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NEW Comi ACF 980 4 Station 36" x 33"

NEW Comi ACF 820 3 Station

NEW MAAC 6' x 10' in Stock

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Cover photo courtesy of Hannes Jacob

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As I step into the role of Division Chair,

I want to thank all of the individuals that came before me. I have been fortunate over the last 10 years on the board to have learned a great deal from their leadership. Reflecting on my 35 years in the industry, there are many people that have had a positive influence on me. Not just customers and suppliers, but also competitors. That is what is so nice about being part of the board. This is a pretty small and amazing industry that we all work in. We are all fortunate enough to have careers that support our families and the privilege to work with - and even compete against - our friends. We are all in this together and our goal is the same: to support and grow the industry that we depend upon.

When I first started attending the SPE Thermoforming Conference, I was a young man, full of energy in my 20s, with dark brown hair. Now I am gray and walk with a bit of a limp! Battle scars that I wear with pride. Over those years I had friends and mentors helping me along my path. In 1991, I met Jim Armor for the first time. Many remember Jim with fondness. I thought of him as a true mentor. A tough one, but also a fair one. Some of my good friends that moved on to work for competitors remain friends to this day. I see more and more of the so called “gray beards” retiring. Let me personally say that they are missed.

We have a real challenge in the years to come. Most of us have experienced the difficulties of finding young employees that are willing to spend the time to work their way up through the ranks. That time allows them to gain knowledge that will support them and their employees for the years to come. We’ve had to become our own technical support team because the knowledge that was so prevalent in the industry has gone away. Even our board struggles getting the younger generation to join. It is critical to have their input so we can be prepared for the future while honoring the past.

Which brings me to some exciting news. Next year’s conference will mark the 30th in the Division’s history. Fittingly enough, the theme is “Navigating the Future, Honoring the Past”. We are mixing things up a bit in 2025. The conference will be held in May at the Cobb Galleria Center in Atlanta. We had always held the conference in the fall, but autumn has become a very crowded space for plastics industry events. The conferences have become smaller over the years with more specialization across technical divisions, but also in the larger plastics and chemicals industries. We also want to explore a more intimate ballroom setting located at resort properties. Hopefully, that will incentivize attendees to bring their families along. We always enjoy meeting spouses and families. We are excited about the future, and hope to continue to support thermoforming for many years to come.

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 ...

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Watttron raises €12m to advance sustainable packaging solutions

The investment will expand the company’s operations into the US and Asian markets.

March 28, 2024, packaging-gateway.com

Watttron, a Germany-based digital temperature control systems provider, has successfully secured €12m ($10.27m) in a Series B funding round.

The funding round was led by the Circular Innovation Fund, a global venture capital fund, and the European Circular Bioeconomy Fund (ECBF), emphasising their respective global commitments to eco-friendly advancements in the packaging sector.

The investment will facilitate the development of Watttron’s technical capabilities for sustainable packaging solutions.

It will also support the expansion of these solutions into the US and Asian markets.

Watttron’s long-term partners, including Technologie-gründerfonds Sachsen, Constancia New Business, SKion, and BA Rico Kleinhempel, along with the new investors, are supporting Watttron’s sustainability mission.

Watttron CEO Marcus Stein said: “Sustainability is more than just a trend; it’s a commitment we take seriously. We believe sustainable practices will shape the future of the packaging industry, and we are excited to contribute with the support of ECBF and the Circular Innovation Fund.”

Established in 2016, Watttron specialises in developing digital heating systems for the packaging industry, with a strong emphasis on sustainability.

The company invented cera2seal and cera2heat, which assist the flexible packaging industry in processing eco-friendly materials efficiently and with energy savings, without compromising productivity or quality.

ECBF investment director Guillaume Gras said: “Watttron’s technology represents a quantum leap in sustainable packaging, drastically cutting carbon emissions by reducing material and energy usage, and enabling the use of monomaterials, which significantly enhances recyclability.

“Simultaneously enhancing production efficiency and cost-effectiveness, this investment signifies more than financial support; it’s a commitment to pioneering a greener, more efficient future in the packaging industry.”

Nefab Group acquires Precision Formed Plastics, Inc. to expand its offering of sustainable thermoformed cushioning solutions

STOCKHOLM and IRVING, Texas, April 2, 2024 / PRNewswire

April 1st, 2024 - Nefab Group, through Nefab Packaging, Inc. USA, has acquired Plastiform, Inc. and its subsidiary Precision Formed Plastics, Inc., a Texas based group specializing in high quality thermoformed cushioning solutions, made from recycled plastics, to further strengthen its global market position and commitment to saving resources in supply chains.

“Through this important acquisition, we further strengthen Nefab’s market position in the Americas and capability to support our customer in key segments such as Datacom and Cloud with thermoformed cushioning trays made from recycled plastics. Our strengthened market presence, in-house production capacity, and extended portfolio of sustainable solutions will enable us to serve our customers even better.”, says Per Öhagen, President and CEO of Nefab Group.

In the last couple of years, Nefab has acquired a number of leading companies in the areas of thermoforming and sustainable packaging solutions, in both the Americas and Europe. Thermoformed solutions provide the quality, precision and flexibility required in many industry segments when replacing less sustainable packaging materials e.g. foam. Moreover, the thermoformed solutions made from recycled plastics provide the circularity required from a sustainability perspective.

With the addition of Precision Formed Plastics, with modern production facilities in Dallas, Texas, Nefab’s global portfolio and know-how in the production of thermoformed solutions is further strengthened. Precision Formed Plastics special-
Together we can shape the future of sustainable design
izes in high quality and precise plastic cushioning solutions and has more than 50 years of history supporting leading industry customers with high quality and sustainable packaging products.

“We are honored and excited to join the Nefab Group and support their purpose and value proposition on a global scale in general and the Americas in particular. Nefab’s market presence, customer-focus, and strong commitment to saving resources aligns well with our values, and we we look forward to continuing our growth journey together in the Americas and globally.” says Jeff Jones, Owner and MD of Precision Formed Plastics, Inc.

“We with this strategic acquisition we further strengthen our ability to serve American and global customers with high quality packaging solutions that generate both financial and environmental savings. We are happy to welcome the Precision Formed Plastics team to the Nefab Group,” Per Öhagen concludes.

With the acquisition of Precision Formed Plastics, the Nefab Group will have over 4,750 employees spread across 38 countries, with a yearly turnover of over 10B SEK.

ILLIG Enters Insolvency, Will Continue Regular Operations During Restructuring

By Karen Laird, Editor, Sustainable Plastics

April 11, 2024 – Illig Maschinenbau GmbH, a German thermoforming machinery supplier, has entered insolvency proceedings in self-administration.

The court in Heilbronn, Germany, the site of Illig’s headquarters, accepted an application to begin the process.

In recent years, the company has battled extremely high costs due to inflation, interest rates and energy prices, the after-effects of the coronavirus pandemic and international conflicts, all of which have weakened the company’s financial situation. Those issues were exacerbated by the lack of investment in thermoforming and packaging machinery. Customers have become skittish due to the interest rate developments and political conditions at national and international level, are reluctant to invest.

Attempts to attract investments from an external source have been unsuccessful.

Insolvency in self-administration is comparable to a Chapter 11 reorganization in the U.S. It allows the company to restructure its finances and business, a process Illig had already undertaken outside the court through a comprehensive strategy program. The project aims to establish a clearer production and supply chain strategy with an innovative technology focus and more intensive market development.

Unlike in standard insolvency proceedings, companies in self-administration do not have an insolvency administrator. The company can continue to be led by its management, CEO Carsten Strenger and Jürgen Lochner, chief sales office and chief technology officer. To protect creditors’ interests, the court appoints a supervisor who is tasked with ensuring compliance with the rules set out in the Insolvency Code.

The court appointed Tibor Braun of IBK Illig Braun Kirschnek in Heilbronn as supervisor. Illig’s management will be supported by restructuring expert Jochen Sedlitz from Grub Brugger, a law firm in Stuttgart.

The restructuring process “should not result in any restrictions for customers,” Illig said in a news release. The company will continue to operate as usual and plans to attend upcoming global events market platforms such as ChinaPlas 2024 and NPE2024 in Orlando, Fla., in May. Illig will be at Booth W7761.

Illig marked its 75th anniversary in 2021.

Looking ahead, Illig said its shareholders and management are convinced that packaging will continue to be an indispensable component of branded products and that it will fulfill even more functions, especially in the area of product protection. At the same time, sustainability will play an ever-growing role in product perception.

Illig also said it will respond to those megatrends with the support of its partners in the market. The company has an extensive “installed base” and is developing a patented new non-plastic packaging project it will launch in 2025.

Illig Group operates eight service subsidiaries worldwide and has two production sites, one in Germany and one in Romania.
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www.senoplast.com
Thermoformer to Reopen Shuttered Former Genpak Facility in OH

By Jim Johnson, Senior Reporter, Plastics News

April 12, 2024 – A California thermoformer is expanding to the east by resurrecting an Ohio manufacturing plant that closed last year.

Nuvo Packaging LLC, which is associated with PinnPack Capital Holdings of Oxnard, Calif., expects to create 100 jobs by reopening the former Genpak LLC thermoforming plant in Columbus, Ohio, state economic development officials said.

Nuvo is investing $10 million in the facility, according to JobsOhio, a state economic development agency that helped with the project.

“The decision to locate the new operation in Columbus marks a significant milestone for Nuvo Packaging and represents a strategic expansion to serve its growing customer base better,” JobsOhio said on its website.

“Columbus offers a strategic location and a skilled workforce, making it an ideal choice for our expansion efforts. We are confident that our investment in this new facility will not only enable us to better serve our clients, but also contribute to the economic growth of the region,” PinnPack and Nuvo Packaging CEO Ira Maroofian said in a statement.

The Ohio Tax Credit Authority approved a 1.19 percent tax credit for eight years for the creation of $5 million in new annual payroll, according to a fact sheet from the Ohio Department of Development.

Ohio competed with Mississippi, Pennsylvania and Texas for this Nuvo’s expansion efforts.

“With its ideal location, Nuvo Packaging’s newest manufacturing operations will provide recyclable food packaging for the Eastern United States with talent from Ohio,” JobsOhio CEO J.P. Nauseef said in a statement.
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Global Dispatches: 13th European Thermoforming Conference

Though the city of Amsterdam will celebrate its 750th birthday next year, preparations for the festivities could be seen throughout the bike-filled metropolis in April 2024. Nearly 300 delegates convened at the city’s historic Bourse for the 13th European Thermoforming Conference. The Bourse, known as The Beurs van Berlage, is an historic building in the city center that served as a commodity exchange in the early 20th century. It was designed by architect Hendrik Petrus Berlage and constructed between 1896 and 1903 in a Renaissance Revival style.

The Beurs van Berlage operated as a commodity exchange until the late 1990s. After closing, it underwent renovation and today serves as a venue for exhibitions, concerts, conferences, and other events. The building is considered one of the masterpieces of the Amsterdam School architectural style and a landmark in the city center. Its innovative design and use of modern materials like iron and glass influenced many later architects and buildings. The building featured a large trading floor with a steel and glass barrel-vaulted roof, as well as offices and meeting rooms. Despite an apparent dearth of polymeric materials in the construction of the building (we didn’t get to check the underground piping for PVC, PEX, or HDPE), thermoformers from all over the world made sure that plastics was the topic du jour over the 2-day event.

The organizers made good use of the traditional split in thermoforming categories, heavy & thin, to arrange a wide range of topics while still ensuring a cohesive gathering in several keynotes and a general session. Attendees were treated to an insightful and witty keynote by Guido Thys, a well-known professional speaker from Belgium. With images including medieval impalements, his grandmother drinking beer into her late 80s, and ironic looks in our collective rear-view mirror, Thys was able to knit together an impressive narrative that, overly simplified here, suggested our ability to manage, accept, and adapt to change is more important now than ever. Plastic converters facing threats from material substitution were put on notice.

Running in Circles

Dr. Ingemar Buhler, Managing Director of Plastics Europe, a leading European trade association, offered some perceptive sunburst diagrams that highlighted the plastics eco-system within planetary boundaries to 2030. The global demand for plastics (all materials, in fact) is growing while planetary resources are limited. The paradox for plastics, of course, is that they generally enable more efficient use of other resources. That said, the potential to increase the use of bio-based and circular plastics remains attractive and will continue to attract investment.

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1 Carbon emissions for production of 1kg of PS and PP respectively: 2.03 and 1.63 CO2eq (LCA for Experts (GaBi) database) (ref. Synthomer ppt at ETD Amsterdam 4/24)
As if to prove these points, Dr. Gerard Liraut of global automotive giant Renault Group, illustrated his team’s march toward decarbonization which includes the increased use of bio-based and recycled materials. Beyond materials, Renault has created a “Refactory” at one of its historic manufacturing sites. The goal, according to the company, is “to reinvent ourselves to develop accessible, sustainable, carbon-free mobility solutions for everyone.” The Refactory is considered to be the first of its kind – a circular economy factory – and encourages collaboration with start-ups and strategic partners. The 11,000 sq m facility will enable the repair and refurbishment of almost 45,000 vehicles each year starting in 2024.

**Thin Gauge: PS vs PP**

Despite the many benefits of polystyrene, including its strength and stiffness properties, its processability, and its CO2 permeability (especially important in dairy packaging where it is widely used), the material continues to suffer from both an image problem (perception) and a lack of recycling (reality). It is thus a challenge for companies like INEOS to convince markets and the public that PS should not be de-selected or uniformly replaced. Dr. Frank Eisentrager of INEOS Styrolution was tasked with presenting the technology of recycling PS. After reviewing the material properties, including a compelling slide on the low diffusivity of PS (relevant for contamination issues in commingled plastic waste streams), Eisentrager offered an overview of a new €100MM recycling venture in Antwerp, Belgium that will eventually recycle 65,000T of both styrenics and olefins via depolymerization. Given the recent news that another high-profile PS recycling venture failed (Aygilyx / Regenyx in Oregon), it seems that the pathway for PS recovery and recycling faces continued headwinds.

As if to pile on the pressure, the next speaker, Mr. Synco de Vogel of Synthomer, a spin-off from Eastman, presented data on new applications of their Plastvance™ modifier to polypropylene. Any thermoformer or form/fill/sealer converter who has tried to switch from PS to PP is painfully aware that it is not a simple drop-in solution. Material performance, especially shrinkage, is significantly different leading to changes in machine settings, tooling, and plug design. Efforts continue apace, however, because the pressure to find a replacement for PS that can be easily recycled in existing streams is not decreasing. According to de Vogel, using Plastvance can both improve top load strength (through a 38% weight reduction) and lower CO2 emissions by up to 48% thanks to lower weight and the overall lower carbon emissions of PP compared to PS. Though impressive, PP also suffers from lack of a wide recovery and a recycling network. And this is before we discuss the ongoing challenges of creating food-grade PP from recycle. Neither Rome nor Amsterdam were built in a day, however, and these problems continue to attract some of the brightest minds in the industry.

The European Thermoforming Division enjoys strong support from a wide range of sponsors and volunteers, and this was reflected in the diverse array of short, commercial presentations from upstream and downstream providers. This condensed program allows for both a critical mass of presentations and an insight into the current state of technology, materials, and tooling for the converters in the audience.

**Heavy Gauge: EU vs US**

It was George Bernhard Shaw who first said that the British and the Americans were separated by a common language and there are traces of this in the European vs. American approaches to thermoforming, usually on the heavy-gauge side of the fence.

The links between the US and EU thermoforming divisions have been strong for over 30 years now and a new generation of volunteer leaders is ensuring that the connections continue to blossom each year. Look for future collaborations in the areas of webinars and joint programming on both sides of the Atlantic.
I found all the sessions that I attended to be interesting, educational, and memorable. The heavy gauge sessions covered topics from conversion projects to meeting the needs of modern farmers. Mr. Florent Voiry provided a case study and explained how his company, Kubota, is facing these challenges and providing solutions to meet strict compliance.

Emma Hockley of Big Bear, a heavy gauge processor in Great Britain, took us through the challenges they faced when a big competitor was destroyed in a horrific fire. They stepped up to help and work with their competitors’ customers. The challenges they faced were daunting. They had to expand double capacity very quickly. They faced many issues head on and learned so much. The big takeaways that resonate in my mind were Emma’s words, “don’t be afraid to fail”. Failure is how we grow. What made this story even more relatable to many of us in the States is that Big Bear uses US-style heavy gauge forming equipment. They stepped up to help for their competitor and for the industry. They did what they could to keep things moving for their own customers and this new customer base. This unprecedented situation was either going to make or break them.

Emma was a tough act to follow, but it was then my turn to have the honor to speak to many about a case study in the US on pressure and vacuum forming. I spoke about a project that was a parts competition gold award winner during the SPE Thermoforming conference in Cleveland. The project was done by Formed Plastics, a heavy gauge thermoformer in New York. My topic was “The Perfect Storm”. 

The final session for heavy gauge was a case study conducted by Westlake Plastics, a material supplier, and Plastiform, a heavy gauge thermoform processor in France. They showed that processing lightweight composite sheet is possible and practical using conventional forming equipment. This was also very relatable to US processors because the equipment was a MAAC single station former. We saw videos of the sheet being formed on male and female tools. There is much more to share on this, and ETD is considering working with SPE TD to offer this information.

A very rewarding experience for me was being honored to speak to the large group that included so many industry heavyweights and renowned people in our international industry. After my session, I was pleasantly surprised that so many people came up to me to ask me questions and to compliment my company on the work it is doing. My team back home was so proud to hear this. This presentation opened the door to many new friendships and awareness of Formed Plastics and our capabilities. I will cherish this event and the people I met.

Steve Zamprelli, Formed Plastics, Inc.
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Keynote presentation by Gerard Liraut of Renault Group

Evie Vens of MCC Verstraete presents on IML decoration for PP and PET packaging

L to R: ETD Chair, Sven Engelmann; SPE TF Prior Chair, Steve Zamprelli; ETD Committee Member, Mauro Fae

R: Mark Strachan, CEO OMV Technologies; Conor Carlin, SPE President; Marek Nikiforov, ETD Program Committee Chair

The 2024 event brought delegates from over 15 countries on both sides of the Atlantic

The Beurs van Berlage conference space was ideal for large gatherings
Former SPE President and ETD Chair, Ken Braney, is presented with a retirement gift.

Amsterdam offered a central location and a wealth of cultural amenities for ETD delegates.

Attendees and exhibitors discuss new developments in thermoforming.

The Amsterdam event saw a record number of sponsors and exhibitors.

Delegates and families enjoyed a gala dinner with speeches and presentations.

Delegates enjoyed a welcome reception overlooking the skyline of Amsterdam.
Thermoforming 2.0

The View from Europe: Material Changes

As new materials continue to roll off the development wagon, thermoforming machinery is busy trialling them all. But which will win out in the battle for packaging shelf space? Steven Pacitti investigates

In what was labelled a ‘significant food packaging industry milestone’, converter Klöckner Pentaplast (KP) last month launched food packaging trays that comprise 100 per cent rPET derived exclusively from trays. Although tray-to-tray recycling has been chugging along as a concept for several years now, recycled trays have largely utilised rPET in the material loop that originates from plastics bottles. By creating a robust closed-loop system of PET flake from trays, KP believes that it is not just moving the needle on plastics tray sustainability, but also beckoning in the next era.

That new era, however, does come against a complex, somewhat paradoxical backdrop of a desire for sustainability and drop-in solutions, mixed with the continued emergence of new materials that fall into different camps. Dare to ask several thermoformers, or even thermoforming machinery suppliers, their opinion on what will be the sustainable polymer thermoformed structure of the future – and you’re likely to receive a wide variety of responses. Well, we did, and they did.

“I think the key word in that question is ‘opinion’ as there are so many options available,” suggests Daniel Coates, UK-based LVF Packaging’s business development director. “My gut feeling is that while all the new biodegradable or compostable materials that are coming through will serve a great purpose, they could slow down the advancement of the growth of UK recycling due to the system being overloaded by too many different polymers.”

The UK recycling issue is a moot point, it must be said, with infrastructure set up regionally as opposed to nationwide, leaving a scenario that is patchwork at best. This is not limited to just PET but all forms of materials in packaging.

“Here in Leeds, we have a very modern recycling centre, but only because the last one burnt down some years back and we were forced into building a new one!” says Coates.

Mustafa Eren, marketing and business development manager for Turkish thermoforming machinery maker Inpak, favours PET due to its ease of recycling but is cautious about making firm predictions due to not being a primary material developer. He adds that PET and PP are experiencing rising demand as core raw materials.

“PET remains at the forefront, closely followed by PP, with biobased polymers like polylactic acid gaining momentum as the sustainable thermoforming polymers of the future,” concurs Mark Strachan, vice-president of innovation and product development, and co-owner of OMV Technologies.

Focused on thermal stable PET and PP from renewable resources and bioplastics, German machinery maker Illig, meanwhile, has noticed a concerted shift towards more sustainable packaging this decade and the implementation of mono-material packaging. And it believes the outlook for mono-material PET that can be recycled is promising, especially as demand for it continues to grow across the thermoforming sector.

Germany’s Kiefel Technologies also notes a switch to compostable or recyclable materials, such as natural fibres or rPET.

“We have observed a trend in our recent collaborations: a significant increase in customers we support in their transition to PP and PET,” said head of sales polymer packaging, Alexander Donabauer.

While mono-material options like PP and PET stand out, Donabauer admits that, according to the US Food and Drug
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Administration, while many plastics are only food safe in their virgin state, rPET is approved for food contact, which makes it a perfect choice for food packaging.

While some multilayer packaging applications are less complex or sensitive to change, others require more rigorous solutions, explains Daniel Ganz, global product manager for additive and colour masterbatches and compounds producer Sukano. "We recognise that the transition away from PE and ethylene-vinyl alcohol in multilayer thermoforming applications will involve multiple strategies, each tailored to specific requirement," he says.

"Moreover, any new solution must comply with mechanical recycling processes, adding another layer of complexity to find alternatives we can consider. The race to meet these evolving needs has long been underway and we remain committed to driving innovation in this space."

Although the temptation with this complex collection of materials would be to go back to basics and get the fundamentals right first – bring in conjoined, nationwide recycling systems, reduce the different materials down to just one or two, and have systems in place to recycle these properly – progress does continue to be made in the recycling sector.

"There is increased interest on the market to establish a collection and sorting infrastructure for thermoforms, and for cooperation across industries that leads to R&D of appropriate recycling technologies to close the loop on PET thermoforms," cites Starlinger’s product manager for PET, Liliana Orban.

While the Austrian recycling technology provider claims that solutions exist for recycling streams containing multilayer thermoforms – either using hardware or chemical products for delamination – there continues to be conversions to mono-PET.

"Successful recycling requires supportive policymaking, upstream steps such as a working collection and sorting infrastructure, specialised washing lines and recipes for 20 THERMOFORMING As new materials continue to roll off the development wagon, thermoforming machinery is busy trialling them all. But which will win out in the battle for packaging shelf space? Steven Pacitti investigates Material changes ECO-PLASTICS IN PACKAGING © 2024 Sayers Publishing Group • May 21 thermoforms, as well as efficient decontamination," adds Orban. “We see active interest in recycling thermoformed packaging in Europe, North and Central America, as well as Asia."

But recycling a PET thermoformed package is not identical to that of a PET bottle, she states, adding how Starlinger has to treat the recycling system differently.

“The intrinsic viscosity [IV] of PET thermoforms is lower than that of PET bottles, and fines develop during the washing process and centrifuging, which significantly impacts the production yield,” Orban admits. “Due to the lower bulk density and risk of lumping during the drying steps, different drying procedures than for PET bottle flakes are used. Compared with PET bottle-to-bottle recycling, which is a fine-tuned process existing for more than 20 years, with bottle specs and logistics in place, the recycling of thermoforms still has scope for improvement both upstream and downstream of the recycling process."

Starlinger carried out trials with ten different input streams and subsequently adapted the set-up of its PET recycling lines accordingly. Instead of static drying, for example, the input material is pre-dried in Starlinger’s Smartfeeder, which handles different shaped materials, bulk densities and moisture levels. The additional high vacuum degassing unit provides an extra cleaning step while reducing viscosity loss, and melt filters before the pelletiser remove solid contaminants that might occur in postconsumer tray streams. The company’s ViscoStar solid state polycondensation reactor at the end of the process ensures decontamination and IV increase.

Thermoforming on trial

As the thermoforming industry increasingly shifts from high-impact polystyrene (PS) or PP to PET, manufacturers like OMV are experiencing heightened demand for trials on their machinery.

Company president Brooke Maltun says that OMV’s inline extrusion to thermoforming option, featuring a single cavity tool mirroring production tools, is particularly sought after.

“Clients often seek trials to optimise plug assist design, determine the ideal starting sheet gauge, and achieve the necessary diameter alignment for lid compatibility,” she explains. “Material trials incorporate a variety of additives aimed at enhancing oxygen and water vapour barrier properties, as well as those designed to render fossil fuel-based materials compostable.

“Our trials also delve into material experimentation involving chemical or gas infusion to create a foamed inner core.
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Extrusion and thermoforming trials are, of course, increasingly exploring materials with high post-consumer resin content and regrind flake, sometimes reaching 100 per cent.

Kiefel Technologies has also noticed rising demand for testing on its machinery as brands and converters prioritise sustainability.

Turkish firm Inpak, too, points to the transition from PS and expanded PS to PP, and now from PP to PET, aided by additives, but also highlights industry trials in the area of crystalline PET, particularly in tilting machines.

“The strong frequency of in-house mould trials has led us to get the opportunity to improve the human-machine interface with minimised interaction,” adds Mustafa Eren. “We are focused on it at the moment. On the other hand, the need for handling and inline packing systems are undeniable.”

Downstream, firms like Sukano also continue to invest in lab capabilities, so that it can screen additives selection for each new product development in advance.

“We only launch new formulations that not only confirm recyclability compatibility with mechanical recycling processes, but also demonstrate viability for multiple loops,” explains Sukano’s Daniel Ganz. “Although there is not yet a standardised protocol for the latter, our technical team defines three loops and different dilution levels to represent the EU recycled content targets and simulate the material performance over time on our lab equipment.”

The shift to more post-recycling of versatile materials in thermoformed packaging is already well underway, and thermoformers and thermoforming machinery makers alike are at the coalface when it comes to driving change.
Roundup from NPE 2024

**Original reporting by Beatriz Santos, Associate Editor, Sustainable Plastics**

**Editor’s Note:** If you didn’t make it to Orlando, the following pages offer a summary of key news releases and company updates, as well as a series of interviews with individuals with a variety of industry perspectives.

**New European Partnership Enters US Thermoforming Market**

Integrated Forming Solutions (IFS) is a new partnership between four European companies — WM Thermoforming Machines from Switzerland, T2 and MacDue from Italy, and Ausil Systems from Spain — being launched at NPE.

Plans for the partnership were set in motion two years ago and have culminated in the opening of a technical service, training, and service center in Houston.

Operating out of that center, IFS will now be able to offer existing and new U.S. customers thermoforming machines which weren’t until now readily available, Luca Oliverio general director at WM explained in an interview with Sustainable Plastics.

“The United States is a demanding market — we are growing and have to follow the requests of our customers,” Oliverio said. “The request is to offer a complete solution, not only the thermoforming machine but also an automation system, spare parts. Obviously, the investment required to expand into the U.S. in this capacity is very high.”

By partnering with other interested parties, the IFS companies can both cut costs and offer products and services they couldn’t have offered on their own.

**BMG Unveils Technology of the future: Plastic and Paper**

A piece of that technology is the modular BMG NXT platform being launched at NPE, the first units of which will be available at the end of this year.

The thermoformer can run either plastic or fiber, offering a modular design allowing customers to go from a plastic to a paper thermoforming machine “at the drop of a hat.”

“The NXT modular platform really plays off our sustainability goals — to develop a system for the future of thermoforming. The way we look at thermoforming is not just a plastic process, it’s also a paper product,” said Jake Kowalewski, Chief Commercial Officer at BMG.

Most of BMG’s customers doing plastic thermoforming also produce several paper products. Many others now want to have the option to also work with fiber due to sustainability concerns, Kowalewski explained, even if the sustainability credentials of paper don’t always match those of plastic.

The NXT also offers ease of access and the ability to quickly add additional stations using plug-and-play modules. Another innovation is on the oven design which can be accessed from either the right- or left-hand side. That double access point allows one operator to work on two machines at the same time, reducing tool change time and increasing output.

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**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.
NPE returned to Orlando in May 2024 after a 6-year hiatus, so expectations were high leading up to the event. With over 50,000 attendees expected, this show was expected by many to be a barometer for the plastics industry as a whole, especially machinery manufacturers whose wares were on display in both the South and the West Halls at the Orange County Convention Center.

We posed the following questions to a cross-section of individuals involved in thermoforming: processors, policy experts, OEMs, recruiters, and more. Though each was not qualified to answer all questions, the answers we received painted a moderately positive view of the outlook for thermoforming. The quotes below are directly attributed to the respondents who participated in our discussion.

**QUESTION 1:** General impressions: compared to previous NPE events, did you think the 2024 show was better, worse, or the same as the most recent show in 2018? Why?

- “We felt the show was about the same as the last one.” H. Kittelmann, Marbach (OEM – tooling)
- “This NPE show was much better than previous. We had many more sheet fed thermoforming companies visit when compared to prior shows.” M. Alongi, MAAC Machinery (OEM – heavy gauge)
- “This was our first time at the NPE, so we do not have a comparison to previous NPE shows, but we would like to see a separate area around thermoforming and all the suppliers for thermoforming in one place.” R. Doshi, Machinecraft (OEM – heavy gauge)
- “It was better than previous NPE events as the quality of the leads were much better. Roughly 90% were actually real thermoforming companies.” P. Caiani, OMG Italy (OEM – thin gauge)
- “NPE this year seemed quieter compared to my memory from six years ago, though I cannot say how accurately recall 2018. Many exhibitors noted that foot traffic felt “slow.” However, nearly every speaking session had standing-room-only attendance. I think the significant number of first-time attendees might be using NPE more for educational purposes rather than networking, as their professional networks are less established compared to those who have been in the industry for decades.” M. Moore, NAPCOR (Policy)
- “The show seemed to be well attended; however in recent years, NPE was combined with ANTEC which brought in a lot of additional engineers and other professionals for the technical conference. There was a lot of energy and buzz going into the week and it felt that everyone was excited to be back at NPE after a 6 year gap. Overall, it seemed to be a very successful show for us and our clients.” Z. Ernest, KLA Industries (Recruiting)
- It’s hard to have a general impression other than “WOW.” What I appreciate about NPE is how it provides a perspective of the scale of the plastics industry. As a sustainability professional, I immediately think about how we can harness the weight of that scale to tackle the issues we face as an industry. How do we get alignment between the converters, raw material suppliers, tooling manufacturers, and equipment suppliers? The Sustainability Hub provided a place at NPE for everyone interested in sustainability to network and discuss potential solutions. We are all facing similar challenges – the stigmatization of plastic, the need to improve resource efficiency, increasing regulation, etc. Collaboration is the only way forward.” Z. Muscato, Plastic Ingenuity (Converter – thin gauge)
- “We did not exhibit at the last NPE, but I did attend it and worked closely with Polytype who owned OMV at the time. This year’s conference, in my opinion, was tremendous due to the fact that we saw a lot of decision makers and had the opportunity to spend quality time with each. We were not yet able to exhibit a machine, due to the size of our booth and having to wait our turn on the exhibitor space waiting list.” M. Strachan (OEM – machinery)

**QUESTION 2:** Did you see any new developments in thermoforming, whether in technology (machinery, tooling), materials, or applications? Please provide a short commentary on why this caught your attention.
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“Digitalization is taking more and more space. From CMM equipment to process settings & monitoring it becomes a forceful tool for the future.” H. Kittelmann, Marbach

“The new technology we demonstrated showing automation and quick change over times was certainly of the highest interest. It seems the customer base is very focused on being more efficient and more repeatable.” M. Alongi, MAAC Machinery

“From the heavy gauge side, there were not a lot of machines on display. We saw new types of materials specially from Highland - the special NVH materials for automotive could be a game changer for lightweighting. Also, the carbon composite from Westlake for sporting gear was fascinating. We also saw the developments around EV battery products at the SABIC booth.” R. Doshi, Machinecraft

“We displayed a new development showing a system for knickless cutting and stacking that is appealing to medical formers with a standard machine.” P. Caiani, OMG Italy

“There was a notable increase in discussions around the production of high PCR-content sheet.” M. Moore, NAPCOR

“I did not see any substantial machinery or tooling developments other than the new Microwave Technology offered by SMC. This new technology for drying PET flake offers shorter drying times with minimal energy and very low moisture (55ppm). I did notice a lot of developments in materials and additives. This caught my attention due to the need for sustainability options. PET is the most recycled material and PET PCR is more readily available to converters. Unfortunately, the heat deflection temperature and barrier properties of PET are not sufficient for some applications, but there are now proven alternatives such as PEF from Avantium that increase the oxygen and water vapor barrier properties substantially. Additives from Sukano AG were used in the development of CPET light that increase the heat deflection temperature such that PET can be used in hot fill applications and even coffee pods.” M. Strachan, OMV

“OEMs seem to be focusing on how to provide more friction to thermoforms flake to remove labels with difficult to remove adhesives, but not so much that fine particle losses increase. I’m referring mostly to AMUT, Sorema, Lindner, etc. The SSP system providers are interested in contending with the increases PE contamination which can cause flakes to stick to the internal surfaces of drying units.” M. Moore, NAPCOR

“The message in the industry continues to be sustainability. It can be difficult to differentiate between the message and the progress for recycling and sustainability. The industry seems to be committed to sustainability if their customers are willing to make the investment.” Z. Ernest, KLA Industries

“This topic came up quite a bit, probably because I raised it with most everyone I talked to. This topic is very important to me and the company I work for, Plastic Ingenuity. As a custom thermoformer, we need to do everything we can to ensure thermoforms get recycled in practice. The fact is, not enough of them get recycled today, which contributes to the stigmatization of plastics in the eyes of consumers.

QUESTION 3: Did the topic recycling - specifically, thermoform recycling (not bottles) - come up in any of your discussions at the show? If so, please comment briefly.

“I specifically asked about tray-to-tray recycling, primarily focusing on recycling OEMs. All indicated that they are developing technology capable of processing the more fragile, lower IV thermoform material. A significant concern highlighted was the increased PE contamination resulting from (what they think is) the growing use of lidding films on trays compared to clamshells. This is crucial to address as the existing PET design for recyclability guidance doesn’t contend with lidding films explicitly. Thermoform guidance is incomplete in a number of areas which need resolution prior to California’s SB 54 mandates going into effect, namely the requirement for 65% reclamation of this category by 2032. If lidding films are indeed hindering circularity, the industry could face significant challenges, as guidelines for acceptable films are not yet established.” M. Moore, NAPCOR

OEMs seem to be focusing on how to provide more friction to thermoforms flake to remove labels with difficult to remove adhesives, but not so much that fine particle losses increase. I’m referring mostly to AMUT, Sorema, Lindner, etc. The SSP system providers are interested in contending with the increases PE contamination which can cause flakes to stick to the internal surfaces of drying units.” M. Moore, NAPCOR

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Many bottlenecks to recycling more thermoforms are outside our direct control, but we cannot wash our hands of the issue.” Z. Muscato, Plastic Ingenuity

“Yes, very much so. Many are concerned about the Single use plastics bans in Europe and the need to include high percentages of PCR into their products. Many are moving to more sustainable materials such as PET and are trying to find ways to broaden the capabilities of the more sustainable materials. OMV performed additive trials for Avantium in Verona, Italy to extrude, thermoform, and test the barrier properties of their PEF additives and the results were tremendous. The additive filled regrind flakes can be fully recycled again and again. This would allow the use of PET in barrier applications that could not till now be feasible using only PET.” M. Strachan, OMV

**QUESTION 4:** Automation and staffing continue to be key topics among thermoforming processors. Did you see or hear anything to suggest that these topics are less important now? Are companies investing more or less in automation? In qualified personnel?

- “Seems that automation will be high in demand also for the future due to lack of available staff for simple and even advanced requests.” H. Kittelmann, Marbach

- “Automation was a big topic but seemed to be more so to gain efficiency, repeatability, and consistency. No companies really talked to us about staffing concerns.” M. Alongi, MAAC Machinery

- “The biggest problem we heard from the heavy gauge thermoformers was the problem of product changeover. It seemed that the time can be reduced by a factor of 10 with the selection of the right equipment and automation techniques.” R. Doshi, Machinecraft

- “Robots and automation only came up when doing ABCD stacking for food trays. Staffing came up a lot of times, as everybody is scrambling for qualified people.” P. Caiani, OMG Italy

- “Exhibitors and visitors to our booth consistently named staffing of experienced plastics professionals as a major challenge. The demographics continue to cause issues as retirements outpace new grads coming into the industry.” Z. Ernest, KLA Industries

- “Companies have become more and more concerned about automation due to staffing issues and this is a worldwide issue. The need for visual checks using cameras and ways to eject poor product before being counted, bagged and boxed are critical. Process and onboarding training is needed in every sector.” M. Strachan, OMV

What do you think? Did you attend NPE and come away with a dramatically different opinion? Let us know or start a thread on the Thermoforming Division social media channels including LinkedIn and X. |
Investigation of Thermoforming Processes of Aerostructures: Simulation and Microstructural Analysis

Merve Çobanoğlu¹ · Remzi Ecmel Ece¹ · Büşra Ünlü¹,² · Yahya Öz¹ · Serkan Toros¹,³ · Fahrettin Öztürk¹,⁴

ABSTRACT

A series of experimental and numerical studies were carried out on the mechanical and geometric performance of an aerostructural part produced by a material out-of-autoclave stamp forming process using unidirectional (UD) carbon fiber (CF) reinforced polyetherketoneketone (PEKK), which provides advantages like reshaping, recycling, welding, and low serial manufacturing costs. As a novelty, initial part geometry, different types of springs, and their attachment type were examined experimentally and compared with simulations. Compression tests were performed to determine mechanical strengths which reach levels up to 550 MPa. In addition, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) were conducted to determine the crystallinity which occurs depending on the cooling regimes of the material. The crystallinity has been observed to vary regionally ranging from 16 to 21%. However, the crystallinity of the part towards the cold mold region decreased from 20 to 17%. In addition, simulations were performed to observe and control the occurrence of wrinkles and other defects.

Keywords Aerospace Applications: · Crystallization · PEKK · Rapid manufacturing · Thermoforming · Thermoplastic

1. INTRODUCTION

CF reinforced thermoset (TS) matrix composite parts (CFRP) are widely desired due to their superior properties such as high strength/weight ratio, impact, and fatigue performance, damage tolerance, and high corrosion resistance [1–3]. These advanced properties are therefore common-

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[15–18]. Due to these advantageous properties, research of TP composites has been accelerated enormously [19–21]. This evolution resulted in large-scale production studies for the transportation field leading the way for the aerospace industry [20, 22, 23].

Within the scope of this study, the matrix material was chosen from the poly(aryl ether ketone) (PAEK) family where ether groups are bonded with ketone groups. The amount of ketone groups affects the melting temperature of TPs. Increased durability under high temperature, high strength to weight ratio and resistance to corrosion make them suitable for aerospace applications. Additionally, since the PAEK group is semi-crystalline, the failure mechanism of the polymer is convenient for primary parts of aircrafts. The most exceptional mechanical and thermal performance in the PAEK family is exhibited by PEKK [24–27]. Furthermore, crystallization kinetics [28, 29], crack propagation properties [30], and effects of the fiber–matrix interface on mechanical properties [31] were also studied in the literature.

Thus, PEKK was used as matrix material in CF reinforced composites in this study. The manufacturing process included preheating, thermoforming, and consolidation. During the thermoforming process, main mechanisms of manufacturing include percolation of polymers via matrix flow through layers, transverse flow under pressurized condition fibers, and intraply shear during the forming operation. This process is advantageous for large-scale production since the cycle time is very low compared to TSs. The thermoforming process requires pre-consolidated plates for manufacturing. Therefore, autoclave consolidation of prepregs under high temperature and pressure was used for this process [6, 32, 33].

The manufacturing process was simulated concurrently. The formability of CF reinforced TP (CFRTP) composites was analyzed and simulated by AniForm in this study. Improved accuracy and lowering simulation times are the most important parameters for the analysis.

Thus, within the scope of this study, an aerostructural part was manufactured by a material forming process applied on CF reinforced PEKK. Part geometry, different types of springs and their attachment were studied by simulations and compared with the obtained aerostructure.

In addition, mechanical and thermal tests were performed. Moreover, effects of the crystallization occurring during the manufacturing process were investigated.

### Table 1: Polymer matrix properties

<table>
<thead>
<tr>
<th>Matrix properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.30 g/cm³</td>
</tr>
<tr>
<td>$T_g$ (glass transition)</td>
<td>160 °C</td>
</tr>
<tr>
<td>$T_m$ (melting temperature)</td>
<td>337 °C</td>
</tr>
<tr>
<td>$T_c$ (crystallization temperature)</td>
<td>265 °C</td>
</tr>
<tr>
<td>$T_p$ (processing)</td>
<td>370–400 °C</td>
</tr>
</tbody>
</table>

### Table 2 Carbon UD tape (semipreg) properties

<table>
<thead>
<tr>
<th>Carbon UD tape (CF+resin) properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.59 g/cm³</td>
</tr>
<tr>
<td>Polymer content by weight</td>
<td>34%</td>
</tr>
<tr>
<td>Consolidated ply thickness</td>
<td>0.14 mm</td>
</tr>
<tr>
<td>Tensile strength 0°</td>
<td>2410 MPa</td>
</tr>
<tr>
<td>Tensile strength 90°</td>
<td>86 MPa</td>
</tr>
</tbody>
</table>

2. MATERIALS AND METHODS

2.1 Raw material properties

Toray Cetex TC1320 PEKK is a high-quality TP composite material that employs the semi-crystalline TP polymer PEKK for superior elevated service performance. It has high mechanical properties as well as good hot/wet strength. The semi-crystalline structure of the polymer matrix assures that it is very resistant to chemicals and solvents, while having outstanding flammability capabilities. In addition, Toray Cetex TC1320 is qualified and certified for aerospace applications. Tables 1 and 2 summarize physical and mechanical properties of the polymer and tape, respectively.

2.2 Pre-consolidation process of blanks

Blanks used for thermoforming were cut from pre-consolidated laminates such that ply cutting and ply orientation processes were executed first. Blanks were manufactured by consolidating imbricated 14 unidirectional PEKK plies which have been orientated in different directions as $[45^\circ, 0^\circ, 90^\circ]_8$, $-45^\circ, 90^\circ, 0^\circ, 45^\circ]_8$. For the purpose of reducing void formation and delamination, an autoclave was preferred for the consolidation operation. Prior the consolidation operation, the hand lay-up process was conducted in a clean room to minimize contamination. After vacuum bagging, a stack of oriented plies started to melt at 380 °C under 8 bar in an autoclave for 2 h. Figure 1 depicts the bagging scheme while it also presents the time/pressure–temperature diagram of the autoclave cycle. In order to obtain the final shape, a water jet cutting machine or guillotine press can be operated.
2.3 TP composite forming process and heat management

2.3.1 Heat management of the composite forming

It is possible to shape carbon/glass fiber reinforced TP matrix composites using the stamp forming method. While materials with polymer matrices are subjected to the forming process, they need a higher heating temperature and pressure in comparison to pure polymer materials. Generally, forming processes of TP composite sheets consist of several stages. These stages include (i) fixing the polymer matrix composite laminate to the movable frame by holders (bolted union with springs per hole), (ii) heating the laminate until it reaches the required temperature to become formable for the stamp forming process, (iii) closing matched dies and initiating the cooling of the laminate, and (iv) demolding and trimming processes.

Basic process steps and temperature variations for the whole procedure are illustrated in Fig. 2. Since the mid section is the coolest part during heating, it is important to follow heating at these locations. Radius parts are also critical. Therefore, three thermocouples were placed (i.e., two of them at the radius, one of them at the middle of the part). TP composite sheets were heated for approximately 240 s with a ceramic heater up to 380 °C. Afterwards, sheets were transferred within a short time to the die system which was already heated. Subsequently, the dies closing operation followed. Finally, dies were held in a closed position to heat TP composite sheets for a specific time period as indicated in Fig. 2.

Dies (prepared by use of the material DM3X which exhibits a low coefficient of thermal expansion) have to be at consolidation temperature during the stamping process, i.e., approximately 230–250 °C for PEKK matrix composites. Remarkably, there are various ways to heat up tools such as infrared, induction, and thermal fluid heating. In this study, composite parts were formed with tools heated by thermal fluid heating. In order to keep the consolidation temperature steady, the tooling enclosure was insulated with glass wool. Also, 25-mm-thick mica insulation plates were placed between the tools and press ram table for reducing heat loss by conductive heat transfer. According to measurements of temperatures on the die system, male and female tools were warmed up by a heating boiler to form melted blanks at crystallization temperatures between 227 and 249 °C. The die heating channels' positions and flow rate of the heating fluid were calibrated to minimize the temperature gradient through die surfaces. Stamp forming was executed under 195 bar hydraulic pressure for approximately 2 min. To cut up excess material, the bench trimmer process was applied. In Fig. 3, the design image of the composite forming exper-

Figure 1: A Time/pressure–temperature diagram of the autoclave cycle. b Lay-up of the corresponding vacuum bagging c in an autoclave and resulting d consolidated TP sheet.
imental setup is shown. Here, composite sheets are transported between stations by a conveying system controlled by servo motors. Firstly, the composite plate placed in the frame is transported to heaters and kept there until the desired temperature level is reached. Afterwards, it is quickly applied to the die system and the forming process is completed. By choosing the closing speed of the dies as fast as possible, the heat loss in the composite plates are minimized. After the last baking molds are completely closed, they are kept under high pressure to consolidate the part.

2.3.2 Gripping of the blank

One of the essential parameters that affect the quality of the formed TP composite sheet is the fixing methodology. The general application at the stamping operation is the fixing of sheets with the help of springs instead of the secondary die system, i.e., the blank holder system. During the closing of the male and female dies, blank holders may prevent sliding of the sheets. This phenomenon may lead to separation between fibers particularly for UD composites. According to the final product design, initial positions and amounts of springs as well as their stiffness are critical parameters to obtain well-formed parts without any defects like wrinkling, folding, and separations [34]. Bolted-union grippers, metal grippers, and springs can be used to attach the blank to the frame of the mechanism. In addition to the gripping system, the initial blank geometry also needs to be studied to obtain flawless parts. In this study, in terms of length and stiffness, four different springs were used to hold composite sheets. Figures 4 and 5 present different fixations of the blanks that were cut in complex and rectangular shape, respectively.

2.4 Numerical modeling of the stamping operation

The commercially available AniForm software, which is specialized on stamp forming simulations of composites, was used. Besides the springs definition (amount of springs and their stiffness) for the fixing of composite sheets, the software performs forming simulations under non-isothermal conditions in which heat is transferred between composite sheets and forming tools. This feature also allows the determination of the crystallinity in the material depending on the time. The composite forming simulation used the applicable Nakamura model which indicates non-isothermal kinetics [35, 36]. Since the Avrami assumption is only valid for instantaneous growth after activation and uniformity of the germ location as well as given crystal growth morphology and isothermal crystallization conditions, Nakamura developed the integration of non-isothermal crystallization of polymeric materials [35–37]. The corresponding equation is presented as Eq. (1), where $K(T)$ is the Nakamura kinetics crystallization function at temperature $T$ and $\alpha(t)$ is the degree of phase transformation at time $t$.

$$\alpha(t) = 1 - \exp\left(-\int_0^t K(T) \, dt\right)$$  \hspace{1cm} (1)

Since PEKK is a semicrystalline material, Nakamura extends the Avrami model for non-isothermal cases while the degree of crystallization is identified by this method [35, 38]. Simulation models were created by importing surface models of dies, frames, and blanks such that the time frame of analyses was minimized and the process was accelerated. In the carried out simulations, corresponding to the experimental system, the frame was first moved down to 52 mm and the composite plate was placed on the male mold. After wards,
the female mold was closed with a speed of 300 mm/s and a pressure of 195 bar was applied on the plate. The temperature, which is another important forming process parameter that depends on the geometry of tools and heating methodology, can vary across die surfaces. However, since the software capability is not appropriate for reflecting this variation, simulations were carried out under constant 260 °C in accordance with the temperature during the forming as observable in Fig. 2. Another important key point in the simulations is to obtain equivalent results with the experiment. Therefore, properties such as heat conduction and friction between mold surfaces and composite plates can be defined as material properties while similar characteristics between composite layers can also be prescribed. The friction coefficient in the composite layups was taken as 0.2 while 0.25 was chosen for the forming tools and composites upper as well as lower surface. In addition, to characterize the permanent forming behavior of the composites, several mechanical tests are required. Required experimental findings like bias-extension characteristics at different temperatures, in-plane shear characterization which is obtained from torsion tests and/or picture frame tests, can be fed to the software. Relevant data were obtained from the manufacturer of Toray Cetex TC1320 PEKK, Toray Industries.

The material behavior in the simulations is composed of combined fiber and matrix deformations. The deformation of the matrix is defined by a cross-flow formulation which is...
the shear rate dependent viscosity model. The corresponding Cauchy stress can be expressed by Eq. (2):

$$
\sigma = \frac{2\eta(\dot{\gamma})}{J} D, \quad (2)
$$

where \(\dot{\gamma}\) is the viscosity which depends on the equivalent shear rate \(\dot{\gamma}\), \(J\) is the Jacobian of the deformation gradient, and \(D\) is the rate of the deformation tensor. Correspondingly, the shear rate viscosity is provided by Eq. (3):

$$
\eta(\dot{\gamma}) = \frac{\eta_0 - \eta_\infty}{1 + m \dot{\gamma}^{1-n}} + \eta_\infty, \quad (3)
$$

where \(\eta_0\) and \(\eta_\infty\) are viscosity values at specified minimum and maximum shear strain rate values which are experimentally obtained, and are material constants that control the model fitting performance. In the simulations, \(\eta_0 = 4.84\) Pas, \(r, \infty = 0.29\) Pas, \(m = 135\), and \(n = 0.046\) were used.

According to a myriad of analyses and experimental studies [39], two simulation models were run in detail as can be seen in Fig. 6. Hence, setups presented in Figs. 4 and 5, i.e., positioning of the springs, were tested and compared by AniForm.

2.5 Characterizations

As can be observed in Fig. 7, test samples were cut by a waterjet for the purpose of observing selected regions with regard to effects of the forming operation and process parameters. In this research, compression tests were applied to samples obtained from the sheet before the thermoforming operation and from the RIB part which was formed in order to determine and compare their mechanical proper ties. A servo controlled Instron 5985 tensile/compression test machine was utilized for these measurements. Deformations were measured by strain gauges which had a resistance of 350.0 ± 0.2 Ω with a 2.125% gauge factor at room temperature. The compression test speed was selected as 1.3 mm/min as described in the ASTM D6641 standard while samples were prepared accordingly. For thermal analyses, 1 1 cm² samples were obtained from specific points depicted in Fig. 7 and labeled as DSC1–DSC6 by scraping the polymer from the resulting surface. DSC analyses were performed to determine the crystallinity of the composite [40]. In this study, the weight of DSC samples was approxi mately 10 mg. Measurements were performed with a heating rate of 10 °C/min under nitrogen flow while aluminum pens were used. Remarkably, the amount of amorphous and crystalline regions of the material provides information about the quality of the TP composite. Furthermore, during DSC, glassy and melting temperatures of the samples were (2) also observed.

For this analysis, a Perkin Elmer Diamond DSC device was used and crystallinities of the samples were determined according to the ISO EN11357 standard. In addition to the DSC analysis, TGA which is another critical thermal analysis technique for studying TP composites was applied on different samples labeled as TGA1–TGA6 as indicated in Fig. 7 by use of a TA Instruments Q500 with a heating rate of 10 °C/min under nitrogen atmosphere. The approach provides information about physical properties of the material such as decomposition and thermal stability. Within this regard, TGA was performed on the composites before and after the stamp forming. In addition, micro-cut characterization is an important technique for considering the quality of materials. Void amount, fiber-matrix bond quality, and thickness distribution of the formed part are essential parameters which are required to be analyzed in an optic microscope. Microstructure images of the RIB part and the blank were prepared based on classical metallographic methods (cutting-grinding-polishing). Critical regions of the RIB part were selected. An Olympus GX-53 Inverted Microscope was used for this purpose. Scanning electron microscopy (SEM) was carried out using a FEI Quanta 200 FEG device. Samples were coated with a gold/palladium thin film before examining the microstructure.

**Figure 6:** TP composite forming simulation

3. RESULTS AND DISCUSSION

3.1 Mechanical and thermal properties of the aerostructure

Characterization of mechanical properties of TP composite materials to be used in structural parts of aircrafts requires a number of mechanical tests.

As can be seen in Fig. 8, samples that are taken from formed RIB parts have higher strength than consolidated sheets prior forming operations which was measured as 330 MPa lying slightly lower than the value of 337 MPa provided by the manufacturer. This observation occurs due to reduced voids as well as pores, strain hardening, and increasing den-
FEG device. Samples were coated with a gold/palladium
microscopy (SEM) was carried out using a FEI Quanta 200
optic microscope. Microstructure images of the RIB part and
quality, and thickness distribution of the formed part are
the quality of materials. Void amount, fiber–matrix bond
characterization is an important technique for considering
Within this regard, TGA was performed on the composites
the material such as decomposition and thermal stability.
approach provides information about physical properties of
a heating rate of 10 °C/min under nitrogen atmosphere. The
formed RIB parts have higher strength than consolidated
a number of mechanical tests.

3.1 Mechanical and thermal properties

There were a number of noteworthy results observed when
DSC results of the RIB parts were studied. The thermoform-
ing operation does neither change polymer nor fiber con-
tent. Therefore, it can be concluded that the thermoforming
operation was successful with regard to the material. Addi-
tionally, crystallinity is a critical parameter for TP compos-
ites since it provides a general opinion about the process.
Before the thermoforming operation, the blank has some

crystallinity; however, when the TP composite reached the
process temperature range, polymer chains move more freely
reducing intermolecular forces. While under pressure, poly-
mer chains come into close contact, promoting intermole-
cular bonding between them. Afterwards, during cooling under
the tool, polymer chains lose their mobility, and as a result,
the material solidifies and retains the shape of the mold [42].
Correspondingly, the crystallinity of the TP demonstrates

Table 3: DSC and TGA results of the RIB. $T_{d,5\%}$ and $T_{d,max}$ represent temperatures at 5% and maximum weight loss, respectively

<table>
<thead>
<tr>
<th>Sample</th>
<th>Resin content (%)</th>
<th>$T_g$ (°C)</th>
<th>$T_m$ (°C)</th>
<th>Crystallinity (%)</th>
<th>$T_{d,5%}$ (°C)</th>
<th>$T_{d,max}$ (°C)</th>
<th>Char yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSC1</td>
<td>34</td>
<td>158.1</td>
<td>330.7</td>
<td>19.3</td>
<td>568</td>
<td>573</td>
<td>13.4</td>
</tr>
<tr>
<td>DSC2</td>
<td>34</td>
<td>158.5</td>
<td>331.6</td>
<td>18.3</td>
<td>565</td>
<td>571</td>
<td>13.1</td>
</tr>
<tr>
<td>DSC3</td>
<td>34</td>
<td>152.4</td>
<td>330.7</td>
<td>21.2</td>
<td>564</td>
<td>570</td>
<td>13.0</td>
</tr>
<tr>
<td>DSC4</td>
<td>34</td>
<td>155.3</td>
<td>330.5</td>
<td>20.0</td>
<td>567</td>
<td>576</td>
<td>15.8</td>
</tr>
<tr>
<td>DSC5</td>
<td>34</td>
<td>160.3</td>
<td>329.7</td>
<td>20.3</td>
<td>570</td>
<td>577</td>
<td>13.3</td>
</tr>
<tr>
<td>DSC6</td>
<td>34</td>
<td>158.5</td>
<td>329.7</td>
<td>16.5</td>
<td>568</td>
<td>576</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Figure 7: Selected regions of the RIB for characterization tests. M1–M4 are used for microscopic analyses while CT1–CT3 are utilized for compression tests

Figure 8: Compression test results of test samples taken from the part
the reliability of the thermoforming process [43]. Moreover, these bonds provide enhanced mechanical strength and toughness. Thus, DSC analysis provides indirect information about mechanical properties of the material.

<table>
<thead>
<tr>
<th>Region</th>
<th>Resin content (%)</th>
<th>$T_g$ (°C)</th>
<th>$T_m$ (°C)</th>
<th>Crystallinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>34</td>
<td>157.9</td>
<td>330.6</td>
<td>20.0</td>
</tr>
<tr>
<td>Middle</td>
<td>34</td>
<td>155.2</td>
<td>329.6</td>
<td>17.4</td>
</tr>
<tr>
<td>Bottom</td>
<td>34</td>
<td>157.0</td>
<td>328.2</td>
<td>17.2</td>
</tr>
</tbody>
</table>

Table 4: DSC results of the RIB through the thickness

When Tables 3 and 4 are examined, it can be observed that the crystallinity of the PEKK RIB composite is nearly 20% while this value is lower in certain regions as shown in Table 3. Note that the contact pressure of the RIB part during forming differs throughout the radius and web surface parts such that this difference may cause variations in the crystallinity. These observations are also supported with void amounts observed in microstructure images (as presented in Section 3.2) since the crystallinity of the TP decreases with increasing void amounts which shows that these results are consistent. Considering Table 3, the maximum crystallinity reaches up to 20.33% for the DSC5 point measured from the top surface of the samples whereas the minimum crystallinity was determined as 16.53% from the DSC6 sample located at the side. A significant parameter which affects the crystallinity ratio is the cooling rate of the parts during the forming operation. It is well known that the crystallinity decreases with increasing cooling rates for some TP polymers [44]. This situation can only occur when the temperature between tool and TP composite is relatively high. As aforementioned, the tools’ temperature can variate from inletting the heating fluid to the outlet. This leads to a crystallization variation of the TP composite parts [44]. The cooling rate can also variate due to the thermal conduction which is affected by the applied force (contact pressure) on the samples. Generally, the contact pressure on the side walls of the samples is less than the flat regions of the dies. Therefore, it is expected that the cooling rate is much higher for flat regions in comparison to the side walls due to the contact pressure effect [44]. Furthermore, the glass transition temperature in Table 3 is comparable to Table 1 while the melting temperature is slightly decreased.

Another important aspect about quantities supplied from the RIB part is the determination of the crystallization ability of the part along its thickness. As mentioned before, especially in the forming processes of TP composites, differences between mold temperatures and ambient temperature as well as temperature differences between mold systems significantly affect these crystallization values. This can lead not only to crystallization rates on selected planes but also to different values in their crystallization along the thickness [43]. In Table 4, crystallization ratios along the thickness of the DSC4 sample, which are in agreement with this argument, are presented. After the polymer was excavated from upper and lower surfaces, they were divided into two pieces with approximately the same thickness throughout the part thickness.

TGA results are presented in Table 3 and Fig. 9. Before stamp forming negligible weight losses until 400 °C occur, implying that all volatiles evaporated during the consolidation of the sheet in the autoclave. Results also show that samples exhibit a one-step degradative behavior which was also revealed by a derivative thermogravimetric (DTG) analysis presented in Fig. 9b. A characteristic mass release of about 15% takes place which starts at 510 °C and ends at approximately 710 °C which is an indication for the high thermal stability of this TP in contrast to TS matrices [45]. This process might start with the rupture of the weakest bonds amid aromatic groups while the major volatile release might contain phenol [45, 46]. After the stamp forming process, it can be observed that temperatures at 5% and maximum um weight loss are slightly decreased while the char yield increased. However, no correlation between the location of the samples and TGA results is detectable.

3.2 Micro-cut analysis of specified regions

Micro-cut analysis results are presented in Figs. 10 and 11. As can be observed, voids caused by separation between layers, trapped air bubbles during the laying and the autoclave process or fiber folding during the shaping are quite rare. The void amount was determined to lie between 0.82 and 1.46% while the maximum void length was 0.15 cm.

Another important parameter of the forming process of TP parts is the thickness distribution in the parts. Especially in the stages of bringing complex geometries such as edge bending and curvature to the part, it is a serious challenge to obtain a homogeneous thickness distribution due to the properties of the part at relevant temperatures. In this sense, a different approach has to be used in comparison to die tolerances used in routine sheet metal forming processes. Die tolerances are a matter of precision in order to avoid formation of previously mentioned defects in the composite, which expand under the influence of heat and transform into fluid
purposes where varying UD PEKK plies and no voids are
more measurements were performed for these locations
since both regions are located at the radius. Therefore,
three different regions with the exception of M3 and M7
in Table 5. Thickness measurements were performed at
forming operation was successful with regard to the visual
are complying with blank and tool tolerances. Hence, the
into fluid form. According to the carried out measurements,
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properties of the part at relevant temperatures. In this sense,
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in the stages of bringing complex geometries such as edge
TP parts is the thickness distribution in the parts. Especially
major importance to define material properties for forming
3.3 TP composite forming simulation results
thicknesses were measured
located at the radius for which
Fig. 11
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Regions a M3 and b M7

Figure 10: Microstructure images of different regions of the RIB part

Figure 11: Regions a M3 and b M7 located at the radius for which thicknesses were measured

<table>
<thead>
<tr>
<th>Thickness (µm)</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>2024.03</td>
<td>2034.59</td>
<td>2041.60</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>M2</td>
<td>2016.97</td>
<td>2027.57</td>
<td>2020.68</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>M3</td>
<td>1920.94</td>
<td>1915.76</td>
<td>1896.81</td>
<td>1951.45</td>
<td>2001.15</td>
<td>2006.60</td>
</tr>
<tr>
<td>M6</td>
<td>1980.00</td>
<td>1983.57</td>
<td>1971.35</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>M7</td>
<td>2040.12</td>
<td>1986.66</td>
<td>1963.34</td>
<td>1947.06</td>
<td>1985.06</td>
<td>X</td>
</tr>
<tr>
<td>M8</td>
<td>1920.21</td>
<td>1909.63</td>
<td>1899.11</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 5: Thickness measurement results
form. According to the carried out measurements, thickness distributions of formed parts of specified regions are complying with blank and tool tolerances. Hence, the forming operation was successful with regard to the visual aspect. Results of the thickness measurements are presented in Table 5. Thickness measurements were performed at three different regions with the exception of M3 and M7 since both regions are located at the radius. Therefore, more measurements were performed for these locations as depicted in Fig. 11. In addition, Fig. 12 presents an exemplary SEM image of the M3 radius for higher resolution purposes where varying UD PEKK plies and no voids are discernible.

3.3 TP composite forming simulation results

The use of qualified software for the evaluation of TP composites’ forming processes in a computing environment is of great interest [47]. In modeling studies developed similarly for sheet metal forming processes [48], it is of major importance to define material properties for forming simulations. Studies are carried out in the literature, especially in software such as LS-DYNA, Abaqus FEA, Pam-Stamp, and AniForm. In this study, AniForm developed directly for composite forming processes was used. Performance comparisons of the relevant software are available in the literature. Results show that AniForm provides an enhancement in estimating dimensional properties for the fixed part as mentioned in the literature [49].

In this present research, firstly, suspended studies were carried out with the initial plate geometry and springs, which directly affect final dimensions of plates shaped in TP composite forming processes and defects such as wrinkles. These properties are ultimately adjusted according to the geometry of the part to be produced while each region must act in a controlled manner at the point of filling the material into the mold during the forming. In addition to the starting part shape, connection points of relevant springs and the stiffness of used springs also play an important role. Note that the two different part geometries and the used connection method within the scope of this study were described in Sections 2.3 and 2.4.

Geometric results of the forming simulations applied for the PEKK TP composite are presented in Fig. 13. As can be observed, although there is no complication in the upper plane areas with regard to wrinkles, minor wrinkle lines on the side walls and/or closest regions to side walls occur in the simulations for the full rectangular part (setup-B). These wrinkles are obtained in accordance with inhomogeneous pulls in each region during the filling of the material inside the mold. Moreover, the design in which geometric dimensions after the shaping matched design dimensions was also obtained from the initial part geometry given in Fig. 13.

The wrinkle problem is one of the most significant complications encountered in the shaping of TP composites. This situation mostly occurs in two different ways. One of them is in the form of significant fluctuations on the surface of the part, while the other occurs in the folds formed by the material thickness of CFs. This has a significant impact on the quality of the final part and necessitates that fiber orientations must be taken into account when the part is filled into the mold. When wrinkle values of the two shaped geometries are examined as depicted in Fig. 14, it is observable that the wrinkle tendency is less in the part with a full rectangular section (particularly in the bending areas).

Another important feature to be observed in the performed shaping simulations is the observation of possible separations between layers of the composite sheet. In general, these decompositions can be observed in parts if fiber wrinkles exceed a certain critical value. This situation is directly dependent on the thickness of the layer related to the fiber and matrix ratio in the initial case. When wrinkle-level behaviors presented in Fig. 14 and the layer separation tendency distributions shown in Fig. 15 are evaluated together, it is obvious that the relevant error is an expected result. It can be foreseen that wrinkles and related layer separations (delaminations) may occur especially in negative-angled wall parts. Moreover, they affect each other. However, in the analyses, it
The wrinkle problem is one of the most significant complications encountered in the shaping of TP composites. One of the causes for wrinkles is in the form of significant fluctuations on the surface of the part.

This situation mostly occurs in two different ways. One of them is the occurrence of wrinkles adjacent to the side walls and/or closest regions to side walls. In the analysis, it is observable that the distribution of defects (delaminations) may occur especially in negative-angled plane areas with regard to wrinkles, minor wrinkle lines on the side walls.

Moreover, these decompositions can be observed in parts if fiber and matrix ratio in the initial case. When wrinkle-level values of the two shaped geometries are examined as depicted in Fig. 14, it is observable that the distribution of defects can be foreseen that wrinkles and related layer separations (delaminations) may occur especially in negative-angled plane areas.

The mold during the forming. In addition to the starting part shape, connection points of relevant springs and the stiffness of used springs also play an important role. Note that the Young’s modulus, Poisson’s ratio, and fiber orientation of the part to be produced while each region must act in a controlled manner at the point of filling the material into the mold.

It is obvious that the relevant error is an expected result. It can be foreseen that wrinkles and related layer separations (delaminations) may occur especially in negative-angled plane areas. Moreover, typical drawbacks like buckling, fiber breakage, and E. Koştur for valuable discussions.

Acknowledgements

Additions, authors thank M. Deveci, M. Özkutlu Demirel, F. Karaboğa, C. P. R. for valuable contributions. A series of experimental and numerical studies were carried out to obtain a better understanding of the forming process of TP composites. The significance of this study is in the form of significant fluctuations on the surface. Table 6 provides a summarized overview.

Figure 13: Isometric views of simulations

Figure 14: Wrinkling intensity of the formed parts

Figure 15: Ply splitting intensity

High thermal stability

Wrinkles might occur at side walls and corners

Easy one-step forming of complex shaped parts

High-quality surface finishes can sometimes be challenging due to high temperature requirements.

Summarized results of the forming simulations applied for the PEKK TP composite are presented in Fig. 13. As can be observed, the distribution of defects can be foreseen that wrinkles and related layer separations (delaminations) may occur especially in negative-angled plane areas.

The International Journal of Advanced Manufacturing Technology (2024) 132:5039–5052
is observable that the distribution of defects depends on the initial part geometry. Remarkably, involved defects are less achieved in the flat rectangular part. High thermal stability

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength increases after stamp forming</td>
<td>Crystallinity might be decreased at side walls</td>
</tr>
<tr>
<td>according to the crystallization</td>
<td>due to different cooling rates and insufficient</td>
</tr>
<tr>
<td></td>
<td>pressures</td>
</tr>
<tr>
<td>High thermal stability</td>
<td>Wrinkles might occur at side walls and corners</td>
</tr>
<tr>
<td>Short cycle times for manufacturing</td>
<td>Delamination may occur in negative-angled parts</td>
</tr>
<tr>
<td>Easy one-step forming of complex</td>
<td>High-quality surface finishes can sometimes be</td>
</tr>
<tr>
<td>shaped parts</td>
<td>challenging due to high temperature requirements</td>
</tr>
</tbody>
</table>

### 4 CONCLUSION

A series of experimental and numerical studies were performed on the forming processes of TP composites. Providing a systematic approach yields structural parts which fulfil mechanical as well as geometric design requirements. Corresponding exemplary results were presented for a RIB part of an aircraft. Simulations revealed that under certain circumstances (for instance, negative-angled wall parts) wrinkles and delamination can occur. As a result, these situations could be avoided in the aerostructure presented in this study. Table 6 provides a summarized overview.

Moreover, typical drawbacks like buckling, fiber breakage, or resin migration did not occur due to the chosen process parameters, i.e., stamping pressure and velocity. In contrast to many previous studies [38], UD composites were used in this work which are in general more prone to wrinkling. Nevertheless, wrinkling was avoided. Moreover, compression levels up to 550 MPa were determined. In addition, crystallinity which affect mechanical properties has been observed to vary regionally ranging from 16 to 21%. Hence, advantages of TP composites (recycling, reshaping, out of-autoclave manufacturing, thermal stability, etc.) might pave a way for future engineering and research applications in various sectors like aerospace or automotive industries especially when brake tools are taken into account while disadvantages like tooling costs and thickness limitations, which exist for thicker complex shapes due to the difficulty of achieving uniformity, should be taken into account.

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### Declarations

Conflict of interest: The authors declare no competing interests.

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Ideation in Thermoforming

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

PART DESCRIPTION

Perforated Ceiling Project: acoustic ceiling panel for use in theme-park rides. The ceiling panels (11 distinctive styles) are used in 12 scenes within a futuristic ride-through attraction at two world-class theme parks located in the United States. Parts formed by CW Thomas.

CATEGORY

Cut-sheet / Heavy Gauge: Electric Vehicles & Battery Applications

FEATURES AND BENEFITS

The goal was to achieve a futuristic look for drop ceiling panels that allow sound to travel through to sound insulation secured to the upper surface of the ceiling panels. The panels represent spacecraft circuitry or styling.

MATERIAL

0.090” perforated sheet of architectural grade PVC – acrylic as forming substrate. The perforations allowed the sound to contact the sound deadening foam. The foam is held in place utilizing a custom design profile extruded clip. The use of the custom profile extruded clip decreased assembly time over the original customer request of using an adhesive to secure the foam.

TOOLING

All molds are temperature-controlled aluminum castings from Springfield, MA. Foundry patterns machined from REN board in our tooling shop then recut to create CNC trim fixtures.

DESIGN & CHALLENGES

Our initial challenge was how to apply vacuum to the sheets through the mold when the sheet is full of holes. Our solution was to utilize a steel pressure box with a silicone sheet over the opening. The pressure box was closed over the heated sheet and allowed the mold vacuum to pull both the sheet and the silicone to create the part geometry.

The real challenge ended up being heating the sheets. Overall cycle time was running at +35% of normal cycle time for 0.090” sheets. The decreased surface area due to the perforations caused a drastic increase in the heating cycle. We overcame this issue by reducing the distance between the sheets and the oven panels.

Parts are manufactured in a work-cell environment. Parts are molded, trimmed, assembled, and packed within the forming cycle. All packaging was custom developed to kit the parts based on the end customer’s requirement for installation at the venue.

Photo courtesy of Ellen Dallager, Dallager Photography

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

**APPLICATION DETAILS**

**INLINE THERMOFORMING**

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

**ROLL STOCK**

- **Process:** Sheet Extrusion
- **Resins:** PS, PP, HDPE & PET (...and more!)
- **Gauge:** 9 – 60 MILS
- **Structure:** Mono- and/or Co-extrusion
- **Winding:** 1 & 2 Up
- **Rates:** 1000+, 2000+, 3000+, & 4000+ pph
- **Width:** 36 - 68 inch sheet widths

**Webinar: “Heavy-Gauge Sheet Extrusion – Equipment for An Optimized Process and Sustainability Outcomes”**

In this SPE Thermoforming webinar, PTi discusses vital components, including thermal modeling data, necessary for the reduction of sheet irregularities and maximization of sheet performance needed for reliable, high-quality, heavy gauge sheet.

**Date:** Sept. 25, 2024 at 2pm EST

**Presenter:** Tom Limbrunner
**VP - Applications & Technology**

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