IN THIS ISSUE:

• Effects of Process Parameters in Thermoforming of Unidirectional Fibre-Reinforced Thermoplastics
• Forming rPET in Southeast Asia
• Innovation Brief: Focus on Europe
The GENESIS™ Program is a comprehensive inventory of complete extrusion systems comprised of stock machines, parts and sub-assemblies that qualify for expedited delivery.

With the GENESIS™ Program...

- attain product availability sooner than customizable options of just-in-time build and deliver methods.
- substantially reduce ordinary deliveries by over 3 months.*
- recognize reduction in lead-times as a contributing factor for expediting product-to-market and financial success.
- be protected with standard warranty and service agreements, safeguarding investment and reliability, now and in the future.

Systems represent current model years and include PTI’s latest state-of-the-art technology!

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

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

Chairman’s Corner | 4
Thermoforming in the News | 6-10
Thermoforming & Sustainability | 34-36

Features

Ideation in Thermoforming: Where Vacuum Meets Pressure | 12
Innovation Brief: Focus on Europe | 16-17
Lead Technical Article: Effects of Process Parameters in Thermoforming Unidirectional Fibre-Reinforced Thermoplastics | 18-30

In This Issue

SPE Foundation Annual Report | 11
2024 European Thermoforming Conference Preview | 14-15

Cosmetic cover for medical laboratory equipment. Courtesy of Dallager Photography.
A few weeks ago I had the honor of speaking at SPE AN-TEC’s Glenn Beall Symposium in St. Louis. There, I was able to recount Glenn’s involvement with thermoforming back in the 1980’s and talk about the influence he had during the development of heavy gauge pressure-forming. It was quite the trip down memory lane of 42 years (yikes!) of my own employment in the thermoforming industry as I discovered while doing research for my portion of the presentation. The exercise helped me to realize not only the importance of a professional like Glenn, but also to reflect on the contributions of many other individuals through considerable time, talent, and drive that advanced and elevated our industry. Contributions such as our Thermoforming Conference, Thermoforming Quarterly magazine, “Thermoformer of the Year” award, sponsoring the creation of the European Thermoforming Division, the parts competition, process workshops, thermoforming machine grants, student plastics scholarships, and the Division website. All of which help our mission to facilitate the advancement of thermoforming technologies through education, application, promotion, and research. We owe a debt of gratitude and thanks to these people and their accomplishments.

Like our own conference, ANTEC prominently features work by students, both graduate and undergraduate. The majority of conference attendees this year were impressed with both the quality and the quantity of student posters. The fact that student groups come from Europe to present their work is testament to the prestige associated with ANTEC. Many of these students will go on to work in a variety of roles in the plastics industry. It is incumbent upon us, as business owners and managers, to establish links with the next generation. Fortunately, this is where SPE excels and where your membership in our 22,000 strong network reflects real value.

With the European Thermoforming Conference just over the horizon (see pp. 14-15), we feature several articles highlighting global thermoforming in this issue. Donite Plastics, based in Northern Ireland, is featured in our “Innovation Brief” section (pp. 16-17). Farther afield in Southeast Asia, we offer a glimpse into how one company in Indonesia is walking the walk in terms of sustainability by extruding and forming 100% rPET for drinking cups (pp. 34-36).

I’d like to thank the Board and Executive Committee for their support over the past two years. It has been an honor and privilege to serve as Division Chair. I look forward to supporting incoming Chair Paul Uphaus as he leads Division into the next two years!

Why Join?
It has never been more important to be a member of your professional society than now, in the current climate of change and global growth in the plastics industry. Now, more than ever, the information you access and the personal networks you create can and will directly impact your future and your career. Active membership in SPE – keeps you current, keeps you informed, and keeps you connected. Visit www.4spe.org for details. The question really isn’t “why join” but ...
MARK YOUR CALENDARS AND DO NOT MISS THE ONLY EVENT THAT IS DEDICATED TO EUROPE’S THERMOFORMING INDUSTRY.

The European Thermoforming Division invites you to the 13th European Thermoforming Conference to be held in Amsterdam from 10th till 12th April 2024.

Who should attend? Thermoformers, OEM’s, Machinery & Tooling manufacturers, Film and Sheet suppliers, Resin producers, Recyclers …

Venue: Beurs van Berlage

Further information about this event:
Society of Plastics Engineers, Thermoforming Europe Division
T +43 670 55 79 714, info@thermoforming-europe.org
www.thermoforming-europe.org
Patrick Industries enters powersports market with Sportech acquisition

By Steve Toloken, Plastics News, Assistant Managing Editor

January 11, 2024 – Recreational vehicle and manufactured housing component maker Patrick Industries Inc. announced Jan. 11 it’s paying $315 million to acquire thermoformer Sportech LLC, which makes cab components for powersports equipment and other vehicles.

The move marks Patrick’s intention to create a platform for powersports equipment the same way it did through acquisitions in the RV and marine industry processors previously.

Both Elkhart, Ind.-based Patrick and Elk River, Minn.-based Sportech have plastics capabilities, and Patrick executives said they see the acquisition helping them expand into a fragmented powersports supply chain.

It continues a string of plastics-related acquisitions for Patrick, which had $4.9 billion in revenue in 2022.

Sportech, which Patrick executives said had $255 million in 2023 sales, had estimated thermoforming sales of $110 million in 2022, with two manufacturing plants and nine lines, according to the 2023 Plastics News North American thermoformers sales ranking.

Patrick had an estimated $20 million in North American thermoforming sales in 2022.

In addition to offering opportunities to grow existing markets, Patrick executives pointed to benefits of combining the two manufacturing platforms.

“We believe numerous synergies exist between Sportech and Patrick that we can begin to unlock in the next 12 to 18 months,” said Kip Ellis, Patrick’s chief operating officer and executive vice president of operations, in a Jan. 11 call with analysts to discuss the acquisition.

“These include, but are not limited to, complementary manufacturing and forming capabilities, our plastics and metal fabrication capabilities, tube bending specialties and over $100 million in similar-sourced materials, including metals, plastics [and] polycarbonates, amongst others,” he said. “Sportech helps to solidify our platform for future organic and strategic growth within the powersports market and in tandem with our industry-leading platforms in the RV and marine markets, [and] enables us to accelerate our momentum in the attractive outdoor enthusiast space.”

Sportech, which specializes in designing and manufacturing cab components for outdoor recreation vehicles, golf carts and industrial and agricultural vehicles, had compound annual growth of 17 percent over the last five years, Patrick said.

The company was founded 30 years ago as a maker of snowmobile windshields and has more than 400 employees today, Ellis said.

Sportech had an estimated $41 million in adjusted earnings before interest, taxes, depreciation and amortization in 2023, Patrick said.

Patrick executives said they see the Sportech purchase leading to more acquisition opportunities in the supply chains for powersports equipment manufacturing.

“From an M&A standpoint, much like what we looked at with the RV space years ago and what we’ve done more recently in the marine space, it’s a fragmented supply base,” Ellis said. “It’s one that we look to Sportech as a foundational platform for us.”

He said the Sportech acquisition will give Patrick close to $500 million in sales in the powersports segment.

“We feel like we have the heft and a presence in the market,” he said.

Patrick has made other acquisitions in plastics.

In 2021, for example, it bought injection molder Sea-Lect Plastics in Everett, Wash.; Alpha Systems, an Elkhart, Ind.-based company that made thermoplastic polyolefin roofs for RVs as well as other plastic components; and Hyperform Inc., a maker of plastic foam flooring for boats.

Patrick CEO Andy Nemeth suggested to analysts on the Jan. 11 call that the company will be looking for more acquisitions.
Together we can shape the future of sustainable design
“We’re in a position to be on offense right now as we look to the future,” Nemeth said. “While the markets are calibrating, we’re in an opportunity position to be able to take advantage of great deals like this and great companies like this. … We’re going to continue to cultivate the acquisition pipeline.”

AmerCareRoyal Buys California-based Thermoformer

**Bridget Janis, Staff Writer, Plastics News Staff**

January 11, 2024 – AmerCareRoyal LLC, backed by private equity firm HCI Equity Partners, has purchased Thermosource Tooling and Manufacturing LLC.

This marks ACR’s ninth acquisition since HCI invested in the company in 2014.

ACR is a supplier of disposable foodservice supplies based in Exton, Pa.

HCI is a lower middle market private equity firm and has headquarters in Washington. The company focuses on partnering with family and founder-owned companies.

“The TTM acquisition is a testament to our strategy of fostering growth through highly strategic acquisitions for our portfolio companies,” said Doug McCormick, managing partner at HCI, in a news release. “We’re excited about the potential TTM brings to enhance ACR’s service offerings and market positioning, and we welcome the talented TTM team.”

Thermosource, based in El Segundo, Calif., supplies thermoformed and flexible food packaging for foodservice, food production and grocery applications.

The addition of Thermosource expands ACR’s capabilities in custom packaging solutions. Thermosource also has complementary products and customer segments to open more opportunities for ACR.

“TTM’s exceptional design and engineering capabilities, particularly in unique packaging formats, complement our existing product lines and capabilities, allowing us to provide a more comprehensive offering to our combined customer base,” said Scott Milberg, CEO of AmerCareRoyal, in a news release. “Bringing TTM under the AmerCareRoyal umbrella presents significant cross-selling opportunities, especially in segments where we have been seeking to expand, while also growing the product offering available to TTM’s customers.”

Other companies ACR has acquired include Team Three Group in February 2023, Ross & Wallace Paper Products Inc. in December 2021, McNairn Packaging in November 2019 and PrimeWare by PrimeLink Solutions Inc. in April 2018.

Thermoforming Systems shifting manufacturing to Connecticut

**Catherine Kavanaugh, Plastics News, Senior Reporter**

February 2, 2024 – Union Gap, Wash.-based Thermoforming Systems LLC will lay off 66 employees starting March 31 as part of a manufacturing shuffle with relocation options.

The manufacturer of thermoforming equipment for the North American food packaging sector notified state officials about the permanent job losses on Jan. 31 by filing a Worker Adjustment Retraining Notice (WARN) with the state’s Economic Security Department.

“We are moving the production of thermoforming products from Union Gap, Wash., to our Pawcatuck, Conn., operations site,” Dan Guthrie, chief operating officer and president of the packaging business, said in an email. “…we are offering relocation to interested employees.”

The Union Gap facility is not closing, he added.

“We are retaining engineering, sales, and support personnel in the Union Gap area,” Guthrie said.

The company was acquired in 2018 by Pawcatuck-based Davis-Standard LLC, which manufactures extrusion and converting equipment, as a complement to its sheet extrusion business.

At the time, TSL employed about 100 people at the 70,000-square-foot Union Gap facility that had been ex-
panded by 20,000 square feet in 2016 as part of a $1.5 million investment.

Davis-Standard remains in the thermoforming equipment business, Guthrie added.

TSL makes machines to produce plastic cups, hot or cold lids, food containers, and ventilated or tamper-evident products.

Amcor announces expansion of thermoforming production capacity to support healthcare customer growth in North America

DEERFIELD, Ill., January 31, 2024 /PRNewswire/ -- Amcor (NYSE: AMCR, ASX:AMC), a global leader in developing and producing responsible packaging solutions, today announced a significant expansion of its North American thermoforming capabilities for the healthcare market.

State-of-the-art thermoforming equipment at Amcor’s healthcare manufacturing plant in Oshkosh, Wis., will support customers in the medical, pharmaceutical and consumer health sectors.

State-of-the-art thermoforming equipment at Amcor’s healthcare manufacturing plant in Oshkosh, Wis., will support customers in the medical, pharmaceutical and consumer health sectors.

The addition of automated, state-of-the-art thermoforming equipment at Amcor’s world-class healthcare manufacturing plant in Oshkosh, Wisconsin will support increasing demand from customers in the medical, pharmaceutical, and consumer health sectors. The additional capacity will provide an efficient option for companies looking to partner with Amcor to support their growth ambitions.

The expansion also will allow customers to source thermoforms and companion die-cut lids from a single location, helping streamline product manufacturing and distribution.

“We’re excited to offer our healthcare customers a critical supply solution by scaling up our manufacturing capabilities,” said Art Castro, vice president and general manager of Amcor Flexibles North America Healthcare. “As demand grows, this strategic investment underscores Amcor’s commitment to being a true growth partner in anticipating and meeting our customers’ unique thermoforming needs.”

The expansion enhances Amcor’s global thermoforming capabilities for a variety of industries. Dedicated healthcare plants include the company’s Sligo, Ireland facility, and plants in Mankato, Minnesota and Carolina, Puerto Rico.

In Oshkosh, the new equipment – expected to be operational as early as December of this year – will be located in the Class 7 cleanroom at the plant, which operates under the ISO13485 quality system.

This Packaging Wave is Over for Thermoforming

Hollee Keller, Editorial Research Coordinator, Plastics News

February 12, 2024 – This week we present our first ranking looking at the 2023 results for North American plastic processors. The trend line is clear: Packaging thermoforming was heading into a trough while industrial thermoforming was bouncing back.

We’ve ranked 206 thermoformers in our annual ranking, with related sales of $16.8 billion. That is down 4.2 percent from the previous year.

The average sales per company is $81.7 million. Looking closer, though, the spread is extreme, maybe even redonkulous. Yup, I used that word on purpose. Our top company, Pactiv Evergreen Inc., comes in at $3.6 billion and our smallest, Modpaksol, is $0.001 million.

It may be more informative to look at these breakouts in the aggregate. Comparing year over year, we see a 4 percent decline in our packaging totals vs. a 1.7 percent gain in industrial.

Packaging represents items such as food containers and clamshells, while industrial includes housings and outdoor
goods. The two do not adhere to the same market conditions nor pricing formulas, which is why we split them apart.

From my research, the biggest factors for the decline in packaging were resin cost pass-through and slowing demand. The major materials for this ranking were all down double digits in their pricing, with polypropylene showing the largest drop at 32.9 percent. However, not all nonpackaging end markets were up. Recreational vehicles and marine products, for example, took a big hit.

Many processors handle a mix of products, so it’s notable that 48 percent of our companies had no reportable year-over-year change.

In total, thermoforming itself makes up about 11 percent of the overall sales we track for all six of our processor rankings, with $156.3 billion in combined annual sales.
SPE FOUNDATION 2023

Thank you for supporting positive plastics education and inspiring future plastics professionals in 2023!

$234,225 in scholarships awarded to 64 students at 35 universities

$27,795 raised from SPE membership renewal donations (1,120 individuals)

$80,327 total grant dollars awarded

8 3D printers awarded to schools in Alabama, Michigan, and Colorado

$758,000+ generously given to support the work of the SPE Foundation

PlastiVan® and PlastiVideo® served over 17,000 students in 17 states and 58 cities

3 After-School SPE STEM Clubs

10 SPE Junior Researchers

65 donors gave more than $40,800 for the SPE Sustainable Packaging Girl Scout Patch on Giving Tuesday

450 Girl Scouts earned their Color Your World with Polymer Science! patch

Positive Plastics Education™ presented to 2,500 Girl Scouts at the National Girl Scout Convention

For more information on how you can support the SPE Foundation education and workforce development, contact us at foundation@4spe.org.
Ideation in Thermoforming: The Perfect Storm

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

Part Description
A series of cosmetic covers with value added assembly for medical laboratory equipment by Formed Plastics, Carle Place, NY

Winning Category
Cut Sheet, Vacuum Form - Gold Award 2023

Features and Benefits
The assembly of covers service a highly modular system which permits multiple configurations to fit any size laboratory footprint. The initial breadboard product phase used cast urethane covers that did not hold up well in the environments where machines are used.

The production parts were originally planned using injection molding. Considering the modularity of the product, however, manufacturing each of the assemblies via injection would be very cost-prohibitive.

The final approached was a tailored thermoforming solution using universal tooling and material blank sizes. This provided a more streamlined, cost-effective, high-quality approach to satisfy any production run size or finish.

Material
Each of the top covers is vacuum-formed using grey-tinted Lexan polycarbonate at 0.236” starting thickness. Each of the bottom covers is pressured-formed using PVC-Acrylic (Kydex T V-103 recycled sheet) at various material gauges ranging from 0.187” to 0.400”. It was critical to maintain uniform finish thicknesses across each of the bottom covers regardless of size or orientation. Custom color and textured paint finishing was required to match with other parts on the same equipment produced via different plastic processing techniques.

Tooling
There is a total of 17 production-grade molds that produce 36 different parts. Molds that vacuum-form the top covers were made from CNC-machined aluminum billet with cast aluminum bases. Each of these molds contain 1- or 2-up articulated mold cavities with multiple independent temperature-controlled zones. Automated articulated cavities provided successful de-molding of undercut features and consistency.

Molds that pressure-form the bottom covers were made from cast aluminum with CNC-machine finishing for tighter tolerancing with embedded temperature-control. These molds were either negative or positive with 2-cavities each and equipped with syntactic foam plug assists where needed.

Design & Challenges
The customer emphasized the overall aesthetics of the product and required see-through clarity. This was achieved through uniform material distribution of each of the top covers, localized heating zones, and careful consideration of the mold design to mitigate marring when de-molding.

In addition, each cover assembly was held within tight-tolerances due to tolerance stack-up considerations. The timeline to roll out initial production units was very restrictive. Speed to market was critical with very close communication among all parties.

Photo courtesy of Dallager Photography
Extrusion solutions built custom for your needs.

PremierCap® TPO for fuel source panels

OneStep® Vinyl/ABS for dashboard and Boltaron® 4800 for bus interiors

Boltaron® 4335 for Medical Device

PVC • ABS • TPO • Acrylic • ASA • PC/ABS • Soft-touch
• textures • metallics • pearls • prints • and more!

SIMONA

www.simona-boltaron.com

SIMONA

www.simona-pmc.com

GLOBAL THERMOPLASTIC SOLUTIONS
13th EUROPEAN THERMOFORMING CONFERENCE
Amsterdam, The Netherlands

Unveiling a diverse programme highlighting cutting-edge topics in the thermoforming industry.

The European Thermoforming Division of the Society of Plastics Engineers is thrilled to announce the near-finalized programme for the 13th European Thermoforming Conference, set to take place at the esteemed Beurs van Berlage in Amsterdam. Carefully curated by the organizers, the conference promises an unparalleled lineup of speakers and topics, making it a must-attend event for industry professionals.

The Keynote presentations in the General Session:

Distinguished speakers will delve into crucial topics shaping the future of thermoforming during the General Session. Highlights include:

• “Plastic Packaging in Retail” by James Bull of TESCO,
• “Digital Product Passport” by Dr. Benedikt Brenken of REIFENHAEUSER,
• “Advanced Recycling” by Ingemar Bühler of PLASTICS EUROPE,
• “Closed Loop Theory” by Gerard Liraut of RENAULT.

Enriching Agenda with Industry Experts:

The conference agenda further features specialized sessions on Heavy Gauge and Thin Gauge topics. Renowned organizations such as KUBOTA, BIG BEAR, SPE, SE KUNSTSTOFFTECHNIK, GEISS, LINECROSS, TRAYTEK, POEPPELMANN, ILLIG, BC EXTRUSION, KURAREY, and BRINK AU- TOMATION will present cutting-edge insights.

Thermoforming Training Course:

As part of the conference, a one-day Thermoforming Training Course on April 10, 2024, offers a unique opportunity to deepen understanding of thermoforming fundamentals. Attendees will engage directly with SPE thermoforming experts, gaining valuable insights into the latest industry trends.

Parallel Exhibition:

Complementing the conference, a comprehensive exhibition featuring tabletop displays will showcase the latest product developments from leading suppliers in the thermoforming industry. This parallel exhibition promises a wealth of information and networking opportunities for attendees.

A must-attend for Industry Professionals:

The 13th European Thermoforming Conference is a must-attend for thermoformers, user of thermoformed products and components, OEMs, machinery and tooling manufacturers, film and sheet suppliers, resin producers, recyclers, and anyone involved in the plastics industry.

Amsterdam, renowned for its vibrant atmosphere, provides an outstanding backdrop for this industry-leading event. The Beurs van Berlage, an iconic venue, has proven to be the perfect setting for fostering collaboration and innovation within the thermoforming industry.

Information about the conference, exhibition, training course may be obtained from:

SPE ETD – Society of Plastics Engineers,
European Thermoforming Division
Contact: Reinhold Plot
T +43 670 55 79 714
info@thermoforming-europe.org
www.thermoforming-europe.org

About the European Thermoforming Division of the Society of Plastics Engineers:

The European Thermoforming Division is dedicated to advancing the field of thermoforming through knowledge sharing, collaboration, and continuous innovation. As a part of the Society of Plastics Engineers, www.4spe.org, the division brings together industry professionals to explore and shape the future of thermoforming technology. For more information, visit www.thermoforming-europe.org
Have an idea for an article?

Article length: 1,000 - 2,000 words.
Look to past articles for guidance

Format: .doc or .docx

Artwork: hi-res images are encouraged
(300 dpi) with appropriate credits.

Send all submissions to:
Conor Carlin, Editor cpcarlin@gmail.com

ALL FINAL COPY FOR EDITORIAL APPROVAL
MARCH 1 SPRING
JUNE 15 SUMMER
SEPTEMBER 15 FALL
DECEMBER 1 WINTER

All artwork to be sent in .eps or .jpg format
with minimum 300 dpi resolution

Follow the SPE Thermoforming Division on
X / Twitter @SPEThermo
Donite Plastics Delivers on Innovative Aerospace Project

Donite Plastics, in partnership with Northern Ireland Technology Centre (NITC) at Queen’s University, Belfast, has concluded an innovative project that will see the introduction of smart technology into the aircraft interiors assembly process and the creation of up to eight jobs later this year.

Donite Plastics has been supporting customers in the aerospace sector for several years and through this project, awarded by the National Aerospace Technology Exploitation Programme (NATEP), which is co-funded by Innovate UK and the Aerospace Technology Institute (ATI), has developed a robotic automated assembly cell for advanced Thermoformed Twin Skin Panels (TTSP) for aircraft seating systems.

Aircraft interiors, and in particular aircraft seating, incorporates many variations of access panels, with the traditional designs generally assembled using conventional assembly techniques. The technology that has been developed will create a human and machine collaborative environment that will see improved efficiency for both Donite Plastics and its aerospace customers, through a reduction in assembly time and increased part quality.

The introduction of bonded twin skin vacuum formed panels, where appropriate, also has the potential to improve sustainability across the sector through significant cumulative weight savings, with the company’s latest development producing lightweight panels and components with up to 39% weight reduction and 89% part reduction per panel, compared with current in-service aircraft parts. The panels are manufactured using thermoformable aircraft grade materials, and a range of tooling technologies. The range included 3D printing tooling technology and soft tooling technology, both of which are compared against each other, and evaluated to establish the break even point before the company proceeds to hard tooling. These technological advancements will enable Donite Plastics to further its offering to its aerospace customers and make a greater impact on the thriving sector.

Patrick Knight, Engineering and Research and Development Manager at Donite Plastics spoke about the project saying, “As a result of our participation in this programme, we have been able to build our knowledge and expertise, not just those within the aerospace sector, but in additional sectors. It has also helped us to engage with potential clients and trial new innovative processes that will expand our capabilities and help meet our growth aspirations going forward.

“With an investment of £500k, which included automated thermoforming and CNC trimming equipment, this R&D project will help us to develop these capabilities going forward and meet the requirements of our customers. Later this year, we will also be commencing a recruitment drive to accommodate the additional workload to the company.”

The new technology developed by Donite Plastics throughout the project will be utilised by one of the company’s largest customers, Thompson Aero Seating. Aaron Robinson, Head of Design at the company said, “This was an excellent project, which has proved beneficial to Thompson Aero Seating. Seeing the development of the new technology as well as the end result, has been very rewarding.”

Rory Collins from the Northern Ireland Technology Centre, which is now part of the Belfast Region City Deal-funded £100m Advanced Manufacturing Innovation Centre being delivered by Queen’s with industry, government and academics partners, said, “Throughout this successful and innovative programme, our staff have been able to further their knowledge and capability in the area of automation and robotics. That will contribute to the success of our projects within AMIC, which is set to reinvigorate Northern Ireland’s industrial potential and address the future technology and skills challenges faced by the region’s manufacturing sector. We wish to thank the team at Donite Plastics for their hard work and dedication throughout the project.”

Donite Plastics is committed to continuous improvement and through the NATEP programme. It plays a pivotal role in the growth of the UK’s aerospace sector, and as a pioneer of lightweight technology, has the ability to produce thermoformed parts and complex assemblies for leading aerospace manufacturing companies across the globe.

The culmination of this project comes at a very exciting time for Donite Plastics as it looks toward further expansion in 2024 and a greater improvement of its processes, whilst remaining a pioneer in the thermoforming sector in Ireland, the UK and beyond.
Donite Plastics, established in 1981, specialises in the design and manufacture of custom moulded plastic parts using vacuum forming and other processes, which are ideal for large, medium or small batch quantities.

Photo1: Thermoforming company, Donite Plastics, in partnership with Northern Ireland Technology Centre at Queen's University, Belfast, has concluded an innovative project that will see the introduction of smart technology into the aircraft interiors assembly process. Pictured (L-R) are Rory Collins, Northern Ireland Technology Centre; Aaron Robinson, Thompson Aero Seating; Steven Stanley, NATEP; and Patrick Knight, Donite Plastics.

Join Us!

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

Thermoforming Quarterly is proud to publish news and stories related to the science and business of thermoforming:

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

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

Johannes Winhard and Daisy Nestler and Lothar Kroll

Department of Lightweight Structures and Polymer Technology, Faculty of Mechanical Engineering, Chemnitz University of Technology, 09111 Chemnitz, Germany

Abstract: Process-induced defects during thermoforming are widespread problems in laminate manufacturing. The aim of this study is to describe the effects of holding time and pressure on several properties of the manufactured laminate. A design of experiments is performed, followed by an analysis of variance to examine significant effects. Subsequently, a regression model is created to predict the laminate’s properties, which is also validated. A significant interaction between holding time and pressure is determined for the resulting tensile strength and elongation at break with a p-value of $1.52 \cdot 10^{-16}$ and 0.02, respectively. The highest values of tensile strength and elongation at break are found for low settings of holding time and pressure. The fibre volume fraction is not affected by the process parameters. As holding time and pressure increase, significant fibre misalignment takes place, leading to a decrease of the mechanical properties. The regression model corresponds well with the validation and a tensile strength of 1049 MPa with an elongation at break of 2.3% is reached.

Keywords: thermoplastic matrix composite; fibre-reinforced polymer; thermoforming; design of experiments; basalt fibres; BF/PA6

1. Introduction

Fibre-reinforced thermoplastics (FRTP) are primarily used in the transportation sector, such as automobiles and aerospace, relying on lightweight structures combined with high strength and stiffness [1]. The manufacturing takes place at temperatures near the melting point of the used thermoplastic matrix to reduce its viscosity and enable sufficient impregnation of the fibres. Common melt viscosity values for thermoplastics are $10^2$–$10^4$ Pa·s, which are much higher compared to those of epoxy polymers during impregnation ($10^{-3}$–$10^0$ Pa·s) [2,3]. As a result, different manufacturing processes need to be considered, and a fundamental understanding of the respective process parameters is crucial. Furthermore, a thermoplastic matrix offers the possibility of short cycle times due to the use of semi-finished materials, such as prepregs (pre-impregnated material), organo sheets, or unidirectional fibre-reinforced tapes (UD-tapes) [4,5]. This paper focuses on UD-tapes, which can be orientated in any load direction, allowing for targeted fulfilment of current load requirements.

The thermoforming process for UD-tapes and hybrid laminates is widely used and has been described in detail in many sources. In general, thermoforming involves a stamping process executed under a specific pressure, time and temperature just below the melting point of the matrix material. The UD-tapes are stacked into the negative die, with each layer having a specific fibre orientation. Then the tool closes by moving down the positive die and the thermoforming process executes with defined process parameters [4,6–8]. Consequently, understanding the impact of process parameters on the quality and mechanical properties of the manufactured laminate is of significant interest. Nonetheless, thermally induced residual stress and process-induced defects, such as fibre misalignment, wrinkling and folding, are common challenges when thermoforming thermoplastic prepregs [6,9–11]. These defects can lead to a decrease in mechanical properties, unintended plastic deformation, or premature material failure. The compressive strength of fibre-reinforced plastics (FRP) in particular is drastically affected even by small fibre misalignments. This is assumed for the first time by Wisnom [12] with a simplified model for carbon fibres and epoxy resin showing a decrease to 26% of the original compressive strength for a fibre misalignment angle of 3°. Furthermore, the tensile strength decreases sharply with an increasing off-axis angle [13,14] as well. This is caused by the fibre-parallel shear stress, whose critical value for failure of the laminate is much lower than shear strength perpendicular to the fibres or tensile strength in any direction [15,16] and illustrates the sensitivity of the mechanical properties to the fibre orientation. Numerous strategies for modelling various effects on the impregnation process have been developed [17–20]. However, each simulation is constrained by simplifications, limitations, or a focus on specific aspects due to the complex and interdisciplinary nature of the problem [21]. Manson et al. [22] emphasized the significance of uniform pressure distribution for consistent laminate impregnation. Their study found that eight-ply UD-tapes subjected to uniform pressure across the entire laminate exhibited negligible void content, regardless of
cooling rates or annealing conditions. Furthermore, annealing increased the crystallinity of the polyether ether ketone (PEEK) matrix [22], resulting in reduced composite fracture toughness [23,24]. Christmann et al. [18] developed a thermoforming model for FRTP based on the so-called B-Factor model. This model demonstrated identical impregnation quality for different parameter settings. Additionally, model validation indicated that varying pressure settings does not affect impregnation significantly for rapid processing times. Lower pressure settings appeared advantageous for impregnation quality and yielded higher interlaminar shear strength values as well [25]. Conversely, various observations [10,26] suggest that higher pressure leads to improved part quality, particularly concerning the surface roughness.

In the present work, a design of experiments (DOE) is conducted to investigate the effects of pressure and holding time on the tensile strength, elongation at break, and compaction behaviour of UD-tapes with basalt fibres (BF) within a polyamide 6 (PA 6) matrix. Furthermore, macroscopic misalignment of the fibres resulting from the thermoforming process is discussed, and a validation of the developed model is performed.

2. Materials and Methods

2.1. Materials and Samples

The material system examined in this study consists of UD-tape comprising basalt fibres and a PA 6 matrix from Cetex Institut gGmbH (Chemnitz, Germany), with a thickness of 0.16 mm. The fibre volume fraction (FVF) of 62% is determined following DIN EN ISO 1172 [27]. Square laminates measuring 260 mm × 260 mm are produced using the Collin P 300 P/M (COLLIN Lab & Pilot Solutions GmbH, Maitenbeth, Germany) hot plate press, in accordance with DIN 65672 [28] standards, resulting in a six-ply laminate oriented of [0]₆. Each specimen is cut out using a waterjet and then subjected to accelerated conditioning (DIN EN ISO 1110 [29]). In this standard, the specimen is stored in a climate chamber at (70 ± 1) °C to accelerate the moisture absorption of PA 6. The mass of the specimen is measured frequently after specific periods of time and is repeated until the measurements of three consecutive cycles differ by less than 0.1% [29]. The tensile tests are performed according to DIN EN ISO 527-5 [30].

A single laminate allows for the creation of twelve specimens (Figure 1), out of which eight are designated for the tensile tests, two for FVF measurement, and two for quality assessment of the laminate. Additionally, two specimens serve as backups in case of damage during waterjet cutting. Multiple light microscopic images are captured from the centre, corner and edges of each laminate, perpendicular to the fibres, to evaluate impregnation and compaction quality.

![Figure 1. Square laminate with cut-out specimens 1–12, each with dimensions of 15 mm × 250 mm, for tensile tests. The dash-dotted lines indicate the positions of the performed light microscopy and the adhesive tape across the laminate prevents the individual specimens from ripping out unintentionally.](image)

2.2. Manufacturing Process

![Figure 2. Program example of a thermoforming process with the set parameters of temperature T, pressure p and measured temperature over the process time τ during thermoforming with a holding time of 530 s. An illustrative instance manufacturing processes is depicted in Figure 2. The stacked UD-tapes undergo preheating to 170 °C and are then heated up to 280 °C at a rate of 20 K/min. Upon attaining the designated processing temperature, the pressure increases to the predetermined value, maintaining a constant temperature for the specified holding duration.](image)
Subsequently, the laminate is gradually cooled at a rate of 20 K/min until reaching 50 ºC. The pressure remains constant until the conclusion of the process. The observed temperature closely aligns with the predetermined values. A marginal temperature disparity is observable at the onset of the heating phase. During the entire cooling process, the temperature differences are somewhat more pronounced, although the cooling rate is effectively maintained.

2.3. Statistical Methods

A full factorial design of experiments is executed, encompassing various holding times ranging from 60 s to 1000 s. These durations are maintained at a consistent temperature of 280 ºC, alongside varying pressures from 0.2 MPa to 2.0 MPa. Each parameter is set at three distinct levels, which results in a total of nine individual laminates. The configuration and assignment of process parameters to each laminate are detailed in Table 1.

<table>
<thead>
<tr>
<th>Laminate</th>
<th>Holding Time τ in s</th>
<th>Pressure p in MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60</td>
<td>0.2</td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>1.1</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
<td>2.0</td>
</tr>
<tr>
<td>D</td>
<td>530</td>
<td>0.2</td>
</tr>
<tr>
<td>E</td>
<td>530</td>
<td>1.1</td>
</tr>
<tr>
<td>F</td>
<td>530</td>
<td>2.0</td>
</tr>
<tr>
<td>G</td>
<td>1000</td>
<td>0.2</td>
</tr>
<tr>
<td>H</td>
<td>1000</td>
<td>1.1</td>
</tr>
<tr>
<td>I</td>
<td>1000</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The primary objectives of this DOE encompasses the evaluation of tensile strength, elongation at break and FVF. The hypothesis is that as the holding time and pressure increase, there will be a tendency for fibre misalignment. Consequently, the fibres may deviate from being parallel to the applied load direction, leading to a reduction in tensile strength. Moreover, a greater degree of fibre misalignment towards the dominant load direction is anticipated to cause a more pronounced decline in elongation at break. This is attributed to potential obstacles in transverse contraction and issues stemming from low adhesion.

After mechanical testing of the samples, an analysis of variance (ANOVA) is conducted to identify significant effects. If detected, main effects and interactions of the manipulated factors are elucidated. Subsequently, a regression model is formulated and its accuracy is validated. Both the ANOVA and the regression model employ statistical tools from MATLAB (version 9.12) [31].

3. Results and Discussion

3.1. Macroscopic Fibre Misalignment and Compaction

Figure 3 depicts the produced laminates, categorized based on the process parameters outlined in Table 1 as well as a close-up of laminate H for a better visibility of the fibre misalignment of several laminates. When the holding time or pressure increases, while the other parameter remains at a low level, a minimal amount of fibre and matrix extrusion occurs (laminate G), or no extrusion transpires at all (laminates A–D). In contrast, when both parameters are elevated simultaneously, a substantial extrusion and fibre misalignment are observed across the entirety of laminates E, F, H, and I. Consequently, this leads to the formation of a curled structure composed of fibres and matrix along the edges of the laminates, parallel to the initial 0º-axis of the fibres. Furthermore, areas devoid of fibres emerge at the edges perpendicular to the orientation of the fibres (Figure 3). These outcomes underscore the presence of an interaction between the process parameters, namely the holding time and pressure.

The optical micrograph captured from the centre of all laminates (Figure 4) reveals minor discrepancies across the samples A–C, D and G. In the case of laminates A–C and D, distinct layers from the original UD-tapes, or even the primary fibre rovings within each layer, are clearly discernible. Occasional microscopic voids (depicted as black regions in Figure 4) are only observable within the initial fibre rovings of laminates A and D. Consequently, the impregnation quality for all laminates is excellent. The compaction process for laminates E, F, G, H, and I has progressed to the extent that fibres from individual layers have merged into adjacent ones, and thus no separation of individual layers is recognisable. The laminates A–D and G exhibit comparable thicknesses, ranging from 0.90 mm to 0.97 mm. In contrast, laminates E, F, H, and I display noticeable thickness variations, with laminate I measuring only 52% of the thickness of laminate A. This divergence is a direct consequence of the pronounced material extrusion detailed earlier and evident in Figure 3. Once more, significant differences are recognisable when both process parameters are concurrently altered, as opposed to modifying only a single parameter. This serves to reinforce the assumption of an interaction between the process parameters.
tension in the 0° direction. In contrast, the tensile samples of fibre orientation and splicing of the specimens at an applied load follow this fracture behaviour.

**Figure 5.** Transparent foreground: image of laminate H with indicators of fibre misalignment (full lines) before tensile tests; background: image of tensile specimen of laminate H after tensile tests at its original position with the local fibre misalignment of laminate H (dashed line).

The tensile tests are conducted following DIN EN ISO 527-5 [30]. It is noteworthy to mention that the thickness of laminates F, H, and I falls below the prescribed range stipulated by the standard, as evident from Figure 4. These mentioned laminates do not align with the standardized method’s specifications. However, it is worth noting that despite this variance, the standard deviation of the tensile strength remains consistent with the values observed in samples adhering to the standard.

The laminates A–C, D, and G show typical fracture behaviour of UD-laminates with breaking perpendicular to the fibre orientation and splicing of the specimens at an applied tension in the 0° direction. In contrast, the tensile samples of laminates E, F, H, and I, with their noticeable fibre misalignment (Figure 3), fail along the path of the fibres with the biggest angular difference to the initial 0° orientation of the lay-up. Figure 5 shows the image of laminate H and an exemplary tensile specimen in their original position on the plate after the tensile test. The dashed line indicates the local fibre misalignment, which matches well with the fracture of the specimen. All samples of laminates E, F, H, and I follow this fracture behaviour.

**3.2. Fracture Types and Mechanical Properties**

Selective electron microscopy (SEM) images of the resulting fracture surfaces show different fracture types for laminates with macroscopically different failure behaviour (Figure 6). The macroscopic splicing of the tensile specimens in laminate A is accompanied by clear fibre breakage and fibre pull-out (Figure 6a). For imaging the fracture surface of laminate H (Figure 6b), the back-scatter detector is used to distinguish more clearly between matrix material and fibres. Due to the higher atomic numbers of metallic elements (e.g., silicon, aluminium, iron and calcium) of basalt fibres, they appear brighter than to the non-metallic elements (e.g., carbon and nitrogen) of PA6. The present fracture type is inter-fibre failure due to matrix fracture and interfacial debonding with matrix residues on the fibre surfaces, which underlines a good fibre–matrix adhesion. Only a small amount of fibre breakage is visible. It can also be seen that the resulting fracture surface follows the local fi-
bre orientation. This failure mode occurs due to the transformation of the initially normal load on the specimen into a localized stress state, resulting in shear-induced failure. It has been proven theoretically and experimentally that for unidirectional laminates, the local shear load along the fibre direction is the most critical criterion in this case and leads to failure of the laminate [15,16,32]. Additionally, the fracture structure of the matrix at position 1 in Figure 6b indicates a failure caused by shear load as well due to initially formed microcracks caused by normal load, which subsequently unite to several inter-fibre cracks, designated as “hackles” [33,34]. Therefore, the laminates A–C, D and G with a splicing fracture behaviour fail due to normal stress, whereas the laminates E, F, H, and I follow a failure caused by shear stress to a fibre-parallel fracture.

The results from the tensile tests substantiate the assumption of diminishing tensile strength and elongation at break, attributed to fibre misalignment in laminates E, F, H, and I. It strongly suggests the existence of a notable interaction among the process parameters. After checking for normal distribution of the target values, an ANOVA is carried out to determine the possible detectability of these effects.

**Figure 6.** (a) Fracture surface of laminate A imaged via secondary electron detector: mainly fibre breakage and fibre pull-out visible; (b) fracture surface of laminate H imaged via back-scatter detector: fibre-parallel fracture with predominate (1) matrix fracture and (2) interfacial debonding with matrix residues on fibre surfaces as well as a small amount of (3) fibre breakage visible.

The results for tensile strength are shown in Figure 7. The highest values are attained by laminates A, B and D with approximately 1050 MPa. A slight decrease in mean tensile strength is observed for laminates C and G, with about 1000 MPa. For these samples, only one parameter is varied while keeping the other at its lowest setting. However, when both process parameters are concurrently adjusted, the tensile strength decreases suddenly below 300 MPa for laminates E, F, H, and I. This trend aligns with the laminates where fibre misalignments are clearly visible (Figure 4). The tensile stress applied to the cross-section of the specimen leads to shear stresses at the points of fibre misalignment whose critical value for fracture is well below the tensile strength in the fibre direction. Therefore, the measured tensile strength of laminates E, F, H, and I is much less compared to the other laminates without fibre misalignment, despite the good impregnation of all laminates (Figure 4). A similar trend is noticeable in the results for elongation at break (Figure 8), but to a lesser extent in a comparison of tensile strength. Furthermore, the variance of the elongation at break seems to rise when the settings are incrementally increased. This variance ranges from (2.26 ± 0.03)% for laminate A up to a 16 times higher standard deviation for laminate H with (1.75 ± 0.50)%. A reason for the higher variances of the laminates lower in pure transverse tensile than in transverse shear and longitudinal tensile [15,35].

**Figure 7.** Tensile strength σ in MPa and the corresponding standard deviation for each manufactured laminate A–I.
LOW FLEX™ FORMER SERIES
- LF5.0 Shown – 190 Ton
- Numerous quick change features
- Easy maintenance access

LINEAR RAIL TRIM PRESS
- LR5 Shown – 45 Ton
- Side Loading of Tool
- Numerous quick change features
- Precise tolerances via linear rails

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

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

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

SERVICE
- Training Classes
- On line help
- Process Training
- After hours help
- Included start up service

tslusa.biz

davis-standard.com
used to test for normal distribution. A $p$-value $< 0.05$ corresponds to a significant deviation from a normal distribution. With a $p$-value of 0.36, it can therefore not be ruled out that the tensile strength follows a normal distribution. In contrast, the elongation at break appears to show a significant deviation from a normal distribution with a $p$-value of 0.03, despite the positive first impression of the Q-Q plot. Nevertheless, subsequent ANOVA is performed for the tensile strength as well as for the elongation at break. Several studies [36–40] emphasize the robustness of an ANOVA in the case of a non-normally distributed sample. However, the following results for elongation at break should be viewed with particular caution.

Figure 8. Elongation at break $\epsilon_b$ in % and the corresponding standard deviation for each manufactured laminate A–I

Figure 9. Q-Q plots of (a) tensile strength and (b) elongation at break.

3.3. Normal Distribution of Sample Values

A prerequisite for an ANOVA is a normal distribution of the dependent variable. For this purpose, 20 samples with the same process settings serve as a random sample to determine the statistical distribution of tensile strength and elongation at break. The normal Q-Q plot can be used for a graphical interpretation if the results of the tensile tests follow a normal distribution. If this is the case, the observed values are approximately at the theoretically expected values and therefore on a diagonal. Figure 9 shows the normal Q-Q plot for tensile strength and elongation at break. The results of both target values seem to fit the standard normal quite well, but slightly failed for the tensile strength and higher values of elongation at break around the mean value. Due to the rather subjective interpretation of a Q-Q plot, especially with a small number of samples, the qualitative method of the Anderson–Darling test is also needed to rule out the normal distribution. With a $p$-value of 0.03, despite the positive first impression of the Q-Q plot. Nevertheless, subsequent ANOVA is performed for the tensile strength as well as for the elongation at break. Several studies [36–40] emphasize the robustness of an ANOVA in the case of a non-normally distributed sample. However, the following results for elongation at break should be viewed with particular caution.

Figure 9. Q-Q plots of (a) tensile strength and (b) elongation at break.

3.4. ANOVA and Interactions

An ANOVA is performed to assess the significance of various effects on the respective objectives of tensile strength (Table 2), elongation at break (Table 3), and FVF (Table 4).

The interaction between holding time $\alpha$ and pressure $p$ with regard to tensile strength shows a very small $p$-value of $1.52 \cdot 10^{-16}$, which indicates a high level of significance.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>$F$-Value</th>
<th>$p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding time</td>
<td>$3.72 \cdot 10^6$</td>
<td>2</td>
<td>$1.97 \cdot 10^5$</td>
<td>206.07</td>
<td>7.20 $\cdot 10^{-23}$</td>
</tr>
<tr>
<td>Pressure</td>
<td>$3.94 \cdot 10^6$</td>
<td>2</td>
<td>$1.97 \cdot 10^5$</td>
<td>206.07</td>
<td>2.22 $\cdot 10^{-23}$</td>
</tr>
<tr>
<td>Interaction</td>
<td>$2.05 \cdot 10^5$</td>
<td>4</td>
<td>$5.12 \cdot 10^3$</td>
<td>53.56</td>
<td>1.52 $\cdot 10^{-16}$</td>
</tr>
<tr>
<td>Error</td>
<td>$4.30 \cdot 10^3$</td>
<td>45</td>
<td>$9.87 \cdot 10^1$</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>$1.01 \cdot 10^2$</td>
<td>53</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 2. ANOVA of the tensile strength $\sigma$. 

---

Note: The tables and figures are placeholders as the actual content is not provided in the text.
This is supported by much higher F-values for both the main effects and the interaction, compared to the critical F-value of 4.85 and 3.46, respectively. However, the significant main effects in Table 2 are questionable, particularly when considering the raw results depicted in Figure 7. In those results, alterations in tensile strength are not substantially apparent when only one parameter changes, contrary to the presence of a significant interaction. Conversely, when the main effects are not factored in, the F-value for the interaction decreases to 3.1, accompanied by a \( p \)-value of 0.02. Additionally, the accuracy of the regression model diminishes. Consequently, the main effects are retained within the ensuing regression model. The affected results concerning the interaction between holding time \( \tau \) and pressure \( p \) are shown in Figure 10. Concurrent variations in both parameters cause a decrease in tensile strength (illustrated by the dotted and dash-dotted lines in Figure 10). Conversely, modifying just one parameter while maintaining the other at its lowest setting yields hardly any discernible effect on the target value (solid line in Figure 10).

Figure 10. Interactions of the process parameters holding time \( \tau \) in s and pressure \( p \) in MPa (abscissa of each graph) for the tensile strength \( \sigma \) in MPa (ordinate of each graph).

The calculated \( p \)-value of 0.02, signifying the interaction among the observed process parameters for elongation at break (Table 3), also highlights its significant influence. As well as for the tensile strength, the presence of interaction between holding time and pressure, along with the similar trends in elongation at break when only one parameter is altered (Figure 8), suggests that debating the main effects might be unnecessary. Moreover, if the interaction is exclusively deemed relevant, the F-value decreases to 1.67 and the \( p \)-value decreases to 0.17. This adjustment would also lead to a regression model of lesser accuracy. As a result, the main effects continue to be considered for the subsequent regression model.

Figure 11 shows the interaction between the process parameters affecting the elongation at break. When one parameter is maintained at its lowest setting, there is hardly any noticeable effect on the target value. However, when the pressure is above 1.1 MPa and holding time increases from 530 s to 1000 s, a moderate increase in elongation at break is observed. Furthermore, an extended holding time of 1000 s seems to result in a relatively smaller reduction in the target value compared to the moderate setting of (530 s).

Table 3. ANOVA of the elongation at break \( \epsilon_b \).

Nonetheless, for achieving high values of both tensile strength and elongation at break, opting for lower settings of both parameters is deemed preferable. This is in accordance with the macroscopic (Figure 3) and microscopic (Figure 4) view of the laminates. A simultaneous increase in the process pressure and the holding time leads to the fibres and matrix material being pressed out, which causes a displacement of the fibres to the \( 0^\circ \)-axis and thus leads to
DEDICATED THERMOFORM TOOLING MANUFACTURER

VULCAN
Plastics Technology Co Ltd

FAST, RELIABLE, FULLY TESTED BEFORE SHIPPING OUT
COMPETITIVE ADVANTAGE WITH A GLOBAL PRESENCE

DESIGN
Full design services provided

PROTOTYPE
Rapid prototype services

MASS PRODUCTION
Modern facility, latest equipment, fully tested before shipping

VULCANPLASTICS.COM
VULCANPLASTICS-NA.COM
premature failure of the composite. This finding is consistent with Christmann et al. [18] and Kropka et al. [25], but is contrar

Regarding the FVF, no main effects or interaction of the process parameters are detected (Table 4). As detailed earlier, the impregnation quality and compaction of all laminates are excellent (Figure 4). This outcome is likely a consequence of the effective pre-impregnation of the UD-tapes, which in turn contributes to the minimal presence of microscopic voids prior to thermoforming. Additionally, the absence of substantial pressure requirement to eliminate macroscopic voids further attests to the quality of the prepreg material. Consequently, the quality of the prepreg may effect the objectives significantly, as proposed by Kropka et al. [25].

Table 4. ANOVA of the fibre volume fraction (FVF).

<table>
<thead>
<tr>
<th>Effect</th>
<th>Sum of Squares</th>
<th>Degrees of Freedom</th>
<th>Mean Square</th>
<th>F-Value</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding time</td>
<td>21.93</td>
<td>2</td>
<td>10.96</td>
<td>0.89</td>
<td>0.42</td>
</tr>
<tr>
<td>Pressure</td>
<td>61.59</td>
<td>2</td>
<td>30.80</td>
<td>2.50</td>
<td>0.09</td>
</tr>
<tr>
<td>Interaction</td>
<td>34.19</td>
<td>4</td>
<td>8.55</td>
<td>0.69</td>
<td>0.60</td>
</tr>
<tr>
<td>Error</td>
<td>554.17</td>
<td>45</td>
<td>12.31</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>671.87</td>
<td>53</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

3.5. Regression Model and Validation

To predict the resulting mechanical properties of manufactured laminates, regression models are formulated based on the experimental and statistical evaluation of the process parameters. The highest possible values for tensile strength and elongation at break are aimed for within feasible process parameters. Equation (1) offers a solution for the tensile strength $\sigma$ in MPa, depending on the holding time $\tau$ in s and the pressure $p$ in MPa:

$$\sigma = 1088.4 - 0.1277 \cdot \tau - 79.4 \cdot p - 0.443 \cdot \tau \cdot p$$  (1)

Equation (2) describes the predicted target value for the elongation at break $\epsilon_p$ in % affected by the process parameters:

$$\epsilon_p = 2.26 + 5 \cdot 10^{-5} \cdot \tau - 0.16 \cdot p - 4 \cdot 10^{-4} \cdot \tau \cdot p$$  (2)

The subsequent process parameters are set to validate the model for predicting high values of tensile strength and elongation at break:

- holding time $\tau = 200$ s
- pressure $p = 0.3$ MPa

A laminate is fabricated with the aforementioned parameters, followed by the execution of tensile tests. Table 5 presents a comparison between the measurements acquired from the validation samples and the corresponding predicted results. The calculated values exhibit a strong correspondence with the measured results. Both the tensile strength and elongation of the validation samples fall within the confidence intervals (CI) established by the model, while the means are slightly above the predictions. The percentage error between the predicted and measured mean values remains notably low, at 4.8% for the tensile strength and 8.7% for the elongation at break.

4. Conclusions

This paper demonstrates the efficacy of employing statistical methods as a suitable approach for assessing the effects of process parameters in the context of UD-tape thermoforming. A strong interaction is observed between holding time and pressure, resulting in a sudden decrease in tensile strength and elongation at break due to fibre misalignment, which occurs when both parameters are concurrently elevated. This confirms the results of previous studies,

Table 5. Results of the validation for the tensile strength $\sigma$ and elongation at break $\epsilon_p$, with the mean values and standard deviation (SD) compared to the model’s prediction and the corresponding confidence interval (CI) as well as the error in % of the means and predictions. which were determined using other methods [18,25].

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Prediction</th>
<th>CI</th>
<th>Error in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$ in MPa</td>
<td>1049</td>
<td>±40</td>
<td>1012</td>
<td>±201</td>
<td>3.7</td>
</tr>
<tr>
<td>$\epsilon_p$ in %</td>
<td>2.3</td>
<td>±0.6</td>
<td>2.2</td>
<td>±0.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Author Contributions: Conceptualization, J.W., D.N. and L.K.; methodology, J.W.; validation, J.W.; formal analysis, J.W.; investigation, J.W.; resources, L.K.; data curation, J.W.; writing—original draft preparation, J.W.; writing—re-
Lead Technical Article

view and editing, J.W., D.N. and L.K.; visualization, J.W.; supervision, D.N. and L.K.; project administration, J.W. and D.N.; funding acquisition, D.N. and L.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financed with tax funds on the basis of the budget adopted by the Saxon State Parliament via the Sächsische Aufbaubank (SAB) and carried out under the project “SmartHouB” in the frame of M-era.Net program. The publication of the article was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) project number 491193532 and the Chemnitz University of Technology.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to thank the Cetex Institut gGmbH (Chemnitz, Germany) for the provision of the UD-tapes free of charge.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

- ANOVA: Analysis of variance
- BF: Basalt fibre
- CI: Confidence interval
- DOE: Design of experiments
- FRP: Fibre reinforced plastic
- FRTP: Fibre reinforced thermoplastic
- FVF: Fibre volume fraction
- PA 6: Polyamide 6
- PEEK: Polyether ether ketone
- Prepreg: Pre-impregnated material
- SEM: Selective electron microscopy
- SD: Standard deviation
- UD-tape: Unidirectional fibre-reinforced tape

References


5. Cherif, C. Textile Werkstoffe für den Leichtbau; Springer: Berlin/Heidelberg, Germany, 2011. [CrossRef]


Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).
RDF 85 XL
Modular and cost-effective thermoforming system with open tool interface

Extended version for US production requirements
- Enlarged forming area: 31.5” x 36.2”
- Interface for multiple OEM tools
- Sencorp 2500 tool compatibility
- Quick tool change
- Reinforced punching press
- Flexible stacking and EOL solutions

ILLIG North America
Technical Service Center
Indianapolis, IN

ILLIG Maschinenbau GmbH & Co. KG
Headquarters | Germany
www.illig.com
Looking for opportunities to promote your company and reach our targeted audience?

✓ Learn how to reach suppliers, processors, engineers, designers, CEOs and key decision makers.

✓ Check out the brand new SPE Thermoforming Division Media Kit!

✓ SCAN THE QR CODE TO LEARN MORE!

• Print and website opportunities on https://thermoformingdivision.com/
• Sponsored e-newsletter advertising opportunities! NEW
• Sponsored email blasts NEW
• Sponsored webinars NEW
• Promoted social media posts NEW

To apply for Essentials of Management & Leadership in Plastics, go to www.4spe.org/LeadershipEssentials.
HYTAC® materials utilize small microsphere sizes giving customers the ability to polish to a mirror-like finish which will eliminate scratch marks.

While HYTAC’s® low thermal conductivity ensures the heat stays in the sheet, the low CTE ensures part to part consistency.

Depending on which plastic film is being used, CMT has several HYTAC® materials that will help optimize temperature, sheet release, and other factors that can effect part clarity.

We invite you to reach out to our skilled technical team anytime for information and advice on the best way to utilize, polish, machine and run with our HYTAC® materials.

+1.508.226.3901   info@cmtmaterials.com
Thermoforming & Sustainability

Pioneering Sustainable Packaging in Southeast Asia: SIP sets the Standard with 100% rPET Cold Cups

The inception and growth of Surya Indo Plastic (SIP), a thermoforming packaging manufacturer based in Indonesia, reflect a unique journey shaped by technical expertise, commitment to sustainability and a keen understanding of market dynamics, particularly in Indonesia and Southeast Asia. Being the region’s only company dedicated solely to producing 100% recycled PET (rPET) food packaging, by using post-consumer recycled materials rather than creating new plastic, SIP sets the example that packaging can and should be made sustainably. Their purpose is to make a difference through innovation, responsibility, and collaboration. By providing food packaging containing 100% recycled PET, while meeting the highest standards of quality and performance.

This article delves into the company’s origin, development, and market dynamics, providing insights into the challenges and opportunities presented by the Southeast Asian thermoforming packaging market.

Transferring Technology to Indonesia

Established in 2006, SIP was born in the vibrant landscape of Indonesia, an archipelagic country in Southeast Asia, home to the most beautiful and pristine natural environments and known for its unparalleled marine biodiversity. The driving force behind SIP is Dutch founder Rob Smeulders, a serial entrepreneur rooted in thermoform technology with numerous years of experience in the development of thermoformed plastic products. Started from a government project for innovative investment projects in developing countries, the initial years were marked by transferring knowledge and technology to Indonesia, laying the foundation for what would become the leader in rPET packaging in Southeast Asia.

Market Dynamics in Southeast Asia

The Southeast Asian market presents a dynamic landscape marked by rapid urbanization, significant economic growth and changing consumer lifestyles, contributing to an increased demand for packaged goods. The packaging industry, including the thermoforming packaging sector, has witnessed strong growth, especially in beverages and dairy segments. This is powered by the increasing population, rising incomes and increased spending on food and beverages by the surging middle class. Numerous F&B multinational corporations have expanded to Southeast Asia and source their packaging locally. The growth of e-commerce has had a notable impact on the packaging industry as well. The need for durable and secure packaging for online deliveries has driven demand for packaging solutions that can withstand transportation challenges while maintaining product integrity. Innovation and technological advancements in machinery and materials have allowed for more efficient production processes, enhanced product performance and customizable packaging solutions. To succeed in this dynamic environment, companies must continue to be adaptable to new trends and effectively navigate the market challenges and opportunities.

State-of-the-Art Equipment

Pioneering the manufacturing of high-quality PET thermoformed packaging in Indonesia and understanding the stringent requirements of the food packaging industry, SIP strategically invested in cutting-edge technologies to ensure its 100% recyclable PET cups, lids and trays meet the highest standards for food safety, hygiene, and performance. The company operates with thermoforming machines and tooling from the world’s leading experts in high-end thermoforming technology based in Europe. To fulfill the high-quality printing requirements on branded cups, SIP utilizes state-of-the-art printing machines from Netherlands based machinery manufacturer Van Dam. These investments not only strengthened the company’s technical capabilities but also positioned it as a front runner in top quality PET packaging in Southeast Asia, supplying to global F&B brands including Starbucks, Tim Hortons, Dunkin’ Donuts, Nestlé, The Coffee Bean & Tea Leaf and Heineken.

Pioneering Sustainable Packaging

Over time the founder of SIP - an underwater enthusiast and nature lover – witnessed the environmental concerns related to single-use plastic pollution in Southeast Asia and felt the need to take responsibility in this area, to prevent plastic waste from entering our environment. Driven by a commitment to reduce the environmental impact of single-use
plastics, the focus shifted. Recognizing the environmental toll associated with conventional single-use plastics, the bold strategic decision was made to completely move away from virgin PET plastic packaging production and solely provide recycled PET packaging.

Pioneering once more, the changeover to rPET increased the complexity of the production process as the operating window for thermoforming becomes narrower when processing rPET material. By maintaining the right equipment and knowledge to process rPET for thermoforming, SIP successfully embraced a sustainable philosophy and now specializes exclusively in producing 100% recycled PET food packaging derived from post-consumer PET bottles. This boasts numerous environmental benefits, including the reduction in carbon emissions, energy consumption, and landfill waste associated with traditional packaging materials. By adopting a 100% rPET approach and investing in implementing sustainable business practices and initiatives, SIP positions itself as the leading player in the production of high quality, food safe rPET packaging for Southeast Asia’s F&B industry. The company maintains consistent compliance with international quality and hygiene standards through its FSSC 22000, ISO 9001 and HACCP certifications.

**Challenges and Opportunities in the Region**

Plastic pollution has become a major challenge in the region due to the lack of plastic disposal systems and waste management infrastructure. As consumers are becoming more conscious of their choices, this shift in preferences has influenced the plastic packaging market, which has led to an increased focus on sustainable and eco-friendly packaging solutions.

In Indonesia, the absence of a reliable tap water system means that many people rely on alternative water sources, such as bottled water, for their drinking water needs. The predominant packaging material used for bottled water is PET. Due to the widespread consumption of bottled water, there is an abundance of post-consumer PET bottles in the waste stream. While the formal collection of PET is low due to a lack of professional collection and source separation, the informal sector dominates collection, and is driven by a network of waste collectors. The post-consumer PET bottles, when effectively collected and recycled, serve as a valuable feedstock to produce recycled PET material. To tap into this high potential for PET recycling, significant investments are made in PET recycling technology and infrastructure in Indonesia.

This high market potential backed by rising environmental concerns provides opportunities for rPET packaging in Southeast Asia. Pushed by the priority on sustainability from investors in fast-growing F&B brands, government mandates to eliminate single-use plastics, and commitments from global F&B companies to use recycled packaging.

**Combining Innovation and Sustainability**

Understanding the unique challenges and opportunities posed by the Southeast Asian market, SIP’s journey has been characterized by sustainable growth and a commitment to regional environmental stewardship. Recognizing that innovation is key to the future of packaging, substantial investments were made in research and development, focusing on innovations that deliver ease and convenience to customers, offer improved functionality and that reduce environmental impact. Product development, prototyping and tooling maintenance are all managed in-house. The technical team at SIP played a pivotal role in tailoring solutions that not only met stringent environmental standards but also resonated with the local market. The development of strawless lids and special take-away and delivery lids, allowed SIP to further enhance its market position. With another development milestone - 100% recyclable rPET cups featuring PET sealing - the company addresses the challenge of non-recyclable components commonly found in conventional cup designs in Southeast Asia. Every element of this packaging, including the sealing, is fully recyclable. Unlike traditional cups with non-recyclable components, SIP’s cups and sealing film are entirely made of mono material PET, allowing the entire cup to be recycled without any need for complex separation processes, ensuring it can be easily reintegrated into the recycling stream. This simplicity in recycling aligns with the principles of a circular economy, emphasizing the importance of closed-loop systems in sustainable packaging. Combining innovation with sustainability, this represents a significant leap forward in the quest to reduce the ecological footprint of single-use packaging in Southeast Asia.

**Circular Economy Contribution**

SIP works closely with local recyclers to verify that the recycling process meets the highest environmental and ethical standards and to ensure the quality and food safety of materials complies with European standards and directives. The company’s commitment to using 100% recycled content in their packaging encourages a sustainable lifecycle for PET materials. The next step is to close the loop on plastic waste.
by championing a circular economy approach: a waste-free cup system where plastic never becomes waste. In this system used rPET plastic cups and lids are collected, recycled, and transformed into new cups and lids. SIP wants to make a difference through partnerships and collaboration on waste collection and recycling. This approach has led to a successful pilot project together with Starbucks, aiming to implement a closed loop cup-to-cup recycling system in Indonesia. As a reward SIP won the Starbucks Sustainability Excellence Award in 2021. With this award Starbucks Coffee Asia Pacific recognized SIP for its sustainability initiatives, helping to transition to recycled PET food packaging and collaborating on the successful waste management and recycling pilot project in Indonesia.

**Shaping the Future with Every Sip**

By embracing sustainable practices, innovative technologies, and collaborative efforts, SIP is setting a new standard for the thermoforming packaging industry with its commitment to producing high-quality 100% rPET food packaging. As the demand for sustainable solutions grows, this is likely to propel SIP and similar environmentally conscious companies to the forefront of the industry. These pioneers are shaping the narrative of responsible packaging, offering consumers the opportunity to enjoy their favorite cold brews with a side of sustainability. As the industry continues to evolve, SIP sets a compelling example for other manufacturers to follow.

Any questions on this topic? Reach out to SIP’s dedicated team via hello@suryaindoplastic.com, WhatsApp +62 855 7467 1243, or call +62 31 892 1028.
Demonstrating leadership in the progress towards a circular economy, members of the CGF Plastic Waste Coalition of Action have aligned on Golden Design Rules for packaging design to increase the circularity of their packaging portfolios where appropriate. This set of voluntary, independent and time-bound commitments which together reach over 90% of plastic packaging available on the market will create significant value for the industry and wider system. For more information about the Coalition, visit www.tcgfplasticwaste.com.

GOLDEN DESIGN RULE

Increase Value in PET Recycling

- Use transparent and uncoloured PET (preferred), or transparent blue or green in all PET bottles
- Ensure material choice, adhesive choice and size of sleeve or label is not problematic for recycling

PET is polyethylene terephthalate, one of the most commonly used plastic materials. This Golden Design Rule applies to all PET bottles in food and non-food applications, including beverages, home care products, personal care products, and more. Switching from coloured to transparent PET bottles will positively impact supply of high quality recycled PET, and helps ensure only materials that have a viable closed loop recycling pathway are used.

THE SCALE

PET bottles represent 13% of plastic packaging on the market, according to data from Plastics Europe and Eunomia.

GOLDEN DESIGN RULE

Remove Problematic Elements from Packaging

a. No undetectable carbon black
b. No PVC or PVDC

PVC or PVDC is polyvinylidene chloride or polyvinylidene dichloride. It can be problematic if in the recycling stream by disrupting the recycling of some other plastics. It is found in several types of plastic packaging, including meat trays, plastic film around vegetables or blister packs.

c. No EPS or PS

d. No PETG in rigid plastic packaging

PETG is polyethylene terephthalate, and is a contaminant in the PET recycling stream which lowers the value of recycled PET materials. It is found in, for example, drinking bottles and cooking oil containers. This element applies to all single-use rigid packaging materials in the consumer goods market.

e. No oxo-degradable

Finally, oxo-degradable plastics contribute to microplastic pollution and are not suited for long-term reuse, recycling at scale or composting. Uses include shrink and stretch film, carrier bags, blister packs, bottles, labels and caps. This element of Golden Design Rule 2 applies to all oxo-degradable plastics as defined by CEN, the European Standards authority, unless use is required by law.

THE SCALE

According to the Ellen MacArthur Foundation, these problematic elements are present in over 10% of plastic packaging.

1) Undetectable means by commonly used sortation technologies; 2) Exception: Where barrier protections (for UV light, CO2 or O2) are required for product shelf life and other solutions (e.g., full-body sleeves) are not possible; 3) Including phase out of PETG and PLA labels/sleeves, non-water soluble/dispersible adhesives and sleeves that cover more than 75% of bottle (unless proven not to limit the recyclability of the product); 4) Exception: Unless proven not to limit the recyclability of the product (e.g., cPET, sleeves that detach during recycling processes prior to optical sorting); 5) Exception: Small non-recyclable packs exempt.
Solar Products custom heater lengths provide more coverage with fewer connections and less maintenance than ceramic heaters or quartz tubes. We provide better:

- Uniformity
- Control
- Repeatability

Design or retrofit your process today with Solar Products Electric Infrared Heaters. Call 1 (800) 616-2601 or visit our website at www.solarproducts.com

Did You Know?
The SPE Foundation offers numerous scholarships to students who have demonstrated or expressed an interest in the plastics industry?

Visit www.4spe.org/foundation for more information.
Since 1965, our mission:
The design and manufacture of the most advanced and energy efficient thermoforming machines in the world, for the processing of thermoplastic materials.

O.M.G. srl currently offers a wide variety of standard series machines for both thin and heavy gauge applications, as well as highly customized complete packaging lines, and custom thermoforming systems.

ENERGY EFFICIENT, ALL ELECTRIC SERVO DRIVE MOVEMENTS

From large to small size inline machines, Cut-in-place machines, to custom thermoforming lines and systems for the processing of all types of thermoformable plastics, including PET, PLA, PS, PP,EVOH, OPS, HIPS, EPS, PE, PVC, PC, PE, HDPE and many more...

O.M.G. can provide a cost effective solution for your everyday challenges!!

OPTIONS:
Edge preheater system, drum pre-heaters for running PP, material grinders, cut-in-place presses, punch & die presses, additional modules for after the press automation, single or double sided A/B stacking robots, complete tooling packages and much more...

Call O.M.G. for all your thermoforming application needs!!
### Board of Directors

#### EDUCATION COMMITTEE

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Browning</td>
<td>McConnell Company</td>
<td>P.O. Box 450633</td>
<td>770.939.4497</td>
<td><a href="mailto:robert@thermoformingmc.com">robert@thermoformingmc.com</a></td>
</tr>
<tr>
<td>Evan Gilham</td>
<td>Productive Plastics</td>
<td>103 W. Park Drive</td>
<td>856-778-4300</td>
<td><a href="mailto:EGilham@productivecompanies.com">EGilham@productivecompanies.com</a></td>
</tr>
<tr>
<td>Erich Kaintz</td>
<td>SAY Plastics</td>
<td>165 Oak Lane</td>
<td></td>
<td><a href="mailto:erich.kaintz@gmail.com">erich.kaintz@gmail.com</a></td>
</tr>
<tr>
<td>Matt O'Hagan</td>
<td>Plastics Unlimited, Inc.</td>
<td>303 1st St. N.W.</td>
<td>563.589.4752</td>
<td><a href="mailto:TravisK@plasticsunlimited.com">TravisK@plasticsunlimited.com</a></td>
</tr>
<tr>
<td>Travis Kieffer</td>
<td>Plastics Unlimited, Inc.</td>
<td>1317 Battalion Drive</td>
<td>248.760.8590</td>
<td><a href="mailto:TravisK@plasticsunlimited.com">TravisK@plasticsunlimited.com</a></td>
</tr>
<tr>
<td>Matt O'Hagan</td>
<td>LyondellBasell</td>
<td>1317 Battalion Drive</td>
<td></td>
<td><a href="mailto:matt.o.hagan@lyondellbasell.com">matt.o.hagan@lyondellbasell.com</a></td>
</tr>
<tr>
<td>Ed Probst</td>
<td>Probst Plastics Consulting</td>
<td>P.O. Box 26365</td>
<td>414.476.3096</td>
<td><a href="mailto:ed.probst@probstplastics.com">ed.probst@probstplastics.com</a></td>
</tr>
<tr>
<td>Dan Sproles (Chair)</td>
<td>Sproles Business Consulting</td>
<td>5210 Canton Street</td>
<td>574.747.7997</td>
<td><a href="mailto:dan@sprolesbusinessconsulting.com">dan@sprolesbusinessconsulting.com</a></td>
</tr>
<tr>
<td>Renee Vinsick</td>
<td>Primex Corporation</td>
<td>4164 Lake Ocone Drive</td>
<td>706.346.2786</td>
<td><a href="mailto:rvinick@primexplastics.com">rvinick@primexplastics.com</a></td>
</tr>
</tbody>
</table>

#### PROMOTIONS COMMITTEE

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steve Zamprelli</td>
<td>Formed Plastics, Inc.</td>
<td>297 Stonehinge Lane</td>
<td>516.334.2300</td>
<td><a href="mailto:s.zamprelli@formedplastics.com">s.zamprelli@formedplastics.com</a></td>
</tr>
<tr>
<td>Brian Golden</td>
<td>Lacerta Group</td>
<td>360 Forbes Blvd</td>
<td>508-861-6761</td>
<td><a href="mailto:goldenbrian02@gmail.com">goldenbrian02@gmail.com</a></td>
</tr>
<tr>
<td>Roger P. Jean</td>
<td>Simona PMC</td>
<td>PO Box 1605</td>
<td>567.208.9758</td>
<td><a href="mailto:Roger.Jean@simona-pmc.com">Roger.Jean@simona-pmc.com</a></td>
</tr>
<tr>
<td>Phillip Karig</td>
<td>Mathelin Bay Associates LLC</td>
<td>11939 Manchester Road #148</td>
<td>314.630.8384</td>
<td><a href="mailto:karig@mathelinbay.com">karig@mathelinbay.com</a></td>
</tr>
<tr>
<td>Todd Harrell (Chair)</td>
<td>Plastics Machinery Group, Inc.</td>
<td>5455 Perkins Road</td>
<td>440.498.4000</td>
<td><a href="mailto:toddh@plasticsmg.com">toddh@plasticsmg.com</a></td>
</tr>
<tr>
<td>Steven Clark</td>
<td>Monark Equipment</td>
<td>PO Box 335</td>
<td>989.662.7250</td>
<td><a href="mailto:sclark@monark-equip.com">sclark@monark-equip.com</a></td>
</tr>
<tr>
<td>Owen Dow</td>
<td>Kydex</td>
<td>6685 Low Street</td>
<td>616-835-2493</td>
<td><a href="mailto:dowo@kydex.com">dowo@kydex.com</a></td>
</tr>
<tr>
<td>R&amp;D COMMITTEE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>James Longi</td>
<td>MAAC Machinery</td>
<td>590 Tower Blvd.</td>
<td>630.665.1700</td>
<td><a href="mailto:jalongi@maacmachinery.com">jalongi@maacmachinery.com</a></td>
</tr>
<tr>
<td>Patrick Castro</td>
<td>Electro-General Plastics</td>
<td>6200 Enterprise Parkway</td>
<td>845-658-9200</td>
<td><a href="mailto:aletsea@usheco.com">aletsea@usheco.com</a></td>
</tr>
<tr>
<td>Juliet Goff</td>
<td>Kal Plastics</td>
<td>2050 East 48th Street</td>
<td>567-525-4924</td>
<td><a href="mailto:eric.short@simona-pmc.com">eric.short@simona-pmc.com</a></td>
</tr>
<tr>
<td>Paul Uphaus</td>
<td>Primex Plastics</td>
<td>4164 Lake Ocone Drive</td>
<td>1.800.935.9272</td>
<td><a href="mailto:puphaus@primexplastics.com">puphaus@primexplastics.com</a></td>
</tr>
<tr>
<td>Brian Winton</td>
<td>PTi</td>
<td>2655 White Oak Circle</td>
<td>630-585-5900</td>
<td><a href="mailto:bwinton@ptiextruders.com">bwinton@ptiextruders.com</a></td>
</tr>
</tbody>
</table>

#### DIRECTORS EMERITI

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lola Carere</td>
<td>153 Gardens Way</td>
<td>Apartment D</td>
<td>770.883.7055</td>
<td><a href="mailto:carerelola@comcast.net">carerelola@comcast.net</a></td>
</tr>
<tr>
<td>Richard Freeman</td>
<td>221 Coldbrook Lane</td>
<td>Soquel, CA 95073</td>
<td>510.651.9996</td>
<td><a href="mailto:rfree@freetechplastics.com">rfree@freetechplastics.com</a></td>
</tr>
<tr>
<td>Steve Hasselbach</td>
<td>CMI Plastics</td>
<td>222 Pepsi Way</td>
<td>252.746.2171</td>
<td><a href="mailto:steve@cmiplastics.com">steve@cmiplastics.com</a></td>
</tr>
<tr>
<td>Donald Hyton</td>
<td>McConnell Company</td>
<td>646 Holyfield Highway</td>
<td>678.772.5008</td>
<td><a href="mailto:don@thermoformingmc.com">don@thermoformingmc.com</a></td>
</tr>
</tbody>
</table>

#### R&D COMMITTEE

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>James Alongi</td>
<td>MAAC Machinery</td>
<td>590 Tower Blvd.</td>
<td>630.665.1700</td>
<td><a href="mailto:jalongi@maacmachinery.com">jalongi@maacmachinery.com</a></td>
</tr>
<tr>
<td>Patrick Castro</td>
<td>Electro-General Plastics</td>
<td>6200 Enterprise Parkway</td>
<td>845-658-9200</td>
<td><a href="mailto:aletsea@usheco.com">aletsea@usheco.com</a></td>
</tr>
<tr>
<td>Juliet Goff</td>
<td>Kal Plastics</td>
<td>2050 East 48th Street</td>
<td>567-525-4924</td>
<td><a href="mailto:eric.short@simona-pmc.com">eric.short@simona-pmc.com</a></td>
</tr>
<tr>
<td>Roger Kipp</td>
<td>Roger C. Kipp Consulting</td>
<td>3C Owens Landing Court</td>
<td>717.521.9254</td>
<td><a href="mailto:srkipp@msn.com">srkipp@msn.com</a></td>
</tr>
<tr>
<td>Renee Vinsick</td>
<td>Primex Corporation</td>
<td>4164 Lake Ocone Drive</td>
<td>706.346.2786</td>
<td><a href="mailto:gmathis224@aol.com">gmathis224@aol.com</a></td>
</tr>
</tbody>
</table>

#### PROMOTIONS COMMITTEE

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jim Arnet</td>
<td>Hagans Plastics Co.</td>
<td>121 W. Rock Island Road</td>
<td>972.974.3516</td>
<td><a href="mailto:jarnet@hagansus.com">jarnet@hagansus.com</a></td>
</tr>
<tr>
<td>Dennis Lemmon</td>
<td>OMG</td>
<td>4213 CO RD N30</td>
<td>419-212-1562</td>
<td><a href="mailto:dlemmon007@gmail.com">dlemmon007@gmail.com</a></td>
</tr>
<tr>
<td>Ian Munnoch (Chair)</td>
<td>MSA Components, Inc.</td>
<td>N7908 Dahlk Road</td>
<td>812.322.5080</td>
<td><a href="mailto:munnoch@msacomponents.com">munnoch@msacomponents.com</a></td>
</tr>
<tr>
<td>Gordy Murphy</td>
<td>LINDAR Corporation</td>
<td>7789 Hastings Road</td>
<td>218-829-3457</td>
<td><a href="mailto:gordy@lindarcorp.com">gordy@lindarcorp.com</a></td>
</tr>
<tr>
<td>Alethea Schaeffer</td>
<td>Ushcco, Inc.</td>
<td>2138 Maple Hill Road</td>
<td>770.772.5008</td>
<td><a href="mailto:don@thermoformingmc.com">don@thermoformingmc.com</a></td>
</tr>
<tr>
<td>Juliet Goff</td>
<td>Kal Plastics</td>
<td>2050 East 48th Street</td>
<td>567-525-4924</td>
<td><a href="mailto:eric.short@simona-pmc.com">eric.short@simona-pmc.com</a></td>
</tr>
</tbody>
</table>

### DIRECTORS EMERITI

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lola Carere</td>
<td>153 Gardens Way</td>
<td>Apartment D</td>
<td>770.883.7055</td>
<td><a href="mailto:carerelola@comcast.net">carerelola@comcast.net</a></td>
</tr>
<tr>
<td>Richard Freeman</td>
<td>221 Coldbrook Lane</td>
<td>Soquel, CA 95073</td>
<td>510.651.9996</td>
<td><a href="mailto:rfree@freetechplastics.com">rfree@freetechplastics.com</a></td>
</tr>
<tr>
<td>Steve Hasselbach</td>
<td>CMI Plastics</td>
<td>222 Pepsi Way</td>
<td>252.746.2171</td>
<td><a href="mailto:steve@cmiplastics.com">steve@cmiplastics.com</a></td>
</tr>
<tr>
<td>Donald Hyton</td>
<td>McConnell Company</td>
<td>646 Holyfield Highway</td>
<td>678.772.5008</td>
<td><a href="mailto:don@thermoformingmc.com">don@thermoformingmc.com</a></td>
</tr>
</tbody>
</table>

#### DIRECTORS EMERITI

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Address</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renee Vinsick</td>
<td>Primex Corporation</td>
<td>4164 Lake Ocone Drive</td>
<td>706.346.2786</td>
<td><a href="mailto:gmathis224@aol.com">gmathis224@aol.com</a></td>
</tr>
</tbody>
</table>

---
Thermoforming Division Membership Benefits

- Access to industry knowledge from one central location: www.thermoformingdivision.com.
- Subscription to Thermoforming Quarterly, voted “Publication of the Year” by SPE National.
- Exposure to new ideas and trends from across the globe.
- New and innovative part design at the Parts Competition.
- Open dialogue with the entire industry at the annual conference.
- Discounts, discounts, discounts on books, seminars and conferences.
- For managers: workshops and presentations tailored specifically to the needs of your operators.
- For operators: workshops and presentations that will send you home with new tools to improve your performance, make your job easier and help the company's bottom line.

Join today!
These sponsors enable us to publish *SPE Thermoforming Quarterly*

- Assured Automation ........................................42
- Brown Machine Group ............Inside Back Cover
- CMT Materials ..................................................33
- ILLIG ...........................................................31
- MAAC Machinery .............................................10
- OMG..................................................................39
- Plastics Machinery Group ..........Back Cover
- PMC/Simona .....................................................13
- PMG Business Services ....................................38
- Profile Plastics ..............................................10
- PTi Extruders ..............................................Inside Front Cover
- Sekisui Polymer Innovations, LLC ..........7
- Senoplast ........................................................42
- Solar Products ..............................................38
- Thermoformer Parts Suppliers .............15
- TSL ..............................................................23
- Vulcan Plastics ..............................................26

**SANITARY PLASTIC SHEETS**

SenaSAN® A45-LAM


SenaSAN® high quality plastic sheet laminates for shower walls:
- Gorgeous bathroom designs
- Highly durable and easy to install
- Proprietary designs available
- Shown Calacutta Marble gray and gold, other textures available

www.senoplast.com

**INTRODUCING THE NEW BMG.**

It’s what the best-dressed thermoformer is wearing this year.

The new BMG is here. One brand, one BMG.

We have integrated a group of highly respected, leading global brands—Brown, Lyle, GN, Freeman, and NAS—to form one global company. Together we are BMG, one BMG.

We bring you more experience, innovation, customer service, and technical support than any other company in the US or the world. We are dedicated to delivering the most innovative and sustainable turnkey and custom solutions that will improve reliability, productivity, and profitability.

The new BMG continues its commitment to assisting customers in need of thermoforming packaging and automation solutions with an acute awareness and attention to detail—providing end-to-end solutions while taking into account the need for shorter developmental timelines, increased ROI, reduced cost of doing business, and an unparalleled service commitment rivaled by none. All under one brand, one BMG.

LEARN MORE about how BMG is leading the future of sustainable thermoformed product and packaging technology at OneBMG.com.

**ASSURED AUTOMATION**

We Make Valve Automation Easy

Reduce Downtime & Maintenance with Compact, Fast-Acting, High-Cycle Valves

**VA Series**

Angle Valves

**RSG Series**

Thermoforming OEM’s and factories all over the world are turning to Assured Automation’s Compact On/Off Valves to improve their machines’ reliability and increase productivity.

For complete product information visit: assuredautomation.com/SPE

Follow the SPE Thermoforming Division on X / Twitter @SPEThermo
INTRODUCING THE NEW BMG.

It’s what the best-dressed thermoformer is wearing this year.

The new BMG is here. One brand, one BMG.

We have integrated a group of highly respected, leading global brands — Brown, Lyle, GN, Freeman, and NAS — to form one global company. Together we are BMG, one BMG. We bring you more experience, innovation, customer service, and technical support than any other company in the US or the world. We are dedicated to delivering the most innovative and sustainable turnkey and custom solutions that will improve reliability, productivity, and profitability.

The new BMG continues its commitment to assisting customers in need of thermoforming packaging and automation solutions with an acute awareness and attention to detail — providing end-to-end solutions while taking into account the need for shorter developmental timelines, increased ROI, reduced cost of doing business, and an unparalleled service commitment rivaled by none. All under one brand, one BMG. LEARN MORE about how BMG is leading the future of sustainable thermoformed product and packaging technology at OneBMG.com.
Comi ACF 820 (running at NPE)

MAAC 6 x 10 in stock

*Second Hand Primary and Auxiliary Equipment
*New in Stock Thermofomers from MAAC and COMI PACKAGING
*New in Stock Blowmolders from MECCANOPLASTICA
*New in Stock Chillers, Temperature Controllers, Grinders, Shredders, and Vacuum Pumps
*Full Remanufacturing Services For: BLOWMOLDERS, EXTRUDERS AND GRANULATORS
*Full time Thermoforming and Blowmolding Techicians on Staff
*Offering parts and service for SENCORP THERMOFORMERS (PMG not affiliated with SencorpWhite)

PMG is your Full Service Equipment Supplier

Rebuild Program

Conair Grinder

Sterling Blow Molder

Blow Molding  Thermoforming  Injection  Extrusion  Size Reduction

“Highest Quality Equipment and Services in the Industry”