstacker/Cuppacker stressed end-to-end sustainability (not just forming speed). WM's MSvS and DLifter play the same card for high-rate discharge and improved efficiencies.

Implications for Converters

1. **AI/HMI is not just marketing: it's creeping into setup and QA**
 WM's AI vision inspection (FX780 IM2) and Cannon's AI recipe guidance both attack the costly minutes/hours between tool-change and spec-compliant production, with knock-on scrap benefits. Expect guided parameterization, fault prediction, and automatic minor-loop tuning to become table stakes in the next buying cycle.

2. rPET and hot-fill are now credible together
The Akestra-enabled 95 °C claim on Kiefel hardware matters: it keeps PET in the conversation for hot-fill beverages and shelf-stable foods, aligning circularity policies with performance demands. Though not entirely new, the continued expansion of PET performance in thermoforming bodes well for increased collection and separation of quality recyclable materials.

3. Expanded PP is getting real machine time
WM's choice to run XPP menu boxes live—paired with an in-line QA loop—signals growing interest in foamed PP for thermal performance and material reduction. It remains to be seen how the benefits of foam are squared with bulk density and economic issues related to recycling.

4. Fiber influence continues, but plastics throughput still leads.
ILLI Gand Kiefel's on going fiber messaging underscores diversification, yet the K2025 story in thermoforming remained overwhelmingly about plastics line speed, automation, and rPET. For converters, this suggests a near-term capex focus on traditional lines with AI-assisted OEE, while keeping an eye on fiber platforms as regulatory signals clarify.

The Takeaways
K2025 illustrated a trio of circularity, digitalization, and efficiency. On the thermoforming floor that translated into (1) recycled-content readiness (notably rPET for cups/tubs), (2)software-forward machines with AI-guided decisions, and (3) automation continuity downstream (stacking, boxing, QA). Messe Düsseldorf's closing note underscored strong visitor energy and "innovation power," despite cautious macro sentiment. Yet for many visitors from North America, an unmistakable take-away will be the pronounced shift of OEM influence from west to east and the increased forming size of several platforms to adapt to the US market. Machines now offer 1016mm x 914mm forming areas (40"x36") which correspond to the preferred steel-rule die tool layouts for protein trays, among other items. This larger area combined with faster, servo-driven speeds from Turkish suppliers, in particular, suggests a permanent shift in the supplier landscape, despite tariffs. Value for money was the inherent message. With fewer US OEMs in the thin-gauge sector, converters will have to get used to this new normal.

Note: *AI was used in the creation of this document to summarize publicly available documentation related to objective, technical data.*


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Plastics Industry Association and Society of Plastics Engineers To Join Forces

October 2, 2025

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Washington, D.C. & Danbury, CT—The Plastics Industry Association (PLASTICS) and the Society of Plastics Engineers (SPE) today announced they are coming together to form a unified organization that will represent the entire plastics supply chain —from technical professionals to corporate leaders, and from molecule to marketplace.

Both Boards of Directors voted last week to accept the recommendation of a task group formed to explore a potential merger. The conclusion of the group was presented to the respective Boards under the banner of "Better Together," outlining how the industry and the organization's members would benefit by bringing these two storied organizations together.

"This is a historic day for the plasΘcs industry," said MaΣSeaholm, President & CEO of PLASTICS."PLASTICS is leading the industry in many ways—sustainability, market insights, advocacy, and of course, NPE. SPE has built an incredible legacy of technical education, scientific research, and professional development. By bringing our organizations together, we're creating a stronger, more connected plaɳorm to serve our members and advance the industry."

"SPE is excited to be joining forces with PLASTICS," added Patrick Farrey, CEO of SPE. "For SPE members, this is about opportunity. Our technical expertise and professional development programs will now reach more people, supported by the resources and global plaɳorm that PLASTICS brings. This combination ensures we continue to serve plastics professionals while advancing the entire industry." The organizations have signed an agreement to finalize the merger by the end of 2025. Then, SPE will become a division of PLASTICS, with the full operational integration expected to begin on January 1, 2026.

Under the terms of the agreement:

- SPE will become a division of PLASTICS, governed by an Executive Committee modeled after SPE's current leadership structure.
- SPE members will retain their membership status, benefits, and identity within the new division as part of the merged organization.
- Patrick Farrey will join PLASTICS as Executive Vice President of SPE and Chief Integration Officer, leading the transition and ensuring continuity for SPE's programs and stakeholders.

"This is a transformational moment," said Jamie Clark, Chairman of the PLASTICS Board of Directors. "By aligning our complementary strengths, we're building a powerful engine for workforce development, advocacy, and global engagement. This is going to be a great thing for the members of both organizations."

"SPE has always been about people—educating, connecting, and empowering them," said Scott Eastman, Ph.D., Chairman of the SPE Board of Directors. "The SPE Board believes this merger will amplify our mission and position us to elevate the reputation of plastics professionals worldwide.

"Founded in 1937, PLASTICS has long served as the leading voice for the plastics industry. SPE, founded in 1942, has built a global reputation for advancing plastics science and engineering.

A dedicated landing page with more information will be available at: plasticsindustry.org/bettertogether

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The Plastics Industry Association (PLASTICS) supports the entire plastics supply chain, including Equipment Suppliers, Material Suppliers, Processors, and Recyclers, representing over one million workers in our $551 billion U.S. industry. PLASTICS advances the priorities of our members who are dedicated to investing in technologies that improve capabilities and advances in recycling and sustainability, and providing essential products that allow for the protection and safety of our lives. Since 1937, PLASTICS has been working to make its members, and the eighth largest U.S. manufacturing industry, more globally competitive while supporƟng circularitythrough educational initiatives, industry-leading insights and events, convening opportunities and policy advocacy, including the largest plastics tradeshow in the Americas, NPE: The Plastics Show.

The Society of Plastics Engineers (SPE) promotes scientific and engineering knowledge in the plastics industry through professional development, educational resources, technical journals, and global conferences to a community of over 85k+ stakeholders in 84 countries. SPE provides resources for career advancement, networking, research, and sustainability initiatives, fostering collaboration and innovation in polymer science and technology. Website:www.4spe.org.

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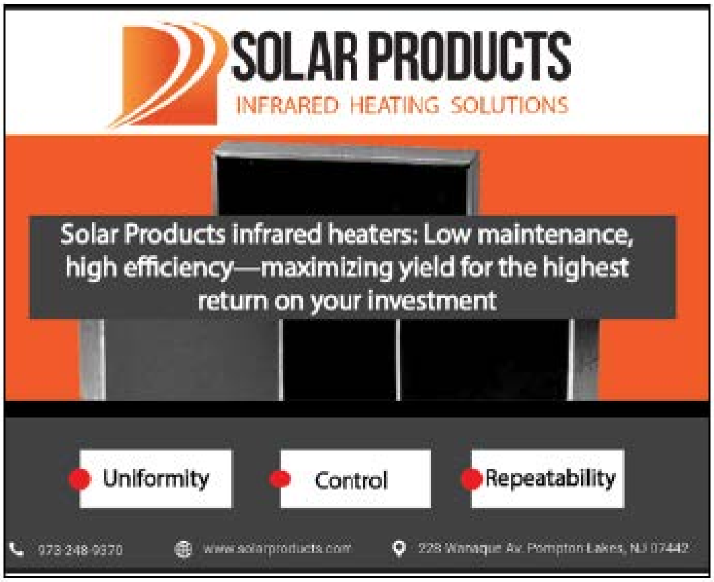


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