



Thermoforming

Quarterly®

A JOURNAL OF THE THERMOFORMING DIVISION OF THE SOCIETY OF PLASTICS ENGINEERS

THIRD QUARTER 2013 ■ VOLUME 32 ■ NUMBER 3

Special Extended Conference Edition



ZEN AND THE ART OF
THERMOFORMING

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Thermoforming Quarterly®

*A JOURNAL PUBLISHED EACH
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OF THE SOCIETY OF
PLASTICS ENGINEERS*

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Cover Photo: *Sound of Silence Garden*
Photographer: Thang Vo Ta



Onward and Upward!

One of our many goals as Directors of the SPE Thermoforming Division Board is to establish ways to encourage networking between the companies and individuals involved in the great industry of thermoforming. Our annual Thermoforming Conference is the most effective way to accomplish this goal. I would like to acknowledge and thank our volunteer Conference Committee led by Eric Short and Bret Joslyn. This year's conference in Atlanta is poised to be one of the most exciting ever.

The theme of the conference is "Forming Tomorrow's Innovations" and it aptly explains it all as the conference committee has exhausted all digital and social media to ensure painless registration and navigation during your time in Atlanta. Starting with the Thick- and Thin-Gauge Thermoforming workshops on Monday, September 9 (and which now includes the addition of Tim Wormer's Extrusion Workshop), the 2013 Conference will leave all attendees with a lot of new materials to take back home.

This edition of *Thermoforming Quarterly* represents a turning point for our division. It will be the first to be available online

in full digital format. That means that we are making the magazine available to our international members and giving advertisers and sponsors the chance to include hyperlinks to their company websites.

You will also notice that this issue is significantly heftier than before. We have doubled the content through a coordinated effort by our volunteer members and staff. In addition to providing a special "Extended Conference Preview" section, we are featuring interviews with industry thought leaders as well as several technical articles representing new advances in the application of thermoforming technology. We have student papers from the undergraduate level up to the post-doctoral level. A special word of thanks is due to all those who accepted the challenge and took the time to either write a paper or encourage other industry experts to do so. Getting this in your hands before September was our priority.

This year's conference will feature a new "Student Parts Competition" where schools will compete for a new trophy. Along with the "Adopt-a-School Program," the SPE Scholarship Programs

and matching grants for thermoforming equipment, we are endeavoring to accomplish our mission "to facilitate the advancement of thermoforming technologies through education, application, promotion and research."

Along with riveting presentations from Taco Bell and John Deere among others, the program schedule will allow for ample networking time at exhibitor booths and will allow you the opportunity to attend the innovation briefs from the exhibitors themselves.

In conclusion, I would like to extend a hearty thanks to our Sponsors and Exhibitors and to you, our valued members, for making our 22nd annual conference possible. |

Thermoforming in the News

Swiss Machinery Group Wifag-Polytype Buys Thermoforming Equipment Maker OMV

By Bill Bregar, *Plastics News*

JULY 17, 2013 — Swiss industrial conglomerate Wifag-Polytype Holdings Ltd. has purchased Italian thermoforming machinery maker OMV Machinery. Wifag-Polytype, based in Fribourg, Switzerland, runs a global group of companies that make production lines for aluminum and steel aerosol containers, beverage bottles, tubes and sleeves, plastic cup and lid printing machines, coating lines for flexible packaging and films/foils, and newspaper and book printing machines. The privately held group employs 1,200. OMV, based in Verona, Italy, employs 45.

In a deal announced July 17, Wifag-Polytype bought OMV shares from Verona-based ISAP Packaging SpA. Terms were not disclosed.

OMV, founded in 1963, makes high-output thermoforming equipment and integrated lines, including extruders and tooling. The company has been known for its large-platen thermoforming machines, but in recent years has targeted food packaging and in-mold labeling. Officials of OMV and Wifag-Polytype were not immediately available for comment.

The deal adds thermoforming to Wifag-Polytype's extensive portfolio of packaging-related equipment. Polytype makes dry offset printing machines that can print from six to nine colors on plastic cups and lids. Its other plastics-related equipment includes machinery to make tubes and sleeves for packaging. Wifag-Polytype also manufactures coating and laminating equipment for flexible packaging applications such as barrier film, metalized paper, labels and tapes, blister foils and backsheets for solar cells. |

Fabri-Form Merges With Penda Plastics

By Brian Gadd, *Staff Writer, Zanesville Times Recorder*

JULY 29, 2013, NEW CONCORD — Custom plastics firm The Fabri-Form Company will merge its operations with a Wisconsin-based company but maintain its corporate headquarters in New Concord.

Resilience Capital Partners, majority owner of Penda Corporation, announced the merger in a joint statement today.

Penda has provided thermoformed products to the automotive industry and is the largest heavy-gauge thermoformer in the country, while Fabri-Form is a market leader in providing material handling, packaging and engineered components for the automotive, grocery and heavy-duty truck industry.

The new company leverages Penda's global sales network and thermoforming resources with Fabri-Form's custom engineering solutions and manufacturing technologies, company officials said.

Former Fabri-Form President Rob Zachrich, who will become the chief operating officer of the new company, said the move would enhance the company's presence and impact on a larger audience in the U.S. as well as worldwide.

Penda President and CEO Jack Slinger, who will keep those positions with the combined company, said the agreement is key to the future direction and growth of both organizations. |



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The Sound of Silence Garden – RHS Chelsea Flower Show 2013

By Mark Robinson, Solid Surfaces Northwest, Ltd.

Editor's Note: The cover photo on this edition of TQ deserves some explanation. We first learned about this project in the May issue of Surfacing Magazine, a UK-based design publication. Solid Surfaces Northwest are "3D thermoforming specialists" using solid surface materials to create desks and other bespoke (custom) furniture. The article below is adapted from the original and describes the genesis of the project and how thermoforming is reaching into new territory through innovative design and manufacturing.

As one of only a small number of companies in the UK that specializes in the thermoforming of solid surface materials, Solid Surfaces Northwest (SSN) were approached by award winning garden designer Fernando Gonzalez to help him turn his innovative design concept into a reality. He had been invited to design a garden for the prestigious RHS Chelsea Flower Show, and had developed a garden design based upon a Japanese Zen garden for meditation. As the main component of the design was striking thermoformed panels intended to represent mountain peaks, SSN recommended LG HIMACS as the material of choice due to the a higher mineral content than other materials. By combining this unique property of the material, along with a rough surface finish, SSN were able to make the HIMACS look similar to a natural stone thus mirroring the real rocks that are used in traditional Japanese zen gardens.

For most thermoformed projects, SSN manufactures timber formers from various sheet materials. For smaller formers, they use multiple stacked layers of MDF and machine a solid former from them using a Pacer HDS CNC router. This type of former can then be placed in a membrane press for forming. Larger

formers are constructed from a combination of MDF and flexi plywood. The internal structure is made in a skeleton-style frame and then over-clad in the flexi plywood. All formers are machined using the CNC router to ensure perfect accuracy. Due to the size of the panels that were required for the garden design, a male and female former were created so that SSN could 'sandwich' the HIMACS during the forming process. The tallest panel stands at over 2 meters high and 3 meters wide. In order to create the panel, three separate sheets of HIMACS had to be used to achieve the requisite height. In order to ensure seamless joints and to give the appearance that the finished panel is made from only one piece, each separate part of the panel had to have exactly the same radius to the curves to ensure that they fitted together perfectly.

Most projects are only ever seen from one side with the solid surface sheet acting as a cladding material. This project was different as it was only made from a 12mm thick sheet and both sides would be seen. This was another reason for choosing LG HIMACS, as the reverse of the sheet is nearly as good as the face side.

As with most thermoforming projects the most difficult and time consuming part of the manufacturing process is the design and construction of the formers. This project was no different with over 28 individual formers manufactured from over 50 sheets of MDF and 20 sheets of flexi plywood. In some instances, SSN also use flexible MDF as it provides a smoother forming surface. However, it doesn't bend to tight radiuses so in this project it was necessary to use flexi plywood. The downside of using flexi plywood for formers is that it can leave a grain impression on the surface unless covered with silicone sheet, which can mean more sanding and finishing of the final product.

Using software, each curved panel was flattened from its 3D state into 2D and these parts were then split into manageable sections of 700mm. Each section was then machined out using the CNC router, before being heated in a flat panel thermoforming oven to 165°C for 12 minutes after which time the hot sheets were transferred to the corresponding former and pressed in between both male and female formers. When cooled, the formers were used to trim the edges that were being jointed to one another using a hand router. The most critical part is making sure you achieve a perfect seam. If not, this can cause the joints to be visible after the gluing process, especially when using a solid white color. The panels were then glued with LGs range of color-matched adhesives. Once cured, the joints and panels were sanded to the desired finish. In this case, a grit of 40 was selected to give the panels a tangible texture like that of real stone.

The panels were delivered and installed on time and won a silver gilt medal at the show. They matched the designers original 3D drawing perfectly. |

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Thermoforming in the New Normal Economy

An Interview with SPE 2013 Thermoforming Conference Keynote Speaker: Dr. Peter Mooney, PCRS

By Lesley Kyle, OpenMindWorks, Inc.

Dr. Peter Mooney will present this keynote address on Wednesday, September 11, during the SPE Thermoforming Conference in Atlanta. Drawing on data and insights from his thermoforming research programs, Dr. Mooney will provide an economist's perspective on recent patterns of growth and technological change, highlighting some of the opportunities and challenges that lie ahead during his presentation titled, "Thermoforming in the New Normal Economy."

Dr. Mooney holds a Ph.D. in economics from the University of North Carolina at Chapel Hill. His company, Plastics Custom Research Services (PCRS), conducts single- and multi-client plastics industry market research programs. Dr. Mooney has researched and published over 75 major multi-client reports and conducted over 100 custom research programs covering the full spectrum of materials, processing methods, and markets.

Following are some of Dr. Mooney's thoughts on how this new economy is impacting the thermoforming industry:

Lesley Kyle: Which hallmarks of economic recovery are you seeing in the North American thermoforming industry?

Dr. Mooney: The automotive and housing industries – two key components of GDP – have been recovering from severe slumps prior to and during the Great Recession. They both have powerful multiplier effects for other sectors of the economy. So they are key to restoring a growth dynamic and job creation across the whole economy.

Kyle: Is the recovery slower, faster or on pace with what you would expect as a result of this most recent recession?

Mooney: From the first quarter of 2010 right up to the present, the annualized growth of U.S. real GDP has been only 2% with minor variations. This is markedly slower than recoveries from other post-WWII recessions. One could make the case on economic and demographic grounds this is the new normal.

Kyle: You published an updated report covering the North American industrial thermoforming business earlier this year. Were any of the findings in your analysis striking to you?

Mooney: I was surprised that the rebound experienced by industrial thermoformers (at least the large sample of companies I used) in 2010 and 2011 was so weak relative to the rebound experienced by other structural plastic part processors.

Kyle: What areas of opportunity do you see for thermoformers of packaging products?

Mooney: One of the leading areas of innovation in the realm of consumer products is food delivery and food packaging. This holds in particular for single-serve food packaging. An example is the proliferation of salad bars in grocery stores, providing meals for office workers and other demographics "on-the-go." This boosts the demand for clear and foamed clamshell packaging.

Kyle: You have completed research on different areas of the thermoforming industry in recent years. Which trends should thermoformers be mindful of as they plan for the next 2-3 years?

Mooney: With the exception of 2009 when packaging thermoformers experienced a rare sales setback, the growth of sales over the past dozen years has been fairly steady. Sales of industrial thermoformers, on the other hand, have been volatile, reflecting the boom-and-bust cycles of the manufacturing industries they serve. This was an integral feature of the "old normal," and it will manifest itself in the "new normal" as well.

Kyle: Do you foresee many thermoforming-related technological advances on the horizon?

Mooney: Clearly the growing consumer and producer acceptance of bioplastics as a packaging medium will dominate the light-gauge side of the thermoforming business. On the heavy-gauge side, the processors I've interviewed don't see all that many disruptive new technologies on the horizon.

Kyle: What are some of the challenges that thermoformers should be prepared for in the coming months?

Mooney: Many of the packaging thermoformers and most of the industrial thermoformers are in the category of small businesses and the greatest challenge small businesses confront over the remainder of this year is the rolling implementation of Affordable Care Act. It has already roiled the labor market, and employer/employee relationships will be further strained going forward.

Kyle: What will SPE Thermoforming Conference attendees learn from your presentation?

Mooney: As a card-carrying economist, I have a different perspective on trends in the thermoforming business – both the packaging and industrial product segments. In this process and all the other plastics processing businesses I cover, I attempt to focus on – and explain – the trend in the vital metrics – that is, the size, growth and technological change in the business. |

Lead, Follow, or Get Out of the Way: Global Consolidation in the Thermoforming Industry

An Interview with SPE 2013 Thermoforming Conference Keynote Speaker: Thomas Blaige, Blaige and Company

By Lesley Kyle, OpenMindWorks, Inc.

Tom Blaige will present his keynote address on Tuesday, September 10, during the SPE Thermoforming Conference in Atlanta. Mr. Blaige's company is an international investment banking firm serving the plastics, packaging, and chemical industries. During the past 30 years, his team of experts has completed over 200 transactions and visited more than 400 operations in over 40 countries. The company's research department tracks and analyzes over 500 plastics industry M&A transactions annually on a global basis.

Lesley Kyle: Blaige and Company has recently conducted considerable research on the impact of global consolidation on the thermoforming market. Which contributing factors led to your decision to conduct this research?

Tom Blaige: Since the turn of the century, a number of events have materially transformed the competitive landscape for packaging converters: the global expansion of the converting supply chain; the rapid growth of available equity capital; the increased scarcity of credit; and the increased activity in mergers, acquisitions, divestitures and recapitalizations.

The need to accommodate the increased scope and scale required by customers has generated a need for converters to fund investments in technology and capacity. In many cases, this requires owners to "double down" or "bet the farm" just to keep up, while larger competitors have access to record levels of institutional capital only available to a select group of large, well-capitalized converters.

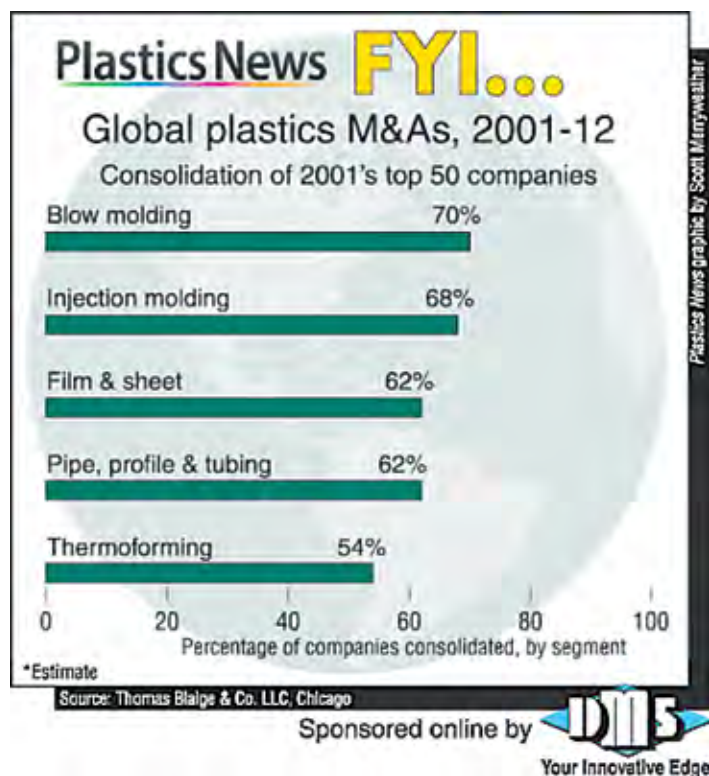
It is essential to communicate the result of this 12-year consolidation M&A research to help global consolidators, private company owners and private equity firms to understand the competitive landscape and to better facilitate a long-term strategy.

Kyle: Were any of the findings surprising to you?

Blaige: Big getting bigger, widening the "gap:" the speed of consolidation in the thermoforming industry is rapid. Of 2001's top 50 thermoforming companies, 54% have merged or sold in the past 12 years.

Thermoforming is highly fragmented, providing a compelling

consolidation opportunity. While the large-cap players have participated in the global consolidation trend, the small and mid-cap companies have not. This will change.



Source: Blaige & Company Proprietary Research – *Plastics News* January 25, 2013

Kyle: What is unique about Blaige and Company? Who are your clients?

Blaige: Blaige & Company is dedicated exclusively to the packaging, plastics, and chemicals industries. Our senior advisory professionals have personally managed, owned or visited over 400 packaging, plastics, and chemicals operations in 40 countries and completed over 200 value-enhancing transactions.

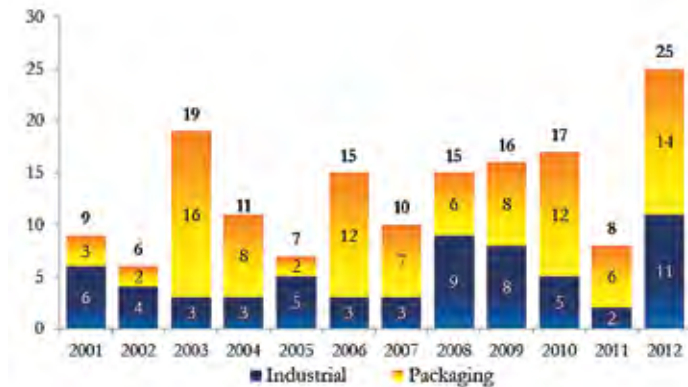
Blaige & Company's approach is from the pellet up, not from the financials down. Our team has over 60 years of CEO experience. Our key strengths (such as operational and industry knowledge) are well adapted to achieving premium valuations with businesses that require a high level of technical sophistication in value-added niches that are outperforming the industry.

Our clientele is comprised of large international corporations (global consolidators), private equity investors and privately held and family-owned companies. We appreciate the concerns that are unique to specific types of clients and we approach each transaction from their unique point of view.

Kyle: What areas of opportunity do you see for the global thermoforming industry?

Blaige: Consolidation has provided the single greatest

opportunity: deal volume in the thermoforming segment has more than doubled since 2001. Averaging 13 deals per year, 2012 was a record setting year with 25 deals (see Figure 21 below). In fact, deal volume more than tripled this year from 2011. The high level of activity in thermoforming bodes well for the sector's M&A in both packaging and heavy gauge industrial sectors.



THERMOFORMING DEAL VOLUME, 2001 - 2012
Source: Blaige & Company Proprietary Research

Kyle: What should thermoforming companies expect more – or less – of in the future?

Blaige: Most companies will eventually be directly influenced by M&A and must adapt now to the shifting segment structure. M&A activity in the thermoforming segment is increasing rapidly, with a record 25 transactions in 2012. This is nearly twice the average deal volume of approximately 13 deals per year since 2001. Segment “Leaders,” such as Rank Group, were all active in the M&A market in 2012 and will continue to pursue growth through acquisitions.

Approximately 83% of the surviving top 50 Thermoforming companies of 2001 are small to mid-sized private processors, highlighting the fragmented nature of the thermoforming segment, which will facilitate its accelerated rate of consolidation. In fact, surviving companies with access to capital finished the decade with sales 4.3 times greater than their privately held competitors. Many of these surviving private companies have also dropped out of the top 50 in the past twelve

years. This is a sign that passive participation is increasingly dangerous. Smaller, privately held companies must develop a well thought out strategic growth plan or risk becoming a victim of the rapidly consolidating market.

Kyle: Which trends are you seeing in other segments of the plastics industry?

Blaige: Although there are differences between specific segments, the plastics industry in general reflects the same common trends:

- Globalization driving growth
- Significant international involvement
- Vast majority of deals strategically motivated - 81% in 2012
- Big getting bigger, widening the “gap”
- Small businesses dominate U.S. plastics industry - 79% have sales \$50mm or less
- Seller’s market
- Blaige & Company’s recommendation to plastics processors: grow to \$100mm or sell/merge

Kyle: What will SPE Thermoforming Conference attendees learn from your presentation?

Blaige: Utilizing proprietary research over the past 12 years, I will address the impact of global consolidation on the thermoforming market. With over 54% of the top 50 thermoforming companies having undergone a change in ownership, or having been eliminated over the past 12 years, I will cover valuable strategies to help company owners understand and “win” in today’s mergers and acquisitions market.

Kyle: Any parting words of advice for members of the SPE Thermoforming Division?

Blaige: It is important to involve a professional advisor early and share the ups and downs of the business. Business owners can formulate an M&A strategy that will have very valuable long-term benefits, even if they decide not to pursue a transaction in the end. The decisions will have been made strategically for the business and not as a reaction to short-term influences. |

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From The Editor

In February of 2008, *Plastics News* ran this cartoon with a brief story called, "The Little SPE Division that Could." At that time, our division was growing while overall SPE membership was in decline. Thankfully, SPE is now back in the black as membership has picked back up (perhaps they learned from our success?!)

After the cartoon and article appeared, *Plastics News* published a letter to the editor from your humble correspondent who was Membership Chairman at the time. Here is an abbreviated version of that letter, because what was true then is still true today.

"What makes our division successful is the volunteer efforts of a diverse group of individuals that carry out the mission statement: 'to facilitate the advancement of thermoforming technologies through education, application, promotion and research.'

Thermoforming encompasses many industries, techniques, materials and end markets. Our divisional board is very representative of this mix and, therefore, we are able to adapt to innovations in different areas of plastics technology. This ensures that we consistently provide relevant information to our members. In fact, many of our members are secondary members belonging to a vast array of industries that are directly and indirectly involved with thermoforming.



The board of directors is responsible not only for the highly successful annual conference but also for the creation and development of strong relationships with universities and technical colleges around the country, including a new network of centers of excellence. The amount of money donated for scholarships each year ensures a steady supply of talent into the industry and thus guarantees future employees for companies involved in thermoforming. Given the relative decline of manufacturing skills in today's economy, this is no small accomplishment." |

2014 EDITORIAL CALENDAR

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Grants Help Kettering Add Thermoformer to its Plastics Lab

July 8, 2013

“Thermoforming is a common technology, used across a variety of industries, especially packaging,” said Mark Richardson, Manufacturing Engineering lecturer at Kettering.

The Kettering University Industrial and Manufacturing Engineering Department has a new thermoformer for its students thanks to \$40,000 in grants from three organizations.

Claudia Deschaine, grants manager for the Dart Foundation, was on campus in April to present a \$20,000 grant to purchase the machine. Kettering also received a \$10,000 matching grant from the Society of Plastics Engineers’ SPE Foundation and \$10,000 from MAAC Machinery.

The machine, used to form a variety of plastics products, replaces a thermoformer that Kettering had since the 1960s that was no longer operational. The process includes loading sheet plastic into the machine, which is sent into an oven. A form is then pushed into the plastic and a vacuum draws the sheet into the form, creating the product.

“Thermoforming is a common technology, used across a variety of industries, especially packaging,” said Mark Richardson, Manufacturing Engineering lecturer at Kettering.

The thermoformer will be used in IME 100 classes, as well as two plastics processing courses, IME 401 and 402.

“All of our freshman engineering students will get to use the machine in IME 100 and get a basic understanding of how it works,” Richardson said. “The students in our plastics courses will get a core understanding and strong functional knowledge about the technology.”

Funding for the thermoformer was aided by alumni connections. Eric Short, who is a class of 1996 graduate, and Brian Winton, whose father is a Kettering graduate, are both members of the Society of Plastics Engineers Thermoforming Division and helped Kettering with the grant. Tyler DeLong ‘94 of Dart Container Corp. and Paul Ryan of MAAC were also influential in helping Kettering obtain the necessary funds to get the thermoformer. |



Mark Richardson of Kettering University and Claudia Deschaine, of the Dart Foundation.



Presentation of \$20,000 check to Kettering University.

Replacing Glass Fiber and Carbon Fiber Products with the Thermoforming of Thermoplastics and Thermoplastic Composites to Reduce Costs and Increase Time Savings

By Harry Koshulsky, Pennsylvania College of Technology
Williamsport, PA

Harry Koshulsky, winner of the 2012 Thermoforming Division Memorial Scholarship, completed his senior project at Pennsylvania College of Technology with an emphasis on thermoforming product design and development. Harry graduated in May with a BS in Polymer Engineering Technology. He utilized the full gamut of resources at the Thermoforming Center of Excellence to complete his project. A significant part of the funding for that center was provided through SPE Thermoforming Division and SPE Foundation grants.

Harry has joined the professional ranks of plastics engineering as he accepted an engineering position at Innovation Tek in the powertrain division at the Ford Research and Engineering Center. However, Harry has not completed his work relating to his new "Rally Light Pod" product as he plans to build a new one-piece mold and have the Plastics Innovation and Resource Center (PIRC) provide an initial production run for commercial development.

We wish Harry the best of luck as he pursues his plastics career and hope his example will inspire others in academia and industry.

Promotion of the thermoforming process, especially the education and development of future plastics professionals, is the true ROI that the Thermoforming Division seeks. In partnership with the Division's loyal conference sponsors, exhibitors, and attendees, we continue to focus on the broader success of thermoforming. —Roger Kipp

Abstract

In the rally racing industry, light pods are used during inclement weather and during night races. These pods provide more light output and are made from glass fiber or carbon fiber fabric.

This paper illustrates the cost and time savings achieved as well as the improvements in quality found by replacing the current method of production with the thermoforming of acrylonitrile butadiene styrene (ABS) sheet. The paper also explores the possibility of thermoforming thermoplastic composites.

Introduction

Rally racing is a motorsport where highly modified cars race down dirt or tarmac roads at high speeds. The drivers and co-drivers must be able to navigate their way through twists and turns, through towns and forests, as quickly as possible. A single accident could cause irreparable damage to the car causing the team not to finish the stage. The teams race regardless of weather, time of day, or track conditions.

On occasion, the teams need more light for better visibility. To achieve this, the cars are fitted with light pods. Designs for these light pods vary greatly among number of lights, placement on vehicle, and overall appearance. The current method of production is to use glass fiber or carbon fiber fabric. The fabric is pre-impregnated with resin and laid-up manually on a mold. Gel-coat is also used to help with strength and visual appearance. The light pods are thick and heavy for strength and rigidity.

The thesis for this project is that it is more time and cost-effective to thermoform composite parts from thermoplastic sheet than to use the existing process. The four individual performance objectives are as follows: make a prototype; create two molds from the prototype; create a part from both molds; and create a duplicate set of molds.

The Current Method

Currently, most light pods are made by employees who place each sheet of pre-impregnated glass fiber or carbon fiber fabric onto a mold. Depending on the company, the glass/carbon fiber fabric may be stippled with resin instead of using pre-impregnated fabric. The mold is covered with a bag and the layers of resin-impregnated fabric are pressed together. The vacuum-bagged composite will then be transferred to an oven to cure. Curing takes several hours though process times vary on size and thickness of part. Once cured, the mold is taken out of the bag and the part is separated from the mold. After separation, final trimming may be required. The part may then be painted or left as-is depending on visual preference.

The Thermoforming Process

There are several different types of thermoforming processes. The process used for this project was single stage drape-forming using the Pennsylvania College of Technology Plastics Innovation and Resource Center (PIRC) MAAC thermoforming machine. A sheet of plastic is placed in the clamp frames. The clamps close, holding the plastic in place, and the carriage shuttles into the oven where the material is heated to processing temperature. This could be designated by either a timer or an infrared thermometer built into the machine. For this project a timer was used. Once time or temperature is reached, the carriage shuttles out of the oven and hovers over the mold. The mold rises into the plastic sheet so the vacuum box top surface contacts the sheet. The vacuum is activated and draws the plastic sheet to the contour of the mold, whether it is a male or female mold. For this project, two male molds were created. The vacuum is held while cooling fans allow the plastic to solidify. Once the cooling cycle is finished, the vacuum is deactivated and the machine pressurizes the vacuum box, assisting with part ejection. At the same time the mold is lowered. Once the platen reaches its lower limit, the clamp frames open and the part is removed. From here, the part requires additional trimming of excess material. This process can take as little as two minutes to more than ten minutes depending on size, thickness, and type of material used and

process used.

Materials

Woven glass fabric coupled with an epoxy resin is used to create a variety of parts. The glass fiber fabric adds greater strength than using just the resin while the resin allows the fabric to bond together in layers and allows the fabric to retain the shape of the finished part.

Woven carbon fiber fabric coupled with an epoxy resin is used to create the same variety of parts as glass fabric. Carbon fiber is lighter and stronger than glass fiber but is also more expensive. The resin used for carbon fiber is usually clear to allow the finished products to show off the carbon fiber weave for visual appearance.

ABS is a thermoplastic that is used for a large variety of products from suitcases to vehicle bumpers. Unfilled ABS sheet has a lower density than carbon/epoxy or glass/epoxy composite materials. Material costs are also much lower. For this project, 1/8" (3.18mm) thick ABS sheet was used.

Tegris is a thermoplastic composite made of one hundred percent polypropylene. It consists of a polypropylene ribbon woven fabric impregnated with a polypropylene resin. This material is used to make high strength composite parts similar to carbon/epoxy composites but has the added benefits of higher strength-to-weight and it has the ability to be reheated and remolded.

Designing the Part

The lighting component of choice was measured. The lights chosen, Hella 500FFs, are 7" (177.8mm) in diameter and 2.5" (63.5mm) thick. Using SolidWorks, a general shape was created with enough offset to allow the lights to be mounted to the light pod without interference. From the front view the rest of the light pod design was created and designed to keep the part smaller and physically appealing. From these two designs, a three-dimensional model was created to ensure physical appearance satisfaction.

Prototype

A prototype was made using a combination of high-density construction foam, low-density expandable foam, automotive body filler, and some glass fiber impregnated with polyester resin. The glass reinforcement was laid-up on the vehicle hood of choice to establish the contour of the hood. The front profile of the part design was printed out and attached to a thick sheet of poster board and cut-out. The poster board was placed on high-density foam sheets glued together with Gorilla glue and then was sanded smooth. The foam was glued to the glass fabric on the hood and expandable foam was sprayed underneath to fill in the voids. The foam was covered in a layer of body filler and sanded to a smooth finish. One layer of glass fabric was laid-up over the prototype and the hood using polyester resin. Once cured, the prototype and glass fiber part were removed from the hood and separated from one another. The glass fiber part was trimmed and the front half was separated from the rear half due to mandatory overhang. The prototype part was created from just one layer of glass fabric whereas typically they require at least three layers to be structurally rigid.

Mold Making

Depending on the company, mold making for all four materials mentioned could use the same process. The molds could be cast aluminum or machined from a block of aluminum. For thermoforming, the aluminum mold would be placed on top of a box made from wood, steel, or a number of other types of materials. The mold would also need vacuum holes drilled into it to allow the machine to draw a vacuum between the mold and the plastic sheet to form the part.

If the company doesn't have the budget for more expensive molds, or only small production runs are required, the molds could be made from less expensive materials. For this project, the vacuum boxes were made with 3/4" (19.05mm) thick birch plywood. Birch was used because the pores of the wood are smaller than other woods which helps keep the box airtight. The plywood was cut to size and then screwed and nailed together. Since the boxes were quite large, reinforcement baffles were installed inside the box with portions of the baffle cut out so the entire box could still draw vacuum. This box was then covered in a layer of luan sheet. The luan skin rises above the plywood vacuum box roughly 1/4" (6.35mm) which helps keep the mold air tight when the mold is pushed into the pliable plastic sheet. The luan was attached with nails and the entire box was covered in duct tape, with the exception of the top surface of the mold. The duct tape ensures the box stays air tight throughout the molding process. Using a hole-saw, a hole was cut in the center of the bottom of the box for vacuum line fitting.

The front half of the prototype mold was waxed and set inside a box and Repro slow-cast urethane was poured around the prototype mold to produce a female mold. Repro is a two part rigid urethane cast used primarily to make thermoforming tooling. The mold was waxed 1/2" (12.7mm) birch plywood, cut to the general contour of the mold and offset by roughly 1/4" (6.35mm), then laid inside the female mold to fill up space and lower the overall cost of the mold. More Repro was poured into the mold and around the plywood to establish the finished front half of the mold. Once the finished male mold was removed from the female casting mold, the male mold was aligned on the vacuum box top surface. The mold was traced to the top surface and the mold was removed. A layer of automotive body filler was placed along the traced contour. Before the body filler was allowed to cure, the male mold was placed back in position on the top surface and a fillet was established using a finger. Once the body filler cured, the mold and the fillet were sanded smooth, the vacuum box was bolted to metal c-channels to provide extra height. The top surface, including the mold, was then re-attached to the vacuum box. This mold is shallow, only 2" (50.8mm) deep, with little to no degrees of draft.

The rear half of the mold was cast from the glass/polyester prototype part. The vacuum box top surface was removed and the glass fiber part was set on top. Plywood was cut to the contour of the part and silicone caulking was used to seal the edges. Two holes were cut on each center light-housing to allow air to escape and to enable quick casting. Once the Repro was cured, the glass/polyester and wood were removed and the vacuum box top surface, including the newly-cast mold, was reattached to the

vacuum box for forming. Unfortunately, due to time and budget restraints, only one set of molds was created.

Part Forming and Trimming

Both parts were formed using the same settings, with the exception of height. For both molds, the ABS plastic sheet was heated to 345°F (173.9 °C) for 145 seconds. The sheet was heated at a slower pace than what is typical for ABS due to the fact that the ABS sheet in stock had absorbed some moisture. The part was formed using 27” of mercury (1.01 bar) and cooled for 120 seconds using 8 psi (0.55 bar) of air pressure.

The first mold formed was for the front half of the part. After the part was removed from the machine a band saw was used to roughly cut out most of the surrounding plastic. A flush trim router bit was used to trim the rest of the excess plastic away from the part.

The second mold formed was for the rear half of the part. After the part was removed from the machine a band saw was again used to roughly cut out most of the surrounding plastic. A flush trim router bit was used to trim the rest of the excess plastic away from the part and a band saw was used to cut the contour of the flange. The two halves of the part were joined using bolts, plastic epoxy, and an airless plastic welder.

Installation

Once the trimming was completed each light had to be drilled in three places and rivets were used to hold custom-made brackets 120 degrees apart to the light housing. Each light was attached to the light pod using bolts, nuts, and springs for easier aiming of the lights.

The pod was placed on the hood and four holes were drilled through both the light pod and the hood of the vehicle - one behind each of the center light housings and one along each outer light-housing. Clevis pins were used to hold the light pod to the hood for quick and easy installation and removal. Due to the weight of the lights and the loss of structural integrity caused by cutting the holes for the lights, the light pod was shaky. A bracket was made using 3/16” (4.76mm) thick metal stock. This bracket was bolted to the front of the light pod and attached to the hood with a clevis pin. All four lights were wired in compliance with the manufacturer’s instructions and quick disconnects were used between the light wiring and the wiring leading up to the lights. The quick disconnects allow for quick and easy installation and removal of the light pod.

Forming Tegr

Tegris parts are currently made using the compression molding process. Compression molding is similar to thermoforming, however the sheet is placed into a two piece matched metal mold, similar to an injection mold, and the mold is heating to processing temperature. The mold is clamped together under high pressure and then cooled while still held under pressure. When compression molding Tegr, the mold is heated to 250°F (121.1 °C) and the mold is clamped using 300 psi of pressure.

Two attempts were made to thermoform the Tegr sheet. A

shallow mold was selected so no issues of deep draw would be present. The sheet was cut and placed in the clamp frame. For the first attempt the sheet was heated to 350°F (176°C). Once the clamp frame shuttled out of the oven it was evident that the Tegr had shrank enough that the sheet pulled out of portions of the clamp frame. Since the material shrank out of the clamp frame, the sheet was not capable of holding a vacuum seal across the mold so forming was impossible. For the second attempt, the sheet was heated to 450°F (232°C) to study the effects of heating the material. At 405°F (207.2 °C) the machine was stopped because the material shrank out of the clamp frame. After looking at the forming data for compression molding Tegr, it was decided to place a sample of Tegr in a drying oven until the material reached 260°F (126.7 °C). Once it reached the desired temperature, the material was removed and checked for pliability. At this temperature it was decided that the material was not pliable enough to thermoform with the machine at hand without risk of damage.

Izod Impact Testing

An Izod impact test was conducted on three of the four materials: glass fabric/polyester, ABS and Tegr. Unfortunately carbon fabric/epoxy could not be obtained for testing. The samples were all 2.5” x 0.5” x 1/8” (63.5mm x 12.7mm x 3.18mm). The glass fiber and ABS were both impacted with a 5 ft/lb (6.78 N/m) hammer and the data was collected. Tegr required a 30ft/lb hammer due to its strength. All the data collected is displayed in Figure 1. The figure illustrates the strongest material tested was the Tegr thermoplastic composite. This is due mainly to the sample bending and twisting underneath the impact surface of the hammer. Also note that the ABS has almost as high of impact strength as the glass fiber composite.

FIGURE 1

RUN	ftlb/in	NATURE OF BREAK
Acrylonitrile Butadiene Styrene (ABS)		
run 1	3.437	Complete Break
run 2	5.015	Hinge
run 3	3.711	Complete Break
average	4.054	
Glass Fiber		
run 1	4.543	Complete Break
run 2	5.348	Complete Break
run 3	5.372	Hinge
average	5.088	
Tegris Thermoplastic Composite		
run 1	13.469	Non-break
run 2	16.179	Non-break
run 3	12.278	Non-break
average	13.975	

Time and Cost Comparison

Low cost materials from Walmart were used to make the glass fiber prototype. The costs of this one-layer prototype part were \$30 in glass fiber mat and roughly \$10 in polyester resin. Again, at least three layers are required to make this part structurally sound and cost about \$100 in materials. It took 4 hours between preparation, laying up the glass fiber, and waiting for the resin to cure.

It would take two full sheets of general purpose ABS at a price of \$50 per 4' x 8' (1.2m x 2.4m) sheet to yield 3 complete parts which equals about \$33 per part. It took 10 total minutes to make both pieces of the part and another 20 minutes for post-processing trimming and joining the two halves together.

At a wage of \$10 per hour it would cost a total of \$38 per part including labor to thermoform the part from ABS. At the same wage it would cost a total of \$140 per part including labor to make one part from glass fiber/polyester. This results in significant time and cost savings by thermoforming these parts compared to using glass fiber. If a thicker sheet of ABS was used, the mandatory overhang could be eliminated and the part could be made in one piece. This would lead to greater cost savings since only one mold and one vacuum box would need to be made. This would also require one sheet slightly larger than one of the two sheets used in this project and would also lead to 5 minutes per part rather than 10. This would also save money by eliminating post processing joining of both halves since they were molded together.

Improvements

There are a few quality issues with glass fiber layup. One issue to watch out for is delaminating. If an air pocket exists in the part, overtime it could grow and separate the layers of the glass fiber part, resulting in a weak spot.

One improvement that thermoplastics have over glass fiber and carbon fiber thermoset composites is the ease of repair. If glass fiber gets cracked it requires a lot of work to repair. First, the end of the crack needs to be drilled through so the crack does not continue to grow. Then a bore is drilled along the entire crack. This allows dry glass fibers to be added to the crack without increasing the thickness of the part. Once these fibers are laid inside the channel, resin is stippled onto the dry glass fiber strands and the excess is sanded off. To repair a crack in a thermoplastic, the crack could be plastic-welded by either a hot air plastic welder or an airless plastic welder. A hot air plastic welder heats a rod of plastic, the same material as the part, with a hot jet of air and the plastic bonds the part back together. An airless plastic welder is essentially a soldering iron with a flat tip. The iron heats up the plastic and bonds the two sides together. A plastic filler rod could be used to provide more material if needed but is not necessary. An airless plastic welder does not provide a uniform weld whereas the hot air plastic welder does. The excess material could then be sanded smooth.

An improvement of thermoforming over thermoset composite layup is the result of experimentation with different materials. Traditional composites have a limited number of materials that can be used for this process, whereas thermoforming allows for

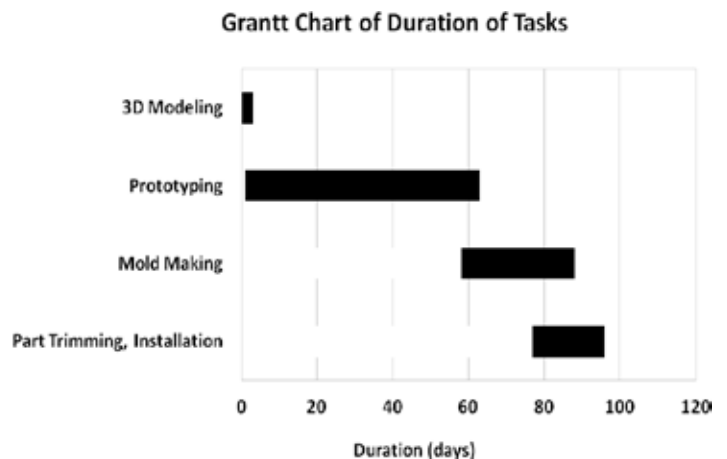
a wide range of materials that can be used. To prove this point, one part was made from 1/8" (3.18mm) thick ABS and one part was made from the front piece mold out of Kydex. The Kydex sheet was 1/4" (6.35mm) thick and is a combination of ABS and polyvinyl chloride, or PVC. The part formed well and was ejected early to reduce the chance of the part sticking to the mold since the mold had little draft. A part would have been made from the second mold however the sheet in stock was a little smaller than what was needed.

A third improvement occurs in using a thermoplastic rather than the glass fiber or carbon fiber composite. Glass fiber and carbon fiber polyester or epoxy can only be molded once and can only be used on the vehicles the parts were made for without extra modification. Some parts may be modified to fit other vehicles by either cutting pieces away or adding more glass/carbon fiber to essentially make the part fit. Since thermoplastics are capable of being reheated and reshaped it is possible to take a model-specific part and with the use of a heat gun reshape the part to conform to the vehicle. This means that almost every part could be declared universal.

Breakdown of Time

This project began on January 22nd, 2013 and was completed on April 21st, 2013, lasting a total of 90 days. Designing took 3 days, prototyping took 62 days. It took 30 days to make both molds and form parts and 19 days were spent trimming and installing the parts. Some of these phases were done during the same time frame as illustrated by Figure 2.

FIGURE 2



Conclusions

According to all the data collected and analyzed it can be determined that there is adequate evidence to illustrate the theory that replacing composite products with thermoformed equivalents is not only cost effective, but time effective. Quality of the parts increase and repair is also quick and easy. It is also plausible that Tegriss thermoplastic composite is not thermoformable without the use of a machine capable of forming at high pressures.

Appendix



Three-Dimensional Model Design



Prototype Mold



Front Mold Casting Cavity



Front Mold Complete



Rear Mold Complete



Finished Product Installed on Vehicle

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From the Editor

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

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

- New materials development
- 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:

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Plastics Technology Education at Illinois State University

Illinois State University's campus is in the twin-city community of Bloomington-Normal near the geographic center of the state midway between Chicago and St. Louis along Interstate 55.

Kiplinger's Personal Finance magazine has ranked Illinois State in the top 100 public universities in the nation for quality and value. The school provides a large-university educational experience with access to state-of-art equipment and faculty with industry experience while offering a small-school atmosphere of individualized attention to student learning with small class sizes.

Courses related to the design and manufacturing processing of plastic materials are housed within the Engineering Technology major of the Department of Technology at Illinois State University.

The Engineering Technology major offers students a comprehensive overview of manufacturing technology. Required subjects include computer-aided design, material testing, plastics processing and process control, machining methods including CNC, electrical circuits and machines, automated fluid power including robotic control, quality control, engineering economics, and project management for manufacturing.

There are five laboratories within the Engineering Technology major that define the scope of design and processing equipment with which students acquire experience.

1. **Automation Lab** with ten identical state-of-the-art ABB articulating arm robot training stations. This lab also houses PLC training stations with integrated pneumatic actuators and vision systems. This lab was made possible by a \$1 million grant from the Caterpillar Corporation.

2. **Molding Lab** with a 30x36 MAAC ASP cut-sheet thermoforming machine, two Engel hydraulic injection molding machines (30 and 60 tons), a 3/4 inch Brabender extruder (outfitted for extrusion of sheet, tubing, and basic profiles), an electric rotational molding machine with an 8 cubic foot oven, a 30-ton Wabash compression molding machine for the processing of thermosets, and cranes and work benches for mold assembly projects. Much equipment in this lab was purchased with financial support from the Society of Plastics Engineers and other industry donations.

3. **Design Lab** with Autodesk Inventor and Siemens NX constraint based parametric solid modeling. The lab also houses a Dimension fused deposition modeling rapid prototyping machine.

4. **Material Testing Lab** with an Instron UTM and a TMI instrumented impact tester to demonstrate the mechanical properties of metals, plastics, and wood. In addition, students conduct heat treatment of metal and analyze the creep behavior of plastics.

5. **Machining Lab** with vertical mills, engine lathes, and a HAAS TM1 3-axis CNC milling machine.

Because of the diverse exposure to design and fabrication methods, some students work on projects involving the design and fabrication of tooling that is used to form or mold products in the Molding Lab.

Find out more information on-line or contact Dr. Lou Reifschneider at lgreifs@ilstu.edu

1. Virtual tour of Engineering Technology labs at http://tec.illinoisstate.edu/Tec_Tours/

2. Engineering Technology curriculum at ISU at <http://tec.illinoisstate.edu/engineering-technology/>

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Plastics Engineering Technology at Pittsburg State University

Pittsburg, Kansas

www.pittstate.edu/departments/engineering-tech/plastics/

The Program:

The Plastics Engineering Technology program emphasizes detailed technical knowledge as well as real world application. The technology subjects range from general and processing to part and mold design and composites. Classes also include thorough reviews of problem-solving techniques for both production and managerial issues.

Because plastics is such a rapidly expanding field, both as a science and an industry, our curriculum keeps pace with changes and anticipates industrial needs. Our graduates are an important information resource, and we have an active industrial advisory committee.

The Career Opportunities:

The career advancement potential is demonstrated by the success of our graduates. For over 30 years, some former students have advanced to the corporate president level, several are plant managers, and many more are plant production supervisors. These positions are with companies throughout the country and the world. Students often begin their professional careers with such job titles as plastics engineer, production engineer, product engineer, and quality control manager.

Scholarships & Financial Aid:

The tuition is the best bargain around and probably the lowest you will find at less than \$3,000 for in-state and \$8,000 for out-of-state. There are also special programs to get discounted tuition with the Midwest Student Exchange, PSU Legacy Program, and Gorilla Advantage. The Plastics Program has also given out over \$45,000 in scholarships over the past few years to students in the program.

The Laboratories & Facility:

The plastics program is housed in the \$27.7 million Kansas Technology Center that is over a quarter of a million square feet and was built in 1997. The facilities and equipment for the plastics program include more than 42 pieces of sophisticated production and testing equipment. In addition, the plastics program works closely with the Kansas Polymer Research Center. The Kansas Polymer Research Center (KPRC) is an internationally-recognized center for chemistry and materials science with a specialization in vegetable oil-based polymer research and development.

Location:

Pittsburg State University is located in Pittsburg, Kansas, with a population of approximately 18,000. Located within a three-hour driving radius are Kansas City, Tulsa, Wichita, and Branson, Missouri. Our enrollment is around 7,000 students and we take pride in our emphasis upon personal instruction and faculty-student-staff interaction.



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Why Ferris State Plastics and Rubber Degrees?

- The plastics and rubber programs are recognized as a national model for Plastics education. It is estimated that 25% of the still continuing programs were modeled from the FSU programs.
- FSU plastics and rubber alumni are sought after by the industry. Many industry job descriptions include "Ferris like skills."
- Companies are actively seeking FSU plastics and rubber alumni as demonstrated by the nearly 100% placement of graduates since the first graduates exited the University.
 - **Average salary 2012- \$53,000 to \$70,000/yr**
- Employers prefer FSU graduates. In most instances, their contribution is almost immediate. The learning curve was absorbed during their undergraduate experience.
- It is estimated that 50% of the local (West Michigan) engineering staff are made up of FSU "Plastics" graduates. In many of these companies, the complete staff is comprised of FSU grads.
- Industry continues to support the program through donations of materials and equipment and consignment of larger pieces of equipment. This demonstrates the value of the program as perceived by industry leaders.
- FSU Rubber program is still relatively unknown; companies are continuously contacting FSU as they identify the Rubber degree as a source for employees.
- Paid internship experiences reinforce the practical "hands-on" approach of the program.
- A broad range of career opportunities from sales and marketing, process engineering, product engineering to materials development is available.
- Strong industry support assures laboratories and faculty stay current with technology
 - Industry-consigned equipment
 - Industry-funded scholarships
 - Industry-funded/supported undergraduates

UNIVERSITY NEWS



2013 Scholarship Winner

Victor Batarseh grew up in Sacramento, California. He is currently an undergraduate Chemical Engineering student at Drexel University in Philadelphia, PA. At Drexel, Victor is part of the Cooperative Education Program where he does research and development at Arkema, Inc. for transparent and translucent impact-modified biopolymer alloys for applications ranging from consumer products to coextruded sheet for thermoforming. In the future, Victor hopes to make plastics more sustainable by increasing renewable carbon content, and improving current processing techniques for raw materials.

The Benjamin Memorial Scholarship is endowed by the family of 2003 Thermoformer of the Year, Bill Benjamin. This is the first year that the scholarship is being awarded. |

Need help with your technical school or college expenses?

If you or someone you know is working towards a career in the plastic industry, let the SPE Thermoforming Division help support those education goals.

Within this past year alone, our organization has awarded multiple scholarships! Get involved and take advantage of available support from your plastic industry!

Here is a partial list of schools and colleges whose students have benefited from the Thermoforming Division Scholarship Program:

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- San Jose State
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- Ferris State
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the end of the day, allow you to decide whether thermoforming is a science or still a black art.

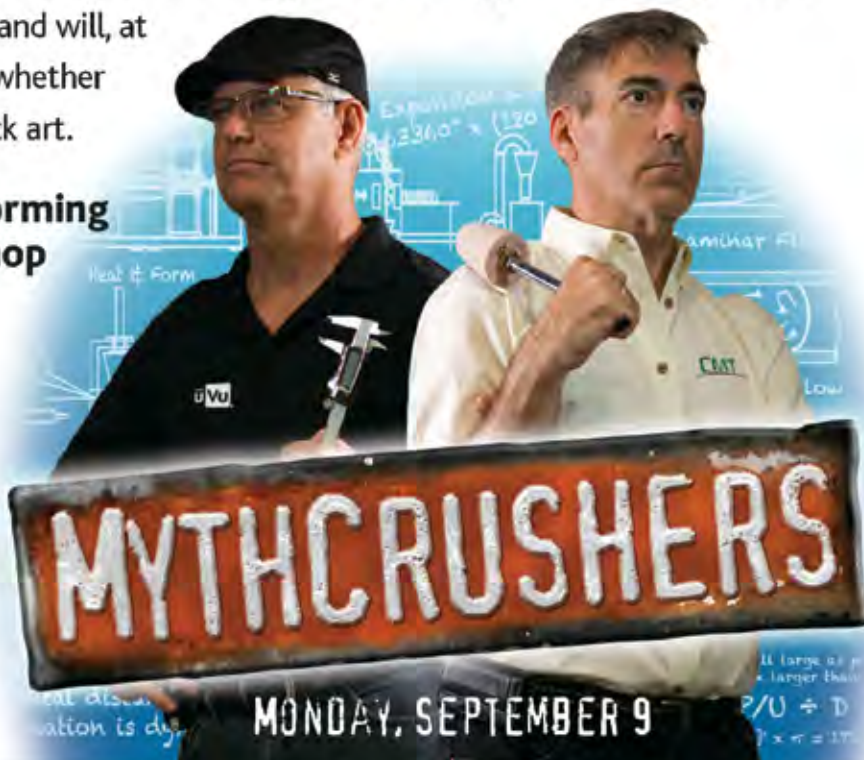
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Direct Digital UV Imaging for Deep Draw Thermoforming

By Spencer Craig, Director of Business Development

EFI Inkjet Solutions

When it comes to commercial development of decorated industrial and consumer products, the thermoforming market faces significant limitations in speed and quality. Traditionally, decorated thermoformed plastic is accomplished primarily through post-forming decoration, decals, self-adhesive labels, air-brushing, etc. Pre-forming decoration – applying graphics to sheets before forming – removes the time-consuming, manual steps required in decoration processes.

More technically savvy formers have implemented pre-forming decoration using analog screen printing inks, but that still has significant limitations. Now, with some new advancements in ink chemistry, superwide-format inkjet digital printers can offer the quality and time-saving benefits of pre-forming decoration while eliminating the full-color imaging and supply chain management challenges that analog screen printing presents.

Pre-forming decoration using screen printing has rightfully found a place in the thermoforming market because, compared to post-forming decoration, it can certainly save time, labor and effort. But compared to other printing processes, screen printing can still be time-consuming and costly, and it can be very wasteful. Screen printing requires an extended make-ready process, where sheets of expensive substrates such as ABS are printed as waste just to get inks to stable levels for saleable product. The more ink colors a decoration requires, the longer the make-ready process takes.

One typical example is a pre-forming decoration process recently observed at a thermoforming facility. The company had at least \$5,000 invested in this six-color, 2'x4' thermoformed screen print job before a usable print came off the company's screen print device. Not only were there numerous sheets of make-ready waste, the company had a few staff members spend a total of approximately 60 hours doing prep labor.

Screen printing jobs of this nature typically do not become profitable to produce until the up-front prep costs are amortized across a large quantity order: perhaps 500 or more pieces. Make-ready waste, which is often 10% or more of the entire number of sheets printed, figures into this calculation as well. Thermoforming materials are not cheap compared to other substrates used for printing, and the higher the cost, the higher the run length needed to preserve profitability.

This type of large, up-front investment with screen printing – especially with multicolor work – makes digital printing an attractive option. On the six-color printing project mentioned

above, for example, prep time could take as little as one-two man-hours using a digital inkjet printer. There is also little to no make-ready waste with inkjet pre-forming decoration, as the printers do not need to run a large number of sheets before the inks and colors are stable.

On some larger, more-expensive thermoforming projects, such as the cartop carrier shown here, the costs associated with make-ready waste in full-color screen printing would be difficult, if not impossible, to absorb. And, in cases like these, digital may be the only decoration option outside of manual methods.

Bringing digital printing to thermoforming

Inkjet printer manufacturers have talked about this type of advantage with screen printing firms for years, but mostly in relation to two-dimensional signage applications. Inkjet inks historically could not handle the heat and stress of the forming process.

Recent developments in inkjet ink chemistry have yielded the first stable, high-quality inkjet inks that can withstand thermoforming. Recently, EFI – one of the leading manufacturers of wide- and superwide-format UV-curable inkjet printing equipment – introduced EFI VUTEk GS-TF ink, a UV-curable inkjet product that withstands the thermoforming processes. It is a high-elongation ink that enables deep-draw thermoforming with excellent adhesion and superb retention of hue and opacity. EFI VUTEk GS-TF is designed to stretch as much as the plastic on which it is printed, and can easily be implemented even in instances where the ink touches the mold.

Thermoformers, signage and printing companies, and industrial manufacturers can use the ink to print directly onto thermoplastic sheet or roll materials, which can then be formed into parts. The ink – which comes in an eight-color process imaging set, plus white ink – runs in newly launched EFI VUTEk GS2000 Pro-TF and GS3250 Pro-TF printers, which are special versions of EFI's VUTEk GS Pro series printers optimized for thermoforming work.

UV-curable inks are already a popular choice in imaging applications because they are durable, adhere to a wide range of substrates, and are cured with UV lamps, therefore requiring no drying time. With the GS-TF product, an initial cure from UV lamps installed on the printer changes the properties of the liquid ink film so it acts like a thermoplastic. At that point, it exhibits a glass-transition temperature right in the range of all common thermoplastic materials and will stretch without smearing or swirling at those temperatures.

While the adhesion of the ink is high after the initial cure, it

remains somewhat softer than traditional, UV-curable inks used in other inkjet printing applications. However, as the printed part proceeds through the thermoforming process, the heat of thermoforming starts another change in the ink's properties, changing the ink so it has a hard, glossy surface with excellent adhesion and scratch resistance.

As a result of the changes made for this newly developed formulation, GS-TF inks withstand heat forming, cutting and routing without cracking, chipping or losing adhesion, with moisture resistance and a durable life resulting in long-lasting graphics. The new printers and inks provide excellent imaging at a 600 dots per inch (dpi) resolution, or a 1,000 dpi resolution for even higher-end graphics. Additionally, the use of high performance enhancement coating helps protect decorated parts in more robust applications where greater abrasion resistance, fade resistance and chemical resistance are needed. These enhancement coatings can be screen printed, roll coated and sprayed. They are also available in UV, Water-Based and solvent-based formulations.

EFI VUTEk GS-TF thermoforming ink's elongation capabilities are enhanced by its high opacity on a broad selection of materials, including PETG, acrylics, polycarbonates, polystyrenes and ABS, plus derivatives and mixes. This makes it ideal for applications including outdoor electrical signage, point-of-purchase displays, backlit vending/gaming panels, automotive/RV recreational parts, consumer products, packaging and industrial product decoration.

The ink has been used successfully in applications with 24" of draw, greater than 1,000% elongation, extremely high aspect ratios (<30:1), and very tight radii of curvature. The cartop carrier shown is one of the first pre-forming decorated parts made with the ink, and it is printed on 1/8"-thick ABS, has 13"+ depth of draw with 30:1 aspect ratio in certain areas.

Other examples of pre-forming decorated objects produced with the ink to date include a miniature version of the same cartop carrier part on various substrates, including 1/8"-thick ABS or Styrene with the image printed on the top surface, as well as 1/8"-thick PETG, acrylic and polycarbonate, with the image printed on the bottom surface. Those sample jobs had 33:1 aspect ratios and 1/32" radii of curvature.

Another sample produced with the ink incorporated drape-forming on parts made of 0.06" styrene, showing excellent retention of hue and opacity at extreme percentages of elongation, greater than 1,000%.

Test users have also used the ink to produce cowlings, shields, bumpers and deflectors for cars, trucks, all-terrain vehicles, boats, snowmobiles and trailers. The ink has also been used to decorate bath enclosures and there are many, many additional applications in development as thermoformers look to address unmet product decoration needs.

For thermoformers, signage companies and other industrial manufacturers, the advent of a thermoformable inkjet ink

presents financial advantages in color and response time. As mentioned earlier, pre-forming decoration eliminates many time-consuming methods, including hand air-brushing, a process that prohibits full-color imaging and requires time-consuming masking steps. Inkjet technology extends these benefits further, making pre-forming decoration a possibility for markets that have low-quantity requirements or specific customization and just-in-time fulfillment needs.

The signage market presents one good example of market segment where pre-forming digital inkjet decoration addresses an unmet need. Today, many thermoformed signs – such as fast food or service station monument signs – use simpler, one or two-color logos because of the prohibitive cost of multiple- or process-color decoration. This happens despite a great deal of evidence that full-color imaging drives higher revenue and response across nearly any form of advertising.

The thermoformed signage market, as compared to most other forms of printing, is a low-volume market; orders might be for a single sign or for very small batches produced on demand. A small, independent hotel, for example, might require a single, branded thermoformed backlit panel with its name and logo for entry sign(s) or a juice or vending machine it has in its lobby.

In those circumstances, analog printing of thermoformed graphics is unprofitable and unaffordable for signage providers. Companies that go the digital print route for pre-decoration can economically offer run sizes of one.

Beyond that, companies that want to reduce their up-front costs can move to pre-forming inkjet decoration to reduce the number of manufactured parts or signs they keep in inventory. Everybody in the supply chain can therefore manage to Just In Time inventory control, whether they need one copy this week or 100.

Creating new market opportunities

Initial reaction to the ink, which has been shown at sign industry trade shows in the U.S. and Europe, reflect the momentum possible to develop new markets in thermoformed graphics.

According to Barney Cox, a print industry consultant who saw the ink at the FESPA 2013 trade show in London, "EFI's introduction of thermoformable UV-curable inks, and the machines in which to use them, offers printers new opportunities for bringing digital printing's strengths to a broad range of innovative applications. This means that printers can offer customers high impact, short run, versioned and customized imagery that has an added dimension, appealing to the increased desire for personalized products."

This advancement offers, at a minimum, cost savings and business-model advantages similar to those experienced by the portion of VUTEk's traditional commercial graphics customer base that has converted from screen to digital printing. However, for some, the savings will be even greater, eliminating extremely labor-intense methods such as post-process hand airbrushing.

Businesses that use thermoformed parts but currently avoid

product decoration altogether can also consider decoration as part of a personalization, branding or advertising strategy. Recently, a manufacturer of hunting blinds, decoys, calving huts and portable structures saw a new opportunity in its low-volume business, using pre-forming inkjet decoration to create structures that can feature a customer's brand names, logos or some other decoration.

This is one of the more promising scenarios, as it shows how the ink can not only replace costlier options, but can grow the decoration market.

Thermoforming signage decoration with fewer steps – key VUTEk Pro-TF ink attributes:

- Ability to image direct to substrate prior to forming eliminates screen printing set up costs or hand painting and vinyl lettering process steps.
- Superior elongation characteristics support deep draw thermoforming while maintaining opacity on various plastics, including PETG, acrylic, polycarbonate, polystyrene and PVC.
- Inks are developed to withstand heat forming and cutting without cracking, chipping or loss of adhesion.
- Water and moisture resistance enable durable, lasting images. |



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An Introduction to Flame Retardant Plastics

Eric E. Unger, Research Leader for Advanced Polymer Systems
KYDEX, LLC

Although most people are exposed to and use flame retardant plastics every day, very few understand them or how they are made, how prevalent they are and what purpose they serve. Without a basic understanding of flame retardancy the reader may find the entire subject too complex and technical and boredom may ensue.

The curious reader may be drawn to learn more about such varied topics as flame sources, flame propagation, flame retardant mechanisms or flame behavior in the solid or gaseous phase. She may also want to understand flame testing including commercial, industrial, and governmental requirements; the role of regulatory agencies and their specifications and many, more aspects of flame retardant plastics.. The entire field of flame retardancy is vast, and this may unnerve someone who does not know where to begin. The following discussion is meant to familiarize the reader with some of the major areas of flame retardancy.

The nature of plastics themselves provides opportunities for combustion.. Most commercially available plastics are based upon hydrocarbons derived from petroleum and as such, they burn readily. Many polymers contain plasticizers or residual chemicals used in their manufacture and these are ideal sources of fuel.

In our everyday lives we constantly encounter items made entirely of plastic or use plastic-containing components. They are in our homes in electronic items such as televisions, computers, game consoles, multimedia systems, and telephones. They are in appliances such as stoves, refrigerators, microwave ovens, washers, dryers, dishwashers, water heaters, and furnaces. We find them in home lighting and wiring, and even in furniture.

You will find flame retardant plastics wherever you go. They are in commercial buildings such as restaurants, schools, department stores, movie theaters, night clubs, and hospitals; in all modes of transportation from automobiles to buses to trains, to subway systems, to boats and naval vessels, to aircraft and aerospace, including the International Space Station and the now-retired Space Shuttle fleet. It would be difficult to find an area or discover a place that is not touched by flame retardant plastics.

GLOBAL CONSUMPTION OF FLAME RETARDANTS

To get an idea of the global usage of flame retardants, we look at the FR market by quantity and then consumption based on volume by regions of the world.

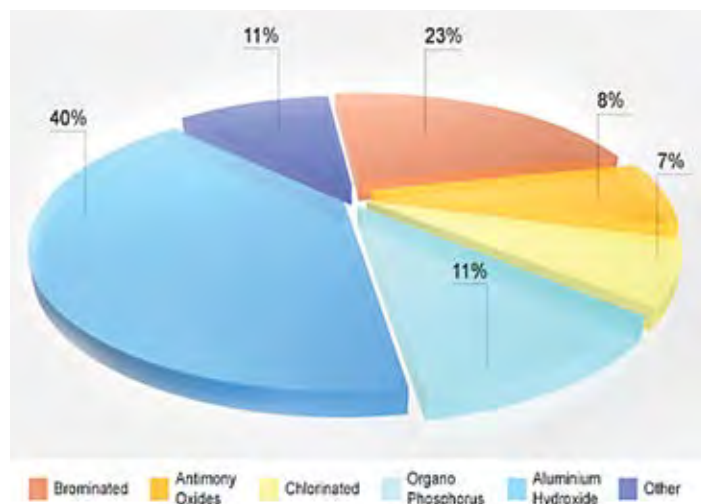


FIGURE 1 - Flame retardants market by quantity
(The base amount is 1.8 million metric tons, data for 2007)

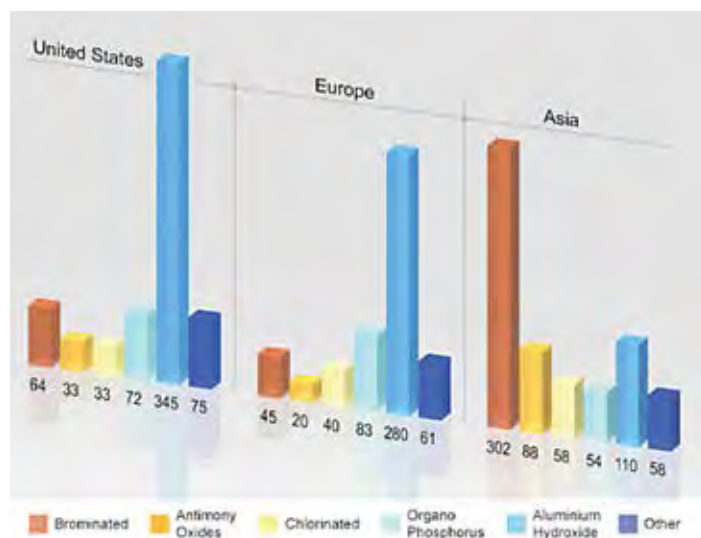


FIGURE 2 – Consumption of flame retardants by region, based on volume
(Figures are in 1000 tons, with a total of 1.8 million metric tons, data for 2007)

GLOBAL MARKET OF FLAME RETARDANTS

In terms of the overall global presence of flame retardants, we look at market size by value and sales of FR by regions of the world. Although this data is from 2007, it shows the major breakdown of flame retardants by type as well as geographical markets.

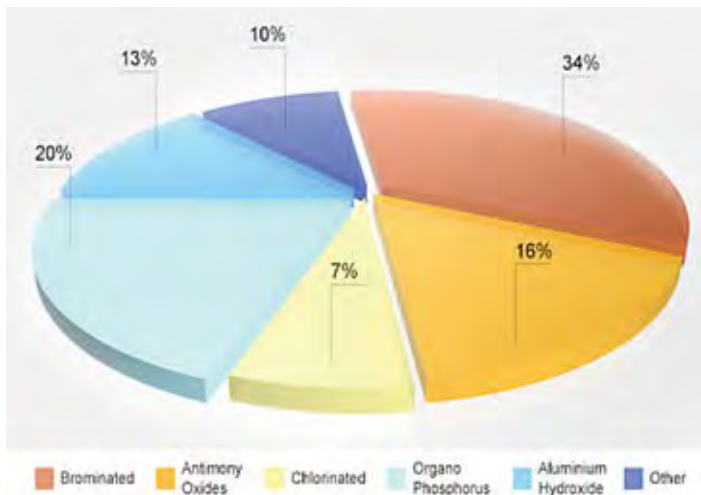


FIGURE 3 - Flame retardants market by value
(Representing a total of 4.2 billion \$US, data for 2007)

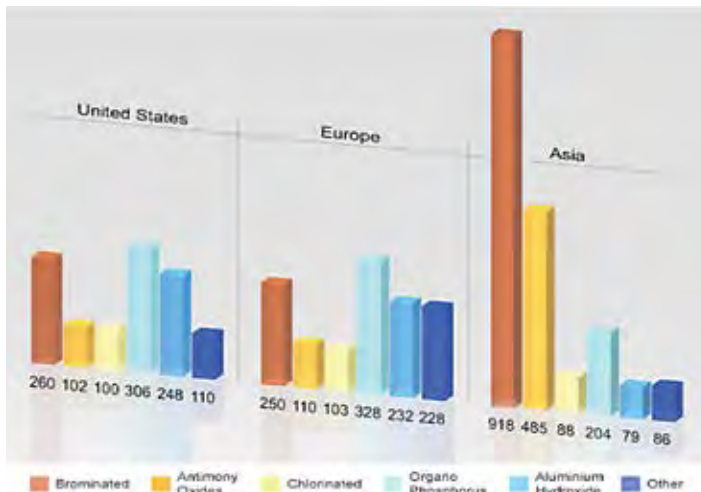


FIGURE 4 – Sales of flame retardants by region (Figures are in million \$US, with a total of 4.2 billion \$US, data for 2007)

We are virtually surrounded by products and articles made with plastics. Without some form of protection, these items can catch fire easily and engulf an area rapidly. Not only are there dangers from flames and toxic gases, but combustion gives rise to smoke which obscures vision and can prevent escape from burning buildings.



It is vitally important, therefore, to develop flame retardant plastics for use in those applications where the chance of fire is high. Flame retardant additives are critical in that they can either prevent a fire from occurring or they can hinder the spread of the flame.

FIRE

What is fire? Fire is a complex chemical reaction that takes place between fuel, oxygen, and a heat source. The process of combustion requires these three elements. Some examples of the fire triangle follow.



FIGURE 5- Visual representations of the fire triangle

To produce fire one must have not only a source of fuel or combustible material, but also heat to raise the material to its ignition temperature, as well as oxygen to begin and sustain combustion. Only if all three elements are present can a fire can occur. The diagram below offers a visual representation of the combustion cycle.

As the polymer is heated to its ignition temperature, flammable gases are released. If oxygen is present, this leads to the ignition of the polymer. As the polymer burns, the heat created by the combustion is not only given off to the surroundings, but some of this energy is directed back into the material allowing combustion to continue and spread.

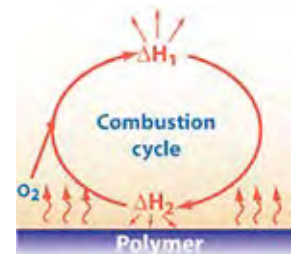


FIGURE 6 - The combustion cycle

Fires generally start slowly then increases as more fuel is consumed.



FIGURE 7 - Diagram of time vs temperature for fires

Flame retardant additives work by interfering with one or more of these fundamental conditions required for combustion, and depending upon the flame retardant, it may be physical or chemical in action.

FLAME RETARDANT MECHANISMS

The following illustrations are from Flame Retardants-Online (www.flameretardants-online.com), a website maintained by Clariant Produkte in Germany and from the Flame Retardants Center at SpecialChem4Polymers (www.specialchem4polymers.com). These will be the basis for viewing the combustion cycle and for focusing where the various types of flame retardants target this cycle to interrupt or end it.

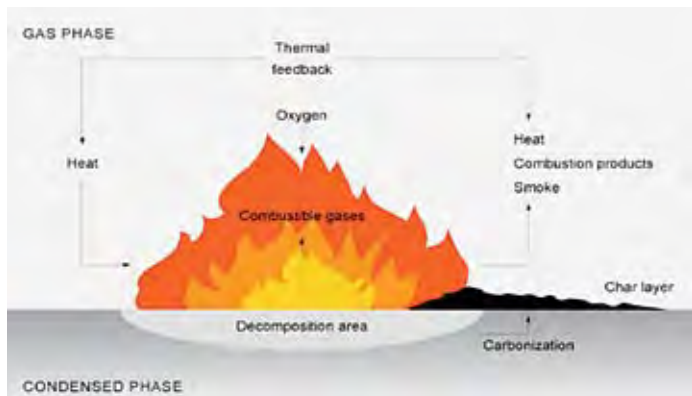


FIGURE 8 - Phases and components of fire

GAS PHASE INTERFERENCE: BROMINATED AND CHLORINATED FR ADDITIVES

As the polymer burns, the flame retardant reacts with the flammable gases in the gas phase and interferes with the production of high-energy free radicals, cooling down the system and stopping combustion. The free radicals HO and H can combine with X radicals from the halogenated flame retardant, forming less-reactive species which break the chain reaction.

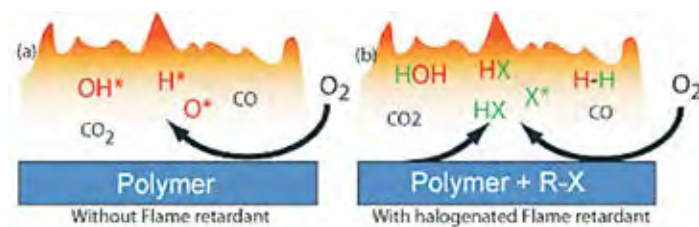
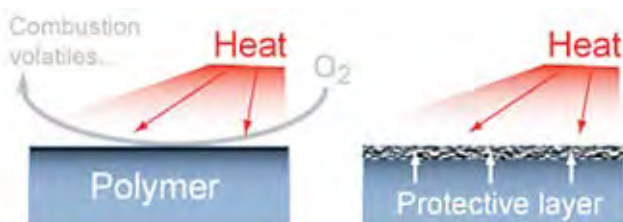


FIGURE 9 - Effect of flame retardant on combustion

CHAR FORMATION/THERMAL SHIELDING: PHOSPHORUS-CONTAINING FR ADDITIVES

A different chemical effect takes place in the condensed phase, as a char layer is formed on the polymer by the heat of combustion. This char layer is formed by a cross-linking process which protects the polymer by creating a barrier which reduces the heat



transfer to the substrate.

FIGURE 10 - Char layer formed on polymer by heat of combustion

Nitrogen-based flame retardants also form char on the surface of the polymer, and they act in the gas phase by forming non-combustible gases. In special cases, nitrogen and phosphorus can react with a carbon source to form intumescent coatings.

INTUMESCENCE: PHOSPHORUS- AND NITROGEN-BASED FR ADDITIVES

A special type of condensed phase mechanism is intumescence. As above, the amount of fuel produced is reduced and char is formed rather than flammable gases. Three basic ingredients are needed: an acid source, a char agent, and a blowing agent. These combine to form an insulating layer through carbonization with foaming.

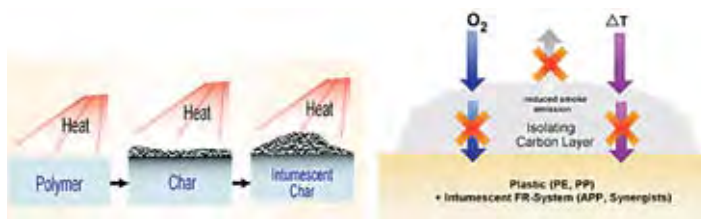


FIGURE 11 - Development of intumescent char and subsequent effects

Some boron compounds can also be used as flame retardants. Borax or boric acid forms glassy films at high temperatures; in some instances these can also be used together.

COOLING AND QUENCHING: HYDRATED MINERALS

Some flame retardants show a physical effect in the condensed phase and gas phase. These are the hydrated minerals, alumina trihydrate, $\text{Al}(\text{OH})_3$, and magnesium hydroxide, $\text{Mg}(\text{OH})_2$.

These degrade endothermically, absorbing heat and thus cooling the polymer surface. At the same time, as these minerals thermally decompose they release water vapor which also cools the substrate and dilutes the combustible reactants in the gas phase.

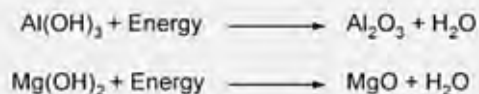


FIGURE 12 - Phase changes of hydrated minerals

TABLE: MAJOR FR APPLICATION MARKETS	
FR APPLICATION MARKET	PRODUCT EXAMPLES
Aviation	Aviation seating, window guards, wall partitions, stairways, lighting diffusers, compartment interiors
Rail / Metro	Seating, wall panels, window masks, enclosures and partitions, tray tables, HVAC ducts
Marine	Floor coverings, seating, furniture
Automotive	Under-the-hood components, interior compartment, seat backs
Electrical/Electronics	Components/parts in appliances such as ovens, refrigerators, dishwashers; office/home automation products, computer monitors, keyboards, telephones, wire/cable products
Building/Construction	Roofing, pipe and conduit, structural products, carpet backing, blown films and extruded shapes for window applications, wall coverings
Furnishings	Public institution furniture such as plastic stacking chairs, the mosaic laminates for countertops, walls, floors
Fibers/Textiles	Draperies, carpets, heavy-duty apparel, automotive interior fabrics

TABLE 1 - Major flame retardant applications markets

Care must be taken when compounding materials with these FR additives, as process temperatures above 200 °C for Al(OH)₃ and 300 °C for Mg(OH)₂ will cause these minerals to give off their water of hydration. If this occurs during processing, the compounds will be negatively affected. These flame retardant compounds are found in many markets (see Table 1).

The choice of flame retardant is dependent upon many factors including the resin to be protected, end-use application, specifications, agency regulations, and cost. In transportation applications, the level of performance required is proportional to the hazard situation of the mass transport considered. The more time needed for escape, the higher the requirements of the regulation.

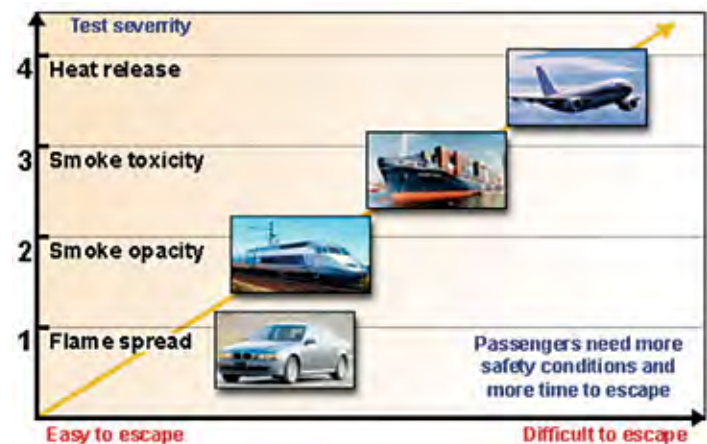


FIGURE 13 –Determination of regulation requirements

For flame retardant plastic applications, specific requirements are written around the flammability performance of the compound. Diverse markets and end-uses dictate the creation of a multitude of specifications each with its own unique set of requirements.

The following is a description of some of the flame retardant tests used in the plastics industry. This list is not all-inclusive, but rather gives some of the more common tests frequently encountered.

FLAME TESTING

Underwriter’s Laboratories, UL94

Testing involves clamping a sample in a holder and applying a specified flame in multiple passes and observing after-flaming, after-glow, as well as any dripping. There are classifications for horizontal burn, HB, as well as vertical burns V-2, V-1, V-0, and 5VA, 5VB. Each of these tests addresses ease of ignition, flame spread, burn rate, intensity of burning, and dripping. These ratings can be applied to multiple thicknesses and colors, based upon customer requirements.

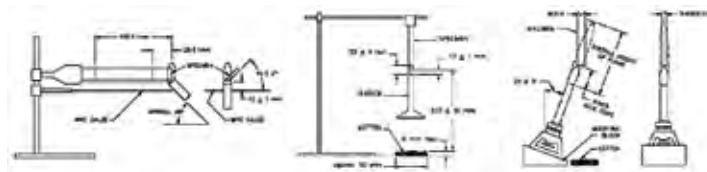


FIGURE 14 – Diagram of UL-94 test procedure

ASTM D-2683, Limiting Oxygen Index, LOI

Vertical burn test in which a specimen is supported in a cylinder filled with an oxygen-nitrogen mixture. The LOI value indicates the minimum percentage of oxygen needed to maintain combustion. Since air typically contains approximately 21% oxygen, any value below 20-21% means that the sample will burn readily.



FIGURE 15 - Diagram of ASTM D-2683 test procedure

ASTM E-84, Surface Burning Characteristics of Building Materials

Testing involves comparative surface burning behavior of building materials such as ceilings and walls, by observing the flame spread along the specimen. Sample size is quite large, nominally 24 feet in length. Smoke Density is also recorded.



FIGURE 16 - Photos of ASTM E-84 test procedure

ASTM E-162, Surface Flammability of Materials Using Radiant Heat Energy Source

Testing involves observing and measuring the surface flammability of a material when exposed to a prescribed level of radiant heat energy. The rate of flame spread across the surface, the Flame Spread Index, can be used to compare against other plastics or to certify to a specification.



FIGURE 17 - Image of equipment used in ASTM E-162 testing procedure

ASTM E-662, Specific Optical Density of Smoke Using Radiant Heat Source

Testing involves determination of the optical density of smoke generated by solid materials. The test employs a radiant-energy heat source delivering a specific irradiance level, and can also include a flaming condition, wherein a six-tube burner across the lower edge of the specimen adds flame in addition to the radiant energy. A photometric system with a vertical light path is used to measure the varying light transmission due to the accumulation of smoke with time.



FIGURE 18 - Equipment used in ASTM E-662 testing procedures

ASTM E-1354, Heat Release via Cone Calorimeter

Testing involves placing specimens horizontally under a conical heater. A spark ignition source supports ignition of the gases. There are two different irradiance levels available from the electric heater, 25 kW/m² and 50kW/m². Heat Release and Average Rate of Heat Emission are calculated and recorded for each energy level.

FIGURE 19 - Equipment used in ASTM E-1354 testing procedure



FAR 25.853, Federal Aviation Regulation, 14 CFR, Ch. 1, Section 25.853, Compartment Interiors

FAR 25.853(a): A vertical burn test with two components, (i) a 60 second test and (ii) a 12 second test. There are established limits for flame time, drip extinguish time, and average burn length.

FAR 25.853(d): This is also a two part test. Section (a) measures Smoke Density as in ASTM E-662; Section (b) measures Heat Release, both the average Total Heat Release during the first 2 minutes and also the average Peak Heat Release Rate in a 5 minute test.



FIGURE 20 - Equipment used in FAR 25.853 testing procedure

FMVSS 302: Federal Motor Vehicle Safety Standard 302, Flammability of Interior Materials

This standard specifies the burn resistance requirements for materials used in occupant compartments of motor vehicles. The Federal standard mandates maximum burn length and flame front travel across the surface of the specimen.



FIGURE 21 – Equipment used in FMVSS 302 flammability testing

Besides flammability and smoke density requirements, many applications also require toxicity testing. The sample is burned and the resultant gases given off are collected and analyzed. Specific gaseous species are listed along with their maximum allowable levels. If the gases measure below these permissible limits, then the compound 'passes'.

The various flammability and toxicity tests were specifically designed by governing bodies of the respective market segments in order to ensure that the materials being supplied to these markets were safe and effective. The tests were designed to represent the type of flammability situation that might actually be encountered in the respective businesses. As such, once a material has been tested and passes all of the requirements, the end user can have confidence that the flame retardant compound will perform as expected in the field.

In addition to industry-directed standards, there are many governmental regulatory agencies involved which establish guidelines to address the impact of these flame retardants on the environment, the disposal of flame-retardant plastic articles after they reach their end-of-life cycle, recycling of flame retardant components, and many other issues. Environmental concerns have resulted in global legislation and directives aimed at reducing or eliminating the use of specific chemicals used in the manufacture of these FR materials and to enforce compliance to far-reaching initiatives.

The European Union has initiated many directives, among them the Restriction of Certain Hazardous Substances (RoHS); Waste in Electrical and Electronic Equipment (WEEE); and Registration, Evaluation, Authorization, and Restriction of Chemical Substances (REACH). These were put in place in order to prohibit the import of hazardous substances into the EU. The European Community has also begun the White Flower initiative, which is an eco-labeling program to promote environmentally-friendly materials.



FIGURE 22 - EU White Flower Eco-Label

Many of the individual EU member countries have also begun their own eco-labeling initiatives, and there are now hundreds of different eco-labels from countries around the world.

These issues become essential if one considers the use of flame retardant materials in countries other than the United States. Individual governments exercise their right to exclude plastic materials from being imported into their country if they contain specific chemicals included in these hazardous substances lists.

The field of flame retardant plastics is vast and complex. The issues involved range from the chemistry of the flame retardant mechanisms at the molecular level to domestic and international policies and politics at their highest levels. This field continues to fascinate as it evolves. |

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RICH FREEMAN President, Freetech Plastics



Richard Freeman has been involved in plastics manufacturing and design for over 45 years, the last 37 with Freetech Plastics where he has participated in the design of hundreds of products. One of the founders of the “West Coast” style of thermoforming, he has been a regular speaker at industry conferences including ANTEC, SPE Thermoforming Conference, and IDSA programs both in the United States and in Europe. Rich spent 21 years as a SPE Thermoforming Board member where he helped develop the annual thermoforming conference as a heavy-gauge program organizer. His unflagging efforts on behalf of the industry have benefited not just his own company, but thermoformers as a whole. As fellow SPE board member Haydn Forward said, “Rich forced us all to get better.”

His experience providing pressure formed products in the close tolerance, technically demanding, and highly competitive environment of Silicon Valley has led to a number of process and design innovations. It has given him a unique perspective on production, quality, marketing, and design issues. Freetech’s products have won numerous industry awards including the 1996, 1999, and 2004 People’s Choice Awards, the Thermoforming Industry’s top prize. Freetech has provided pressure formed parts

for 12 ID/IDEO/Innovation Magazine award winners.

Rich’s articles, company and products have been featured in publications such as Plastics Engineering, Appliance Manufacturer, Innovation, Machine Design, Plastic News, Mechanical Engineering and International Designer to name just a few. He has spoken on many issues important to designers and manufacturers over the years.

While Chairman of the Asset Allocation Review Committee, he launched and managed the Thermoforming Division’s Machinery Grant Program which has placed equipment in over 25 schools and universities. These machines have been used to produce thousands of student-designed parts, many of which have gone on to win national awards.

Rich started and continues to sponsor the IDSA Student Thermoformed Parts Competition that encourages schools to use the equipment donated to them and teach students about the thermoforming process while providing thousands of dollars in scholarships. Focusing on design schools and their students helps develop future demand for our industry and its products.

Rich has been an IDSA member since 1999 and has spoken on Thermoforming at several IDSA National and Regional Conferences. He has also been a sponsor of both national and regional IDSA conferences since 2000.

He organized three SPE Thermoforming Division exhibits at the Industrial Designers of America conferences. Starting in 1999 at the New Orleans IDSA Conference, the Division exhibited 60 products from 29 thermoformers. Two more major exhibits were put on, in Boston and in Monterey. This work has been instrumental in getting thermoforming recognized as a viable process by the design community. Rich has continued to do this on his own at IDSA the last 11 years.

He developed and maintained the first three versions of the SPE Thermoforming Division website. By putting industry resources such as Thermoforming Quarterly, Thermoforming 101 and other critical information online, Rich has helped give thermoformers a vast pool of knowledge on a wide range of topics from which they can draw, any time.

Rich readily acknowledges none of this would be possible without a dedicated and creative group of associates, several of whom have been with the company 20-30 years. Their enthusiastic support has allowed him to engage in a wide range of volunteer work while keeping the company on the cutting edge of the pressure forming industry.

Though he now concentrates on non-industry volunteer work, he still serves as chairman of the IDSA Materials and Processes Section, as an advisory board member of the Silicon Valley Chapter of IDSA, and as a board member for the Plastic Design and Development Division of SPE. |



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Troubleshooting and Mitigating Gels in Polyolefin Film Products

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The term “gel” is commonly used to refer to any small defect that distorts a film product. Eliminating gel defects from extruded polyolefin film products can be difficult, time consuming, and expensive due to the complexity of the problem and the high levels of off-specification product produced. This paper discusses the identification of gel types, the common root causes for gels, and the technical solutions for mitigating gels in film products produced using single-screw extruders.

Introduction

Troubleshooting extrusion processes where gels are appearing in polyethylene (PE) film products can be difficult due to the number of different gel types that are possible. For these processes, the troubleshooter must be able to diagnose the problem quickly and provide an economically viable technical solution [1]. Because gels can originate from numerous sources, the troubleshooter must be able to identify the characteristics of the gel and recognize the likely possibilities of the source. Process changes must then be performed to mitigate the gel defects.

There are many types of gels [2] and the most common include: 1) highly oxidized polymeric material that appears as brittle black specks, 2) polymeric materials that are crosslinked via an oxidative process, 3) highly-entangled polymeric material (such as high molecular weight species) that are undispersed but not crosslinked, 4) unmelted resin, 5) filler agglomerates from masterbatches, and 6) a different type of resin or contaminant such as metal, wood, cloth fibers, or dirt. A crosslinked resin gel is typically formed during an oxidation process, resulting in the crosslinking of the resin chains and the generation of discolored gels. Highly-entangled gels are typically high molecular weight polymer chains that are entangled and thus difficult to disperse during the extrusion process. When analyzed using a hot stage microscope, this gel type will melt as the stage temperature is increased. When the stage temperature is then decreased, the gel will crystallize, creating the appearance of a gel as a solid polymer fragment. Since these gels are not oxidized they are not associated with color. They are commonly referred to as undispersed or unmixed gels. Unmelted resin exiting with the discharge can sometimes occur, especially at high extrusion rates. These gels will melt during heating with a hot-stage microscope, and typically they will not reform during the cooling phase. Numerous sophisticated methods are available for analyzing gels including epi-fluorescence microscopy, polarized light microscopy, and electron microscopy with x-ray analysis. These methods are discussed in the next sections.

Gels can be generated from many different sources and include: 1) the resin manufacturer, 2) the converting process, 3) pellet blending of resins with significantly different shear viscosities, 4) pellet blending of different resin types, and 5) direct contamination. Modern resin manufacturing processes exclude oxygen from the system and are very streamline such that process areas with long residence times do not exist. As such, crosslinked and oxidative gels are likely not generated by the manufacturer. Improperly designed extrusion equipment and processes, however, are common, leading to the oxidative degradation of resins and crosslinked gels. Several case studies in the next sections show how poorly designed processing equipment can lead to crosslinked and unmixed gel contamination of film products.

The goal of this paper is to describe the different type of gels that are likely to occur in polyolefin film products, techniques for identifying the gel type, and technical solutions to mitigate them from single-screw extrusion processes.

Protocols for Gel Analysis

Established protocols for gel analysis in polymer films are well documented in the literature [2-4]. For example, gels can be identified using the schematic process [4] shown in Figure 1. Typically a film with defects is visually inspected using a low power dissecting microscope. The gels can be classified based on size, color, and shape, and isolated using a razor blade or scissors. Cross sections of the gels ranging from 5 μm to 10 μm thick are collected at temperatures below the glass transition temperature (T_g) of the film using a cryogenic microtome; i.e., -80°C to -120°C . For optical examination, a thin section containing the gels is placed on a glass microscope slide with a drop of silicon oil and covered with a glass cover slip. Additional sections are collected for examination via hot stage microscopy and for compositional identification if needed.

After collecting the sections, the polished block-face containing the remainder of the gel is retained. In many instances, gels arise from inorganic contaminants such as the metallurgy from pellet handling equipment, extruders, or components from masterbatches. Examination of these inorganic components are best performed with the block-face sample using a scanning electron microscope (SEM) equipped with an energy dispersive x-ray detector (EDX) [5,6]. In some cases, additives or inorganic residues are present in low concentrations within the gels. A method to enrich the concentration of these materials is to expose the block-face containing the gel to oxygen plasma. Etching will preferentially remove the polymer at a much faster rate than the inorganic materials, enriching the inorganic components for elemental analyses. It must be noted that prior to SEM and EDX analyses, a thin conductive coating like carbon is typically

evaporated onto the sample to render it conductive under the electron beam.

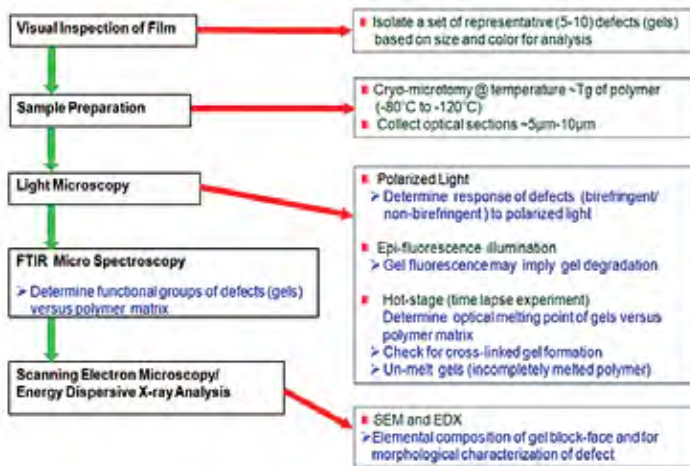


FIGURE 1. Methodology for characterizing defects in polymer films [4].

The next sections will demonstrate various methods of analysis used for common gel types.

Oxidized Gels

The most common type of gel is caused by oxidative processes that crosslink the PE chains. The best way to identify this gel type is by observing them with polarized light and ultraviolet (UV) light sources. Transmitted polarized light microscopy represents an effective technique [7] that can be used to investigate structures in crystalline films. For example, black speck gels were contaminating a multilayer film product. The gels were relatively brittle when cut for analysis. The source was unknown. The detail of a gel is clearly visible using transmitted polarized light, as shown in Figure 2a. Close examination of this gel using epi-fluorescence with an ultraviolet light source caused an intense fluorescence emission, as shown in Figure 2b. This type of emission suggests thermal oxidation and crosslinking of the polymer. Micro-infrared analysis of the gel indicated that it contained oxidized PE and maleic anhydride, as shown by the spectrum in Figure 3 (for clarity, this figure can be found at the end of this paper). This material likely formed on the metal surfaces of the extruder and then flaked off during a minor process instability. The material then flowed downstream and contaminated the film as a gel.

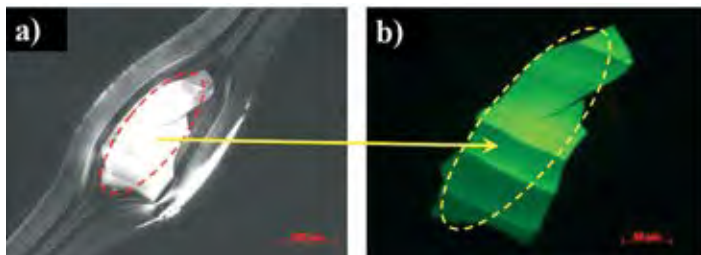


FIGURE 2. Transmitted polarized light images of a thermally oxidized and crosslinked gel in a multilayer film: a) photograph in polarized light, and b) the gel fluorescing under UV light.

Crosslinked Gels

Crosslinked gels are oxidized gels, but the level of oxidation may not be enough to cause them to fluoresce under UV light. These gels may have a level of crystallinity and thus be birefringent under polarized light. For example, the slightly birefringent gel shown in Figure 4a was studied using a temperature programmable hot stage, polarizing light microscope [7]. The optical melting temperature (T_m) of the gel was measured at 128°C and consistent with the PE used to make the product, as shown in Figure 4b. To determine if the gel was unmixed (highly entangled but not crosslinked), the gel was held above the melting temperature (135°C) and then stressed. A dental tool was used to stress the top of the glass cover slip. Crosslinked gels will appear birefringent, (Figure 4c) in response to the anisotropy of stress distribution in the gel to polarized light. The gel dimensions and shape remained after cooling verifying crosslinking, as shown in Figure 4d. If the gel was highly entangled and not crosslinked, the gel would have disappeared after the stress and cooling were applied.

Gels from Foreign Contamination

The origin of defects causing discoloration in polyolefin pellets can be identified using light and electron microscopy. For example, PE pellets from an in-plant recycle re-pelletizing process contained pellets that were off color and had black specks, as shown in Figure 5a. One of these defects was isolated using the cross sectioning technique, as shown in Figure 5b. The cross section revealed an intense reddish particle that caused the discoloration of the pellet.

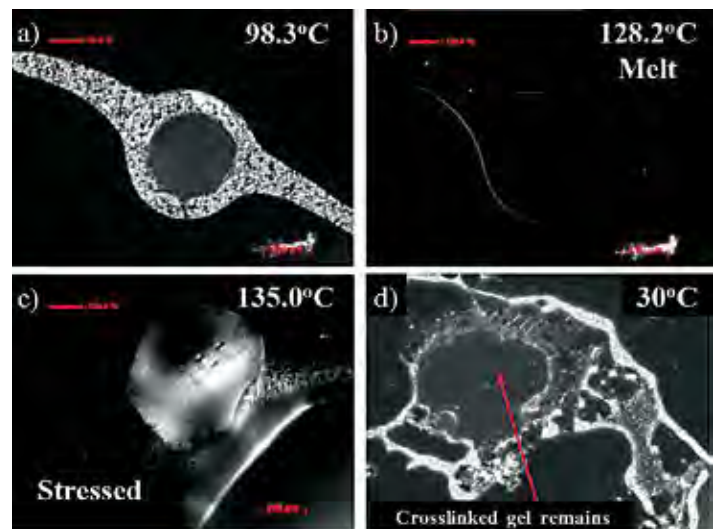


FIGURE 4. Hot stage microscopy of a crosslinked gel in a crystalline monolayer film: a) below the melting temperature, b) optical melting point at 128°C, c) appearance of birefringence after stressing at 135°C, and d) intact crosslinked gel after cooling to 30°C.

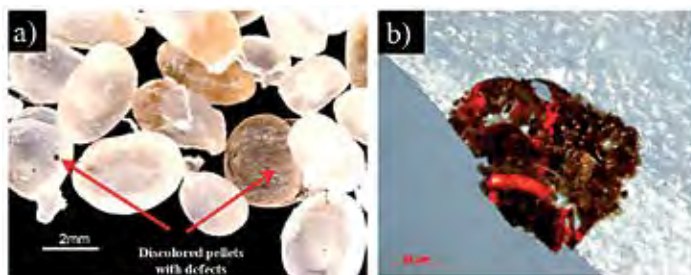


FIGURE 5. Photographs of foreign contamination in pellets of a re-pelletized reclaim stream: a) photomicrograph of discolored polyolefin pellets containing dark defects, and b) transmitted polarized light micrograph of a pellet cross section containing a defect.

SEM and EDX microanalysis were used to determine that the defects contained primarily iron and oxygen, and it likely was iron oxide. Figure 6 shows a backscatter electron image (BEI) of the pellet block-face sample showing the defect causing the discoloration and the elemental spectrum. Metallic based defects can originate from process equipment, railcars used for shipment, pellet transfer lines, and poor housekeeping. The origin of the iron oxide was likely from a storage bin.

In another example, a multilayer film product was experiencing occasional gels. The gels were isolated and the cross sections were collected as shown in Figure 7a. These gels contained highly birefringent particles that resided in the core layer. The outer film layers appeared amorphous and the core layer was slightly birefringent. The optical melting temperature of the core layer was determined to be 123°C while the birefringent gels melted at 265°C. The melting temperature of 123°C was consistent with the PE resin used to produce the core layer. The higher melting temperature material and micro-infrared analyses of the defects indicate that they were foreign contaminants, and they were identified as a polyester resin. The polyester resin was used in another process in the converting plant, and it inadvertently contaminated the PE feedstock.

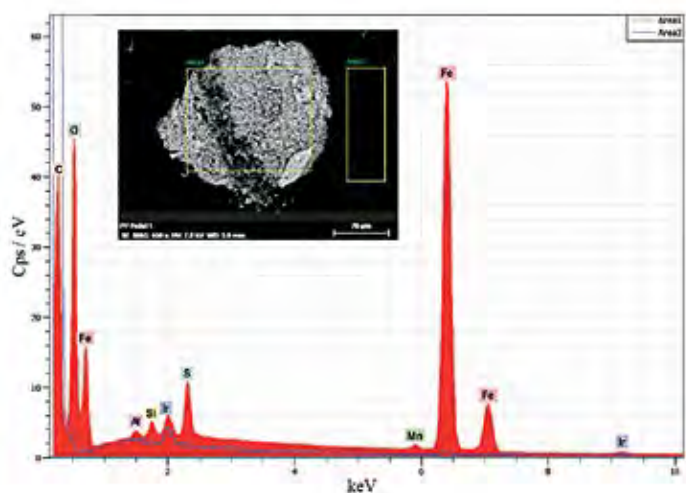


FIGURE 6. EDX microanalysis of an inclusion in a polyolefin pellet cross section (Figure 5b). The analysis indicated that the particle was likely iron oxide.

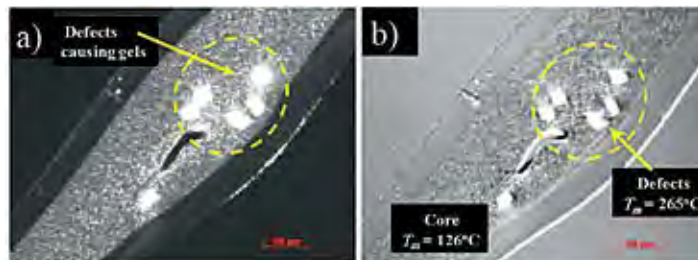


FIGURE 7. Photographs of gels in the core layer of a three layer film: a) transmitted polarized light, and b) hot stage microscopy was used to determine the melting temperatures of the core resin and defects.

Another common contaminant that produces gels is fibers, as shown in Figure 8. In many cases, these contaminants are cotton fibers from clothing and gloves or cellulosic fibers from packaging materials. Fourier transform infrared (FTIR) spectroscopy is one of the best techniques for determining the chemical functionality of organic based defects in PE films. The infrared absorbance characteristics of the defect were determined using FTIR spectroscopy, as shown in Figure 9 (for clarity, this figure can be found at the end of this paper). The broad absorption bands near 3600 cm^{-1} to 3100 cm^{-1} are due to hydroxyl (-OH) stretching vibrations, the C-H vibration stretch is near 2916 cm^{-1} to 2851 cm^{-1} , and the ester carbonyl group absorption is near 1734 cm^{-1} . Based on the infrared absorption characteristics, the defect in the PE film is a cellulosic fiber with degraded PE resin.

Once the contaminant is identified, the troubleshooter must determine how the material entered the feedstock stream. Process controls must be identified and implemented to mitigate the contaminant source.



FIGURE 8. Transmitted bright-field image of PE film containing a fibrous gel.

Case Studies

Oxidized gels, carbon specks, and unmixed gels can be created inside the extrusion processing line. Crosslinked gels and black specks occur due to regions in the process that are stagnant and have very long residence times in the extruder. Unmixed gels and solid polymer fragments occur because the resin was not subjected to a high stress level during processing. This section

provides several case studies where these types of gels occurred. The technical solutions to mitigate the gels are then presented.

Gel Showers in a Cast Film Process

Crosslinked gels can form in stagnant regions of screw channels, transfer lines, and dies. The time required for these gels to form range from about 30 minutes for linear low density polyethylene (LLDPE) resin up to 12 days for low density polyethylene (LDPE) resin. Stagnant regions can occur at entries and exits of mixers [1] and barrier sections, and they can occur when the metering channel of smooth-bore extruders is not controlling the rate. In these cases, a section upstream of the metering section is rate limiting, causing portions of the metering section to operate partially filled [8,9]. When these channels operate partially filled the main flow is on the pushing side of the channel while the trailing side operates void at first. After a period of time, clean resin gets into the void regions and rotates with the screw for long durations. Eventually the resin will degrade, forming crosslinked gels. Slight process upsets can dislodge this material, allowing the material to flow downstream creating a gel shower in the film.

A film plant was extruding a LDPE resin into a specialty product using a cast film process [8,9]. Due to high demand, a new 88.9 mm diameter, 33 L/D extruder was installed in the plant. Soon after startup the product was acceptable and high quality. After 12 days, the line began to experience intermittent discharges of crosslinked material (gel showers) and carbon specks. Photographs of these gels are shown in Figure 10. In some cases, the gel showers were observed 2 to 3 times per day and would last from 1 to 5 minutes. The gels were clearly crosslinked and were brown in color. The extrudate temperature was higher than expected for the process. The intermittent gels resulted in production downtime due to purging and in numerous customer complaints. A high and costly level of quality control was required to remove the gel contaminated product from the prime product. Due to the high amount of downtime and the high levels of quality control needed, the operation of the new line was considerably more expensive than planned.

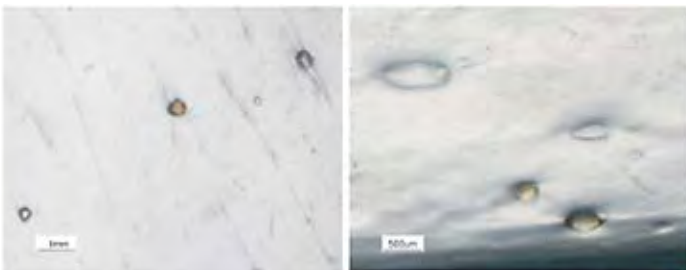


FIGURE 10. Photographs of crosslinked gels in a LDPE film.

It was hypothesized that the extruder was operating partially full due to the low specific rate during operation. To determine if partially filled channels were the root cause of the reduced rate, high discharge temperature, and degraded material, screw rotation was stopped and the screw was removed while hot from the extruder. Examination of the polymer on the screw indicated that in the meter section about half of the channel width on the trailing sides of the flights for all but the last diameter were filled

with a dark colored, partially carbonized LDPE resin, indicating that these regions were stagnant. The reduced flow rate caused these regions to be partially filled, creating void regions on the trailing side of the channel. Some of the resin adhered to the trailing side of the screw in the void regions and stayed there for extended time periods, as shown in Figure 11. The resin adhering in the void regions eventually degraded into the dark-colored, crosslinked material. Small process variations dislodged some of this material and caused the intermittent gel showers that contaminated the product. Moreover, compacted solids were found wedged in the channel at the entrance to the barrier section. The wedged material was caused by the relatively large width of the entering solid bed being forced into the continually decreasing width of the solids channel of the barrier section.

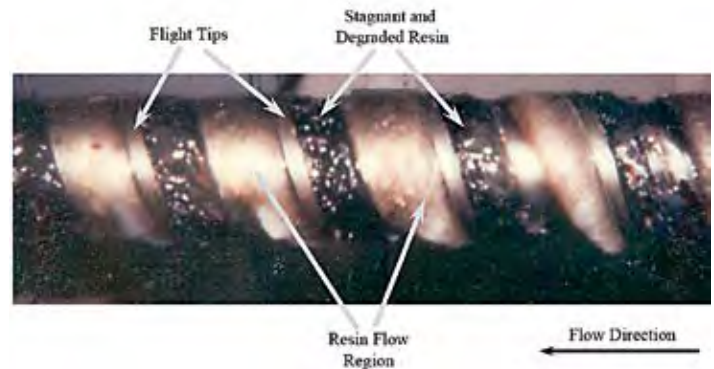


FIGURE 11. Photograph of a removed screw showing the resin flow and degraded resin due to stagnant regions [9].

The technical solution to eliminate this problem was a simple modification to the entry of the barrier melting section. For this modification [8], some of the metal in the melt conveying channel was removed along with a portion of the barrier flight, allowing some solid material to enter the melt channel and reducing the restriction at the entry. By reducing the restriction, the rate limiting step of the process changed from the entry region of the barrier section to the metering section. After the modification was made, the gels were eliminated from the process.

Unmixed Gels

As stated previously, unmixed gels are highly entangled species that are molten when they are discharged from the die, but solidify first upon cooling to produce a gel that appears as a solid polymer fragment. These types of gels are easily removed from an extrusion process by subjecting all molten resin to a one-time high level of stress near the discharge of the extrusion screw. This stress is easily applied using a Maddock-style mixer with a relatively tight clearance on the mixing flight.

A film process was producing a monolayer film that had a low level of gels. The gels were tested using hot stage microscopy and identified as highly entangled species (unmixed gels). These gels melted and then disappeared when heated and stressed via pressure smearing using a dental tool, as shown in Figure 12.

The unmixed gels were removed by increasing the stress level in the Maddock mixer. The stress level was increased by decreasing

the clearance on the mixing flight. The stress level required to disperse unmixed gels depends on the resin and the level of chain entanglement. In past experiences, the stress level required to disperse PE unmixed gels is about 100 to 200 kPa.

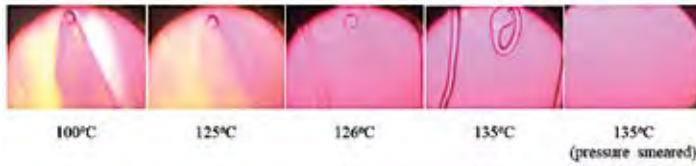


FIGURE 12. Photographs of an un-mixed gel at select temperatures using a hot-stage microscope. The un-mixed gel melted at about 135°C. When the gel was smeared by moving the glass cover slip, the stress was enough to disentangle the polymer chains such that the gel would not reappear upon cooling.

A similar problem with solid polymer fragments occurred for a thermoplastic polyurethane (TPU) resin [10]. For this case, a combination of a lower compression ratio, a longer barrier section with a very small barrier flight clearance, a Maddock mixer with a small mixing flight clearance, and deeper metering channels allowed the TPU resins to extrude at twice the rate and provide high quality extrudates that were free of solid polymer fragments.

The shear stress that the material experiences for flow across the mixing flight of the Maddock mixer can be estimated using Equations 1 and 2. The shear stress level is responsible for breaking up the entangled species. This calculation is based on screw rotation physics [1].

$$\dot{\gamma}_M = \frac{\pi(D_b - 2u - 2\lambda)N}{(u + \lambda)} \quad (1)$$

$$\tau_M = \eta \dot{\gamma}_M \quad (2)$$

where $\dot{\gamma}_M$ is the average shear rate for flow over the mixing flight in 1/s, N is the screw rotation rate in revolutions/s, η is the shear viscosity at the temperature of the mixing process and at shear rate $\dot{\gamma}_M$, D_b is the barrel diameter, u is the undercut distance on the mixing flight, λ is the main flight clearance, and τ_M is the shear stress that the material will experience for flow over the mixing flight.

Carbon Specks in a Film Product

Carbon specks can be generated in the extruder channels and in downstream transfer lines and dies if stagnant regions are present. In general, these regions are not very large like those in Figure 11. Instead, they are thin coverings that occur at the flight radii or at entry and exits of mixing devices [1]. In general, the region will first create small crosslinked type materials that adhere to metal surfaces. With additional residence time, the crosslinked material will form a thin carbon layer of highly oxidized material. When the layer breaks away from the metal, it is discharged as black specks in the PE film. These specks will fluoresce under UV light.

A LLDPE blown film line was experiencing black specks in the product. In order to locate the source, a Maddock solidification experiment [11] was performed where a small amount of a red color concentrate was added to the feedstock resin, after the red color appeared in the extrudate screw rotation was stopped, and the resin was solidified in the channels. A photograph of the experimental sample [12] is shown in Figure 13. Here a thin layer of carbonaceous material was formed at the pushing flight due to the formation of Moffat eddies [13]. Moffat eddies are recirculation or vortices that occur at sharp corners as shown in Figure 14. When fluid is put in motion with top driven cavity flow the main circulation is shown in Figure 14. A secondary circulation is set up in the stationary corners of the channel, creating a low velocity helical eddy that is outside the high velocity flows of the main part of the channel.

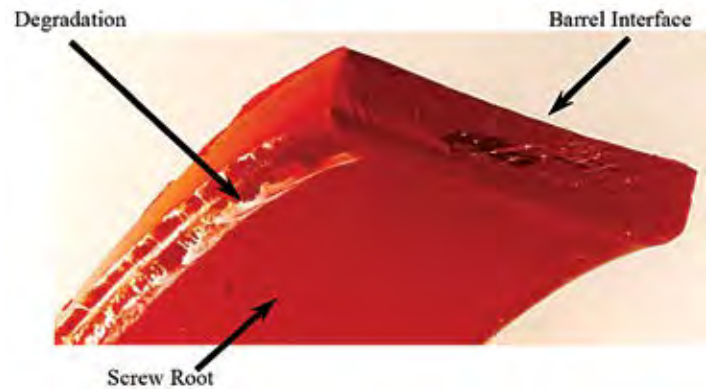


FIGURE 13. Photograph of degradation at the pushing flight for a screw running LLDPE resin [12].

The Moffat eddies that created the degraded resin occurred because the flight radii were too small for the depth of the channel. If the flight radii would have been larger, the Moffat eddies would not have occurred and thus carbon deposits would not have formed.

The Society of the Plastics Industry, Inc. (SPI) guidelines state [14] “unless otherwise specified the root radius will not be less than 1/2 of the flight depth up to 25 mm radius.” Many screws are often designed, however, with flight radii that are very small and approach values that are between 10 and 20% of the channel depth. Previous research [12] has indicated that the SPI guideline as a minimum is appropriate for many resins. But for thermally sensitive resins, radii up to 2.5 times the depth are optimal. Flight radii sizes are shown in Figure 15. When a new screw with radii equal to the depth of the channel was built and installed into the blown film line, the black specks were essentially eliminated.

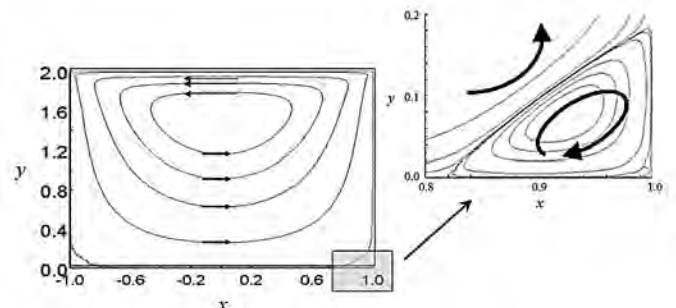


FIGURE 14. Two dimensional flows in a screw channel with an $H/W =$

l (channel depth / channel width). The arrows show the recirculation flows. The shaded area in the lower right corner is expanded to show the Moffat eddy [1].

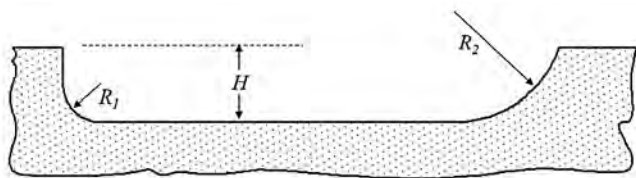


FIGURE 15. Schematic of small (R_1) and large (R_2) flight radii.

Filler Agglomerates

Some specialty films are produced using masterbatches with high levels of mineral fillers. The filler materials must be compounded with a properly designed process such that fillers are not agglomerated prior to dispersion into the base resin. If agglomerates are produced and contained in the masterbatch, then they are essentially impossible to disperse in the filming process, leading to optical defects in the film. For example, a compounding operation for making a specialty resin from a high impact polystyrene (HIPS) resin and specialty filler chemical was not designed properly. Here the filler chemical was partially agglomerated prior to the melting process in a twin-screw extruder. As shown in Figure 16, the resin was colored black and the filler chemical was white. These white agglomerates could not be eliminated in the final plasticating process (injection molding in this case) and created defects in the product. The goal for this type of application is to produce masterbatches that are free of filler agglomerates since the final film making extrusion process is incapable of dispersing them.

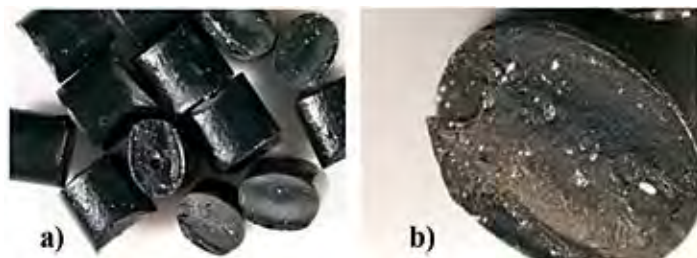


FIGURE 16. Photographs of specialty HIPS resin pellets made using a poorly designed process. The white specks are filler agglomerates: a) 1x magnification, and b) 4x magnification.

Discussion

Gel defects are common in PE film products, and they can originate from many different sources, causing a reduction in the product quality and sometimes stopping production. Gel types, identification protocols, and mitigation strategies were presented in this paper. Mitigating or eliminating gels quickly via the best technical solution will reduce costs to the plant and maximize profits.

The equipment and techniques required to diagnose properly many of the gel types can be expensive and require highly trained people. Many small converters will not be able to afford the development of these types of capabilities. Most resin suppliers, however, have the capabilities and are willing to aid customers on the identification and mitigation of the gels.

Summary

This paper describes the different type of gels that are likely to occur in polyolefin film products, techniques for identifying the gel type, and technical solutions to mitigate them from single-screw extrusion processes.

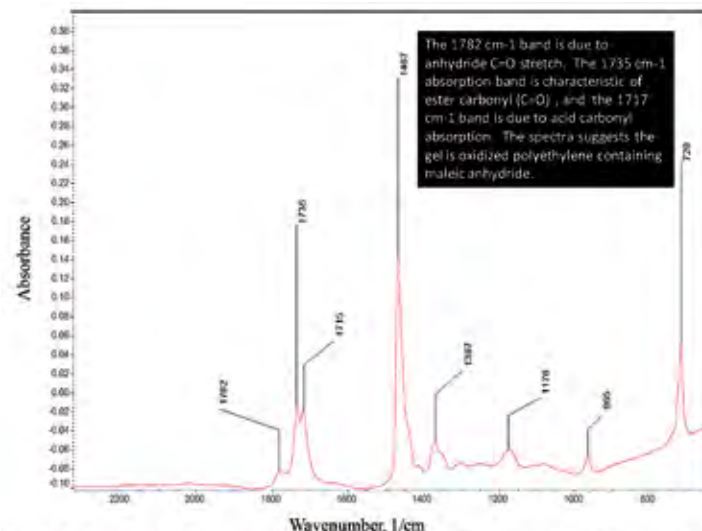


Figure 3. The micro-infrared spectrum of gel shown in Figure 2. The spectrum suggests it is an oxidized polyethylene gel containing maleic anhydride.

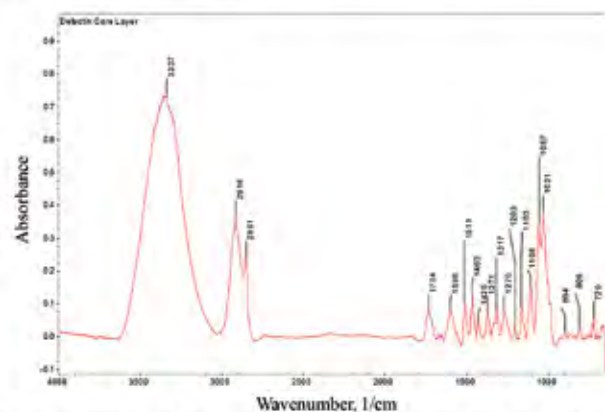


Figure 9. FTIR spectrum of defect in a polyolefin film. The spectrum indicates that the gel is cellulosic fiber and degraded PE resin.

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Driving Out Part Costs

By Pier Luca Boga, Self Group
Rivignano, Italy

This article focuses on production molds and associated characteristics that will yield a reduction in the finished part cost. This is the first of a series to be provided through a number of resources to help thermoforming processors and their customers better understand the impact of tooling on the final piece price. Future articles will drill deeper into the detail specifications for each of these identified features.

A tool can be a physical object including molds and fixtures or a technical object such as CAD files or programs. Furthermore, a concept such as Lean Manufacturing can also be a tool. Proper design and implementation as well as continuous improvement of all tools lead to cost optimization of the finished component or product. This article focuses on one of those tools: production molds.

Where do we start when initiating the development of molds for production thermoforming?

This process, like all manufacturing planning, needs to be the result of team collaboration. A design review including sales, manufacturing, design engineering, project engineering and a qualified toolmaker results in the exponential value of diverse thinking. With knowledge and understanding of customer expectations, design limitations, project scope, tooling possibilities, and manufacturing's needs, the team will be able to communicate the required **mold specifications**.

Well defined, comprehensive specifications are the number one input for an accurate, competitive mold cost and ultimate finished part cost savings. These complete specifications should be available at the mold quotation stage of the project. The specification defines the exact scope of work and documents mutual understanding and agreement. Everyone benefits from detailed mold design and construction specifications.

- The value of design review collaboration is lost without specifications to assure that the project starts according to the team vision.
- The most accurate tooling estimate only comes with complete specifications.
- The most accurate part cost estimate only comes with a complete understanding of the mold design.
- Defined production standards can only be achieved when the mold is completed as perceived by manufacturing.
- Part quality and subsequent cost of quality-related issues are the result of mold construction and performance to plan.
- The customer's part expectations and perception of mold value is best communicated through defined specification

benefits. For example, how does the mold material selection impact the customer's finished component. What are the benefits to the final user?

What production mold design features impact final part cost?

■ **Mold Material**

In order to achieve the most efficient production rates, temperature-controlled molds must be used. The material of preference is aluminum due to its superior heat transfer capacity and its ability to be cast and machined to the best possible surface finish versus cost for thermoforming. Under ideal circumstances, consistent mold temperature will be maintained throughout the production run. Non-temperature-controlled molds will act as a heat sink and become hotter during processing therefore requiring an increase in cycle time to allow for extraction of that excess heat from the mold. An increase in cycle time of 20% or more can be expected with non-temperature-controllable mold materials.

■ **Mold casting metal quality**

Thermoforming processors generally do not audit the tool builder's aluminum casting processes. They specify wall thickness, flatness, etc. but usually don't require that good foundry practices are followed. Using "any" foundry creates a risk of poor quality casting results. Porosity affecting the casting density can impact heat transfer and temperature control, thus impacting the optimization of processing cycle times. Optimum mold finish is obtained from "porosity-free" castings and surface finish directly affects part release. To obtain a good mold surface the casting thickness is an important factor that must be considered: the less material milled, the better the mold surface. In a controlled process (pattern maker, foundry, mold maker) it is possible to obtain a cast "NEAR NET SHAPE". In this way there will be cost savings because less aluminum is required and the milling time is also reduced. Moreover, with the same "NEAR NET SHAPE" process, when the final plastic product tolerances allow it, the cast tool can be polished, guaranteeing high product quality. Overall, the high quality mold surface will promote minimum material-to-mold friction resulting in the ability to optimize the material minimum starting gage with superior part release.

■ **Temperature control lines and manifolds**

Temperature control systems designed to provide maximum heat transfer will result in the most efficient cycle times and provide cost savings. A system that promotes turbulent flow, maintains proper aluminum material thickness surrounding the flow tube or channel, minimizes the length of tubing runs within the mold wall as well as outside and provides manifold spacing and size appropriate to mold configuration, will provide maximum results. For complex parts it is also possible, particularly in the cast aluminum tool, to control the temperature of specific areas using multiple manifolds. Do not forget to control the

temperature of the loose piece inserts, i.e. the ones to obtain undercuts.

■ **Thermocouples**

The application of thermocouples mounted in the mold provides the opportunity for mold temperature management that will improve energy efficiency but can also lead to decreased cycle times, cycle time consistency, and material optimization. This ability to measure and control will lead to lower part costs by reduction of scrap at start up and through production.

■ **Air evacuation**

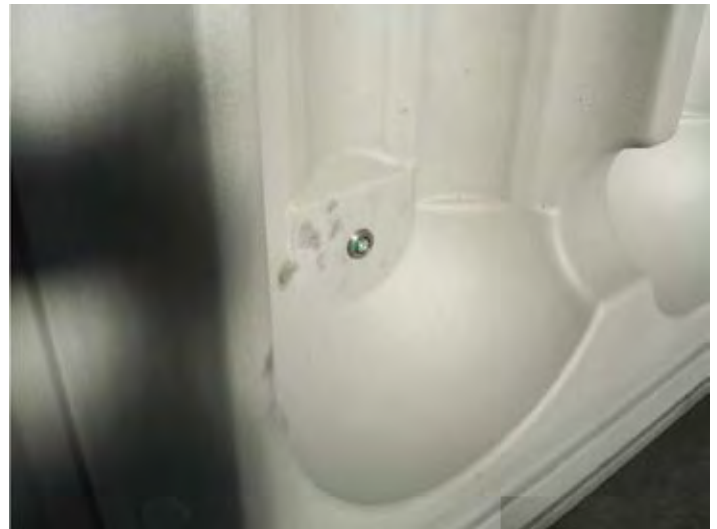
Efficient, managed removal of the air between the clamped sheet and the mold surface will provide the highest quality thermoformed component at the best final cost. Air evacuation impacts material optimization and cycle time. Mold design and required specifications need to minimize air evacuation restrictions, support zoned evacuation when appropriate, and maximize vacuum recovery time. With proper mold engineering including back drilling specifications, the number and size of evacuation holes can be optimized offering savings opportunities for critical surface finished part requirements.

■ **Undercuts / Mold actuation**

This is a mold design feature that can have a huge impact on final part cost. Undercuts and “back draft” are best avoided in thermoforming and any other process for that matter. However, as thermoforming is generally a single mold surface process with lower processing pressure than other processes, these features can generally be attained at a lower tooling cost and with less impact than in other processes. While removable loose pieces are commonly used, the addition of automated actuation is best for reduced finished part cost. An evaluation of the amortization of that added cost for actuation over the anticipated production volume should always be done. Properly designed actuation will result in no negative impact on forming cycle time. Of course, mold damage and the associated cost of process interruption needs to be considered when designing loose pieces considering the potential for those pieces to fall away from the part prematurely and into the mold cavity. An actuated mold tilt rather than a mold built on a tilt can potentially provide a material savings allowing for reduced starting sheet size and thickness. The design of an actuated tool to provide an undercut or to allow back draft should also be considered for reduction or even elimination of secondary trim and assembly costs. An example would be the forming of internal threads.

As you can see, consideration of formal documented specifications, along with the mold design features identified here, provides a significant opportunity to reduce production thermoforming costs through collaboration of the mold maker, part designer and processor.

Part 2 in this series, Cause and Effect Characteristics of Mold Materials, will appear in the next edition of TQ. |



PICTURE 1: Internal Thread Actuation



PICTURE 2: Mold Tilt to Accommodate Undercut



PICTURE 3: Mold Tilt to Accommodate Backdraft

Developments in Thermoforming Thermoplastic Composites

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University of Massachusetts Lowell

ABSTRACT

Today many thermoplastic resins have entered the foray of composite materials in applications such as aerospace, vehicle and recreational applications. The advantages of thermoplastics are well known and include storage and shelf life, short processing cycles, recyclability and sustainability. In combination with reinforcing materials, synergies in strength, modulus, impact resistance and other properties, thermoplastics can be tailored for a wide range of applications. In this paper, the current state of the composite market, current commercial materials, and various production process used in industry are reviewed. A focus is made on the thermoforming process which is an under-utilized, yet highly efficient manufacturing method, practical for composite applications with limited deformation requirements. A thermoforming technique of layering commingled glass-polypropylene woven fibers with various surface layers is introduced in order to demonstrate this manufacturability.

Introduction

Composite materials are found in thousands of applications across many industries from aerospace, to automotive, to recreation, to packaging. Starting in the 1940s, with the advent of thermoset plastic materials, the fiberglass reinforced plastics (FRP) industry began to develop composites [1]. Today, many thermoplastic-based materials have also been developed to address a wide range of applications. Nielsen [2] listed many advantages of composite materials including strength and modulus, impact resistance, corrosion resistance, chemical resistance, improved mechanical damping and increased heat distortion temperature. Essentially, the advantage of a composite material is the ability to combine the desired properties of its building blocks. To date, the driving force in development of composites has been enhanced strength-to-weight ratios in the aircraft industry [1], but now cost advantages are also becoming a major factor, particularly in automotive applications [3]. There is even a burgeoning industry to incorporate sustainable materials into composite structures [4].

The use of the thermoforming process for smaller scale, higher volume applications is now being considered as it has been proven to be a highly efficient manufacturing method for polymer-based products. A thermoforming technique of layering commingled glass-polypropylene woven fibers with various surface layers is introduced in order to demonstrate manufacturability and the ability create composite materials with synergistic properties. The mechanical properties of twelve composite laminations were compared versus single-

ply homogeneous components to present the usefulness and limitations of the process.

Markets Served by Composite Polymer Materials

According to JEC Magazine [5], through 2012 there was a rebound in the American composites market of approximately 15% to 210 million pounds. This represented 35% of the global composites industry that was valued at over \$100 billion and currently employs approximately 550,000 professionals worldwide [6]. The major domestic market segments were further broken down in Figure 1.

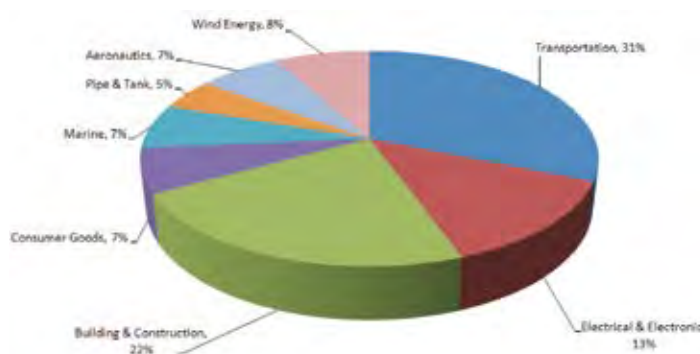


FIGURE 1 - US composites market by volume (2012) [5].

The largest market sector today is the transportation industry. Costs to produce final assembled modules of composites in several automotive applications have proven advantageous, particularly in structural and semi-structural components when compared to other various materials technologies [7]. In the aircraft industry, significant portions of structural fuselage and airfoil components are now made from composites, primarily due to their high strength-to-weight ratios. For example, Boeing's 787 Dreamliner and Airbus' A350 XWB are built with 50% and 52% advanced composites, respectively [8].

Current Thermoplastic Composite Materials

Today, thermoplastic composites are still a niche market, occupying only 10% of the composites markets [9]. Thermoplastics are typically 500 to 1000 times more viscous than thermoset resins which tends to hinder the infusion of polymer into the reinforcing substrate [9]. They also necessitate higher pressures, and so require more robust and elaborate tooling and equipment than competing thermoset resins [9]. In addition, thermoplastic composites require significantly more energy input to heat and cool the polymer. In applications, thermoplastics also have very different maximum service temperatures than thermosets. Table 1 shows the thermoplastic polymers most commonly used for thermoplastic composites along with their corresponding glass transition temperatures, T_g ,

melt temperatures, T_m , and processing temperatures, $T_{process}$ [9].

Polymer	Morphology	T_g (°C)	T_m (°C)	$T_{process}$ (°C)	Cost (Relative)
PBT	Semi-crystalline	56	223	250	\$\$
PA-6	Semi-crystalline	48	219	245	\$
PA-12	Semi-crystalline	52	176	224	\$
PP	Semi-crystalline	-20	176	190	\$
PEEK	Semi-crystalline	143	343	390	\$\$\$
PEI	Amorphous	217	---	330	\$\$
PPS	Semi-crystalline	89	307	325	\$
PEKK	Semi-crystalline	156	306	340	\$\$

TABLE 1. Common thermoplastics used in composites [9,10]

One benefit of thermoplastic matrices is that they are relatively flexible compared to thermoset matrices. This flexibility improves impact resistance and reduces damage in the thermoplastic-based composites. Thermoplastic polymers currently are the only matrix materials that allow the new intermediate modulus, high-strength, high-strain, carbon fibers to be used to their full potential in composite design [11]. Designs engineered with unidirectional reinforcing materials have optimized this property.

Another advantage of thermoplastics is that they mitigate many end-of-life issues that have become critical for the automotive industry [12]. This is due to the fact that at the end of product life, an advanced thermoplastic composite component may be ground to a pellet-size processable material, whereas most thermoset composite materials can only be ground and used as filler [9]. Processing methods of thermoplastics also have a lower environmental impact than typical thermoset processing, where the chemical reactions in fabrication commonly emit volatile organic compounds (VOCs). For example, environmental regulations regarding styrene emissions of unsaturated polyester can significantly affect the total cost of processing [9].

Glass Mat Thermoplastic Composites

The most common class of thermoplastic composites is glass mat thermoplastic (GMT) materials that have been in production for decades [9]. Matrix polymers utilized have included polypropylene (PP), polyvinyl chloride (PVC), polycarbonate (PC), polyamide (PA), polyphenylene sulfide (PPS) and polyesters such as PBT and PET. Due to its low cost, the majority of products in this category are made with PP, which holds more than 95% market share [13]. Traditional GMT composites contain milled short fibers (less than 6 mm) whereas the category termed long-fiber-reinforced thermoplastics (LFRTs) contains reinforcement fiber with lengths up to 10 mm and longer. Both types commonly contain fiber loadings of 30-50% by weight [14]. Chopped long-glass fibers provide superior fill-in thin sections such as ribs and bosses. Unidirectional, very-long glass fibers offer extremely high stiffness and strength along one axis. The glass fibers are commonly formed in an interlocking network of reinforcement. In the typical fabrication process, the blanks are passed through an indexing infrared (IR) or convection oven

then moved manually or robotically to a nearby press and for compression molding [7].

Lightweight Reinforced Thermoplastic Composites

Lightweight reinforced thermoplastic (LWRT) composites are a development of GMT materials with added key features of higher stiffness-to-weight ratio, impact resistance, higher flexural modulus, higher damping, higher thermal insulation when compared to short fiber composites with the same fiber percentage [7, 14]. These materials are commonly produced with glass and polypropylene fiber fleeces [7]. The proportion of the various fibers (20-60% glass) and the way the fleece is needled allows numerous mechanical properties to be tailored to suit the application. In processing, during the heating stage, the PP fibers melt and form the matrix material, forming a composite with individual reinforcing fibers but no fiber bundles [7]. Then in a subsequent stamping stage, engineered tooling designed to not to press down as deeply in selected areas, allows local stiffening, similar to a sandwich composite. In areas where higher tensile strength is desired, such as stress concentration points, the blank can be more fully pressed and the material consolidated. Since LWRT composites are typically stamped at very low pressure, this process allows very large parts to be created or multiple parts produced in a multi-cavity or family mold [7].

Textile-Reinforced Advanced GMT Composites

Textile-reinforced advanced GMT composites further outperform earlier materials because of highly engineered mat structures. These sheet-formed laminates have been found to have improved performance in higher stiffness applications, longer fatigue life, higher impact resistance across a range of temperature conditions, and have proven superior in managing loads at higher strain rates [7]. This category of composites commonly uses a combination of traditional glass mats and one or more layers of textile reinforcements. The textile layers are formed from continuous fibers woven using glass, aramid, thermoplastic polyester, or carbon. Figure 2 shows some of the reinforcing weaves in use today in the automotive industry including plain weave, (Figure 2a), twill weave, (Figure 2b) and two specialty weaves, (Figures 2c and 2d).

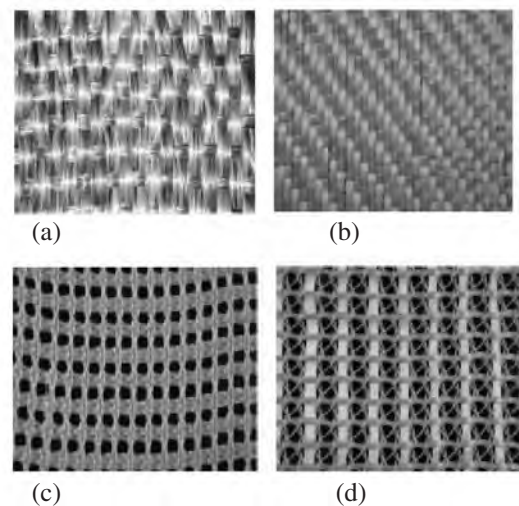


FIGURE 2. Common thermoplastic weaves: (a) plain weave, (b) twill weave, (c) multi-axial weave and (d) plain weave with fill [7]

With this technology, properties can be tailored for specific applications. Mechanical characteristics can be modified by varying the ratio of fibers in the warp and weft directions. Secondly, the order of placement of the fabric layers in the lamination plan can be varied to affect physical properties. When the fabrics are used on the surface, the lamination will generally display a higher flexural modulus. If better surface conditions are required for aesthetics, chopped, non-woven mat is preferable for the top layers [7].

Commingled Thermoplastic Composites

The fiber commingling process is a method of producing a pre-impregnated thermoplastic-based material for manufacturing. Here, fine reinforcing fibers and fine polymer fibers are blended to produce a multi-component thread. Alternatively, the glass fibers may be coated with polymer in a precursor stage of thread production. Cohesion of a polymer, such as polypropylene to high surface energy glass fibers, is achievable with the use of compatibilizers, which are often copolymer additives to the resin melt. The "hybrid-yarn" thread produced is then woven into various textile forms. In downstream fabrication processes, the application of sufficient heat and pressure cause the polymer to flow between both the fibers of the threads and between adjacent threads such that upon cooling, a solidified three-dimensional form is manufactured [9].

The main advantage of the commingling process is that the textile pre-form weave is now quite drape-able over projected mold shapes, and is significantly lower in cost than many alternatives, when considering the additional strength to weight ratios that are possible. Disadvantages can include higher processing pressures relative to thermoset options and longer times in the heating phase relative other thermoplastic options such as injection molding. Quality issues associated with using woven reinforcing substrates include excessive fiber movement, as the commingled yarns can undergo much de-bulking during the melting process.

Twintex®, a trade name of Fiber Glass Industries of Amsterdam New York refers to a commingled fabric of glass and polypropylene fibers. The fiber volume fraction of this material is typically 60 percent by weight and the material is commonly hand-laid and processed by a vacuum bag method and presses under heat at 50°C^{and} higher depending on cycle/cure time. The polypropylene component of the weave, with its low melt makes it relatively easy to form. In the recommended process, hand lay-up and thermoforming under a vacuum membrane is performed at 90°C for twelve hours [15]. Herein, a process is presented, utilizing a sheet-fed, two-stage industrial thermoforming machine, demonstrating 120-180 second cycle times are practical.

Composite Forming Techniques

The manufacture of composites has primarily centered on methods to create laminations of thermoset polymers within female molds or over male molds by manual wet-layup techniques. These methods are commonly augmented by vacuum assists to even resin reinforcement consistencies, followed by autoclaving to assist curing.

Other processes include pultrusion, compression or matched die molding, resin transfer molding and thermoforming. Pultrusion is a common method of producing composite profiles (including hollow profiles), rubber hose, pipe, building panels, and electrical insulators [16]. This is a continuous process where spool-fed fibers are impregnated with resin by drawing through a bath, or in a spray chamber, then passed through a die and cured. Compression molding is a matched die molding technique. The equipment is a press (usually hydraulically-driven) utilizing pressures that can range up to several hundred tons. The process can be used to shape condensation polymer-based composites such as acrylic, urea, and phenolics. Systems of this type are often used for the final formation of pre-preg materials such as sheet molding compound (SMC) or bulk molding compound (BMC). These materials, made of resin, initiator, and reinforcement components, are sold in ready to form sheets, logs or ropes. Parts as large as car bodies have been made in this manner [16]. In resin transfer molding (RTM) and reaction-injection molding (RIM), a mold is loaded with reinforcing material. Reinforcements are often stitched or bonded to tolerate the pressure of injection and retain the proper shape. After the mold is closed, resin is injected into it. The pressure of injection forces the resin to flow through and wet the reinforcement. Often a vacuum is applied to remove trapped air. These techniques have been used to make relatively large parts, such as the body panels for the Pontiac Fiero [17].

Thermoforming of Thermoplastic Composites

Advantages of the thermoforming process for composites are the same as with homogenous materials: low cycle time, low cost of tooling, speed to market, and relatively clean in comparison to competing processes. A disadvantage of thermoforming for highly reinforced laminations arises due to the fact that it is a stretch forming process. The ability of a material to form is subject to its ductility relative to the desired geometry. Depth of draw, radius of curvature, stress concentrations and surface friction are variables to be considered along with material properties. With composites, consideration must also be given to the adhesion of any layers in lamination prior to the application of the forming force. The lamination plan, clamping and venting is critical, such that when forming force is applied, delamination does not occur.

Process factors affecting the performance and quality of final product, according to Gunel [18], are heating period and rate, mold temperature, forming rate and cooling rate. These factors are often published based on trial testing by material manufacturers. Operating conditions have a great influence, so pre-production trials to fully characterize grades of material are encouraged.

Computer numerical simulations using finite element analysis (FEA) software can now evaluate deformation to a great detail based on several mathematical models. They have been proven to be useful for both part designers and tool makers in the development of a thermoformed product, particularly in identifying stress concentrations, formation problems and thickness, which is the foundation of many critical features.

Experimental: Thermoforming Composite Laminations with Commingled Twintex®

In order to validate the two-stage thermoforming process as a viable, efficient manufacturing process for composite laminates several factors were considered. To begin, the thermoforming process requires thermoplastic materials which heat quickly, become relatively soft for deformation, and cool quickly making the process efficient. In general, reinforced materials have not found a home with this process because they are generally not highly elastic. Recognizing that fact, there are many applications that are not extremely demanding in deformation that could still benefit from the economics of the process.

A search of available reinforcing thermoplastics led to a product called Twintex®, which was originally developed by Saint-Gobain S.A., who sold it to Owens Corning (OCV Reinforcements), who have since sold the rights to Fiber Glass Industries (FGI) of Amsterdam New York. For this research, FGI provided two lots of material for testing and evaluation in the thermoforming process: TPP60N22P, a plain weave 745 GSM (22 ounce/yd) commingled E-glass and polypropylene product; and TPP60N44T a heavier 1492 GSM (44 ounce/yd) twill weave of the same fibers. When combined in lamination with surface layers with selected characteristics, the additional strength rigidity and impact performance afforded by the reinforcement enhance the laminated material's structural performance and expand the window of applications. The selection of surface materials was somewhat limited, but four commodity materials and two engineering polymers were procured for evaluation. Polyvinyl Chloride (PVC) was selected due to its wide usage in the thermoforming industry and its good characteristics for weatherability. Polyethylene terephthalate (PET) was selected for its good stretch characteristics and the fact that is a preferred substitution to PVC due to biological concerns. High density polyethylene (HDPE) was selected as a good laminate due to its known chemical resistance. Polypropylene (PP) was tested as a laminate as it should be wholly compatible with the commingled glass-PP weave. This product, displaying cohesive bonding, should result in an economically produced, high strength material. The last products sampled, provided by Topas Advanced Polymers of Florence, KY, were a single-ply cyclic olefin copolymer (COC) Topas 8007 and a multilayer sheet with outer layers of Polyethylene Terephthalate Glycol (PETG) and an inner layer of the Topas 8007 COC. The advantage of COC has been seen in outstanding moisture and biological resistance. The layered film was created to enhance processability [19].

Owing to the lack of elasticity with Twintex®, the manufacturer has recommended the process of manual formation and autoclaving [15]. It is the objective of this experiment to demonstrate that this material can be utilized with the simple two-stage stretch-vacuum process. The guidelines of the manufacturer were adhered to in regards to minimum radius of curvature, with radii less than 5mm and draft angles less than three degrees. To deform the laminations, a simple three-dimensional male mold was produced with three levels of protrusion in order to evaluate the stretch potential of the reinforcement. Another design feature of the protrusions

was the rectangular shape which afforded a better evaluation of anisotropy in the 0-90 degree woven materials. This was particularly important with the unbalanced TPP60N44T twill weave. It also provided the opportunity to evaluate the performance in the stress-concentration points at the upper level corners, as per Figure 3.



FIGURE 3. Thermoforming mold as machined for lamination trials

The lamination plan was comprised of the surface layer and the reinforcing layer. Essentially, the surface layer was the vacuum retaining layer, which would pull the reinforcing layer down to the mold in the second (vacuum) stage. According to the manufacturer of the reinforcement, this simple technique has not been utilized in industry [20]. To evaluate the viability of this process, sections were cut to 500 mm wide, 750 mm long sections to accommodate the clamp size on the sheet fed thermoforming machine. Figure 4 shows the material as clamped in the machine prior to heating. Figure 5 shows the material under heat in the oven section of the machine, and Figure 6 shows the product post-forming and prior to off-line trimming.



FIGURE 4. Clamped laminates prior to heating

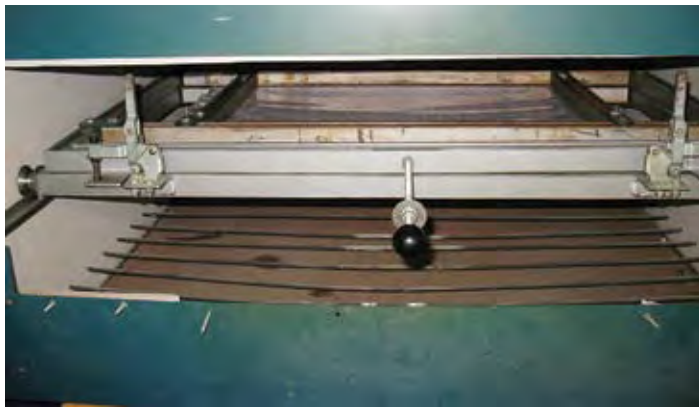


FIGURE 5. Laminates in oven approaching forming heat.



FIGURE 6. PVC-TPP60N22P lamination post-forming, prior to trim.

Edges were taped in order to hold the laminates together during mounting. In a continuous process, this could be accomplished by needling, or tacking together with thread. This would entail using two feed rolls, and a needling station prior to the oven section.

During the heating stage it was found that in order to achieve an optimum deformation cycle time of 120 seconds, an average 190 degree Celsius heat was required for the TPP60N22P laminations. For the TPP60N44T laminations the time had to be extended to 180 seconds for the same process temperature.

Results

The initial observation was that deformation of the laminations was limited due to the inelasticity of the reinforcing layers. As anticipated, formabilities of the laminations were found to be quite limited. Table 2 displays the max depth of deformation per half width (radius) of separation of the initial upper contact surface. Cavity formation percentage was calculated as a percentage of the actual strain length versus the lineal mold cavity length in the same plane of deformation.

TABLE 2. Deformation Results for Various Laminations at 23.6 Pa

Material	Max. Deformation (mm/mm):	Cavity Form %:
PVC-22P	0.193	7.8%
COC-22P	0.171	5.7%
PCP-22P	0.221	4.5%
PETG-22P	0.236	4.9%
PP-22P	0.274	10.9%
HDPE-22P	0.189	2.6%
PVC-44T LONGITUDINAL	0.193	4.8%
PVC-44T TRANSVERSE	0.238	4.8%
PCP-44T LONGITUDINAL	0.132	4.9%
PETG-44T LONGITUDINAL	0.136	5.4%
PP-44T LONGITUDINAL	0.158	6.1%
HDPE-44T LONGITUDINAL	0.168	3.7%

Deformation depth and cavity formation percentage was seen to be directly related to the vacuum generation of the equipment and the cooling rate of the material. The results listed in Table 2 are based on the maximum vacuum capability of the sheet fed thermoformer utilized, at 23.6 Pascal as measured at the vacuum box. The lack of deformation can be attributed the high strength and modulus of the reinforcing threads at measured at in uniaxial tension tests 377 MPa and 20.7 GPa respectively, which is 7.6 to 12.7 times greater than that of the surface layers.

Second, performance of the process varied greatly due to the cohesion and adhesion of the laminates. Some of the materials exhibited pull-through of the surface layer into the reinforced matrix creating an exceptional mechanical bond. Several tests of composite strength in these regards were performed to ASTM Standards, the most useful being T-peel testing performed to ASTM D1876-08 [21] that quantified the adhesion strength. The PVC- TPP60N22P laminations displayed a low 11.47 N/m peel strength, whereas COC- TPP60N22P showed a 11.2 N/m peel strength. The PP- TPP60N22P showed a high 2270 N/m peel strength due to the cohesive nature of its bond. The PVC surface layer specimens did not adhere well and often delaminated in trimming and handling. The semi-crystalline, HDPE and PP laminations exhibited much greater warp when cooled off the mold. These materials had excellent adhesion and cohesion properties and thus were deemed successful composite products. The PET products exhibited little warp and had good adhesive qualities, whereas the COC materials also had little warp and clearly showed outstanding stiffness and strength.

Other tests regarding flexural and impact resistance showed the synergies of combining reinforcement with surface layers. Generally, the mechanical properties increased significantly. For example, the PET- TPP60N22P, tensile strength increased 136%, modulus increased 102% and impact resistance increased to 85.6 kJ/m² from 3.48 kJ/m² versus the single-ply material. Contact the author for complete comparative mechanical results.

Conclusions

Further development of the thermoforming process is warranted due to the successful lamination of commingled woven reinforcing fabrics with various surface layers. Tailoring these laminations to desired properties in applications is the primary feature, followed by the efficiency and economy of the process versus competing materials and processes. In many cases the physical properties are enhanced dramatically compared to that of the sub-components. The disadvantages found have been primarily based on low thermoformability of the reinforcement due to the lack of elasticity and the lack of compatibility in adhesion as found in the PVC-TPP60N22P laminations.

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SPE 2013 Thermoforming Conference Presentation Title:

Clear Anatomy: Understanding Packaging through the Eyes of the Consumer

Presenter:

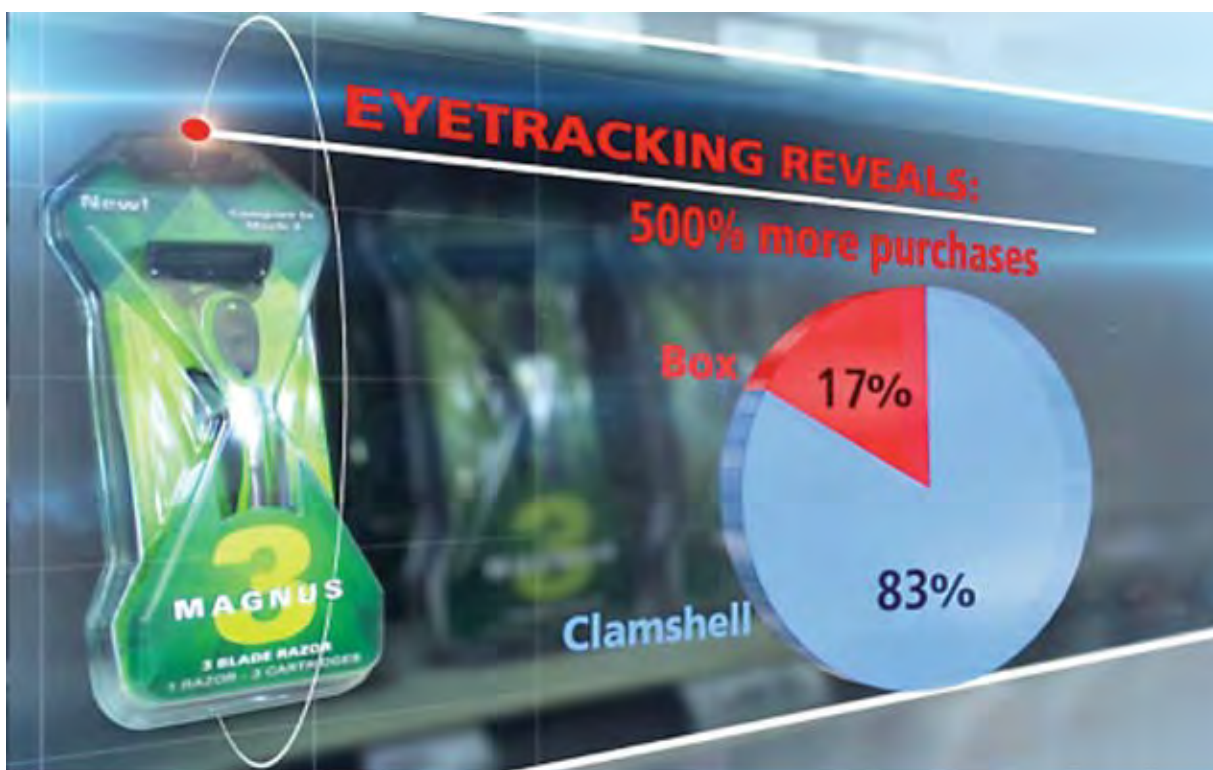
Peter Gianniny, Thermoforming Films,
Klöckner Pentaplast America

Extended Abstract:

Different packaging options can make an enormous difference to the bottom line, both through manufacturing costs and influencing a customer's point of sale decision. A study was conducted in the CUshop™, a recreation of a shopping environment, to examine the differences in how customers shop for products when they have the option for either a clamshell package or a printed paperboard box.

To accomplish this, 68 participants wore eyetracking glasses and shopped for several products. Three different products were present in both a clamshell and box variety (electric toothbrush, men's razor, and air freshener) and were placed amongst many other products in the CUshop. Participants selected which product they would purchase if they were shopping as they normally would with a provided shopping list. During this process, their eye movements were recorded at a rate of 30 times per second. These eye movements were used to corroborate the results and provide insights on why participants purchased the item they did.

Results indicated a strong purchase preference for clamshells over boxes, with more than 400% more purchases being received for clamshells. Eye movement metrics supported this result, with clamshells being looked at faster, more frequently, and for longer periods of time. Statistical evidence shows that there is a strong correlation between fixation duration and purchase decision, and thus longer fixations on clamshell packages show that they are a more attractive packaging option to consumer. |



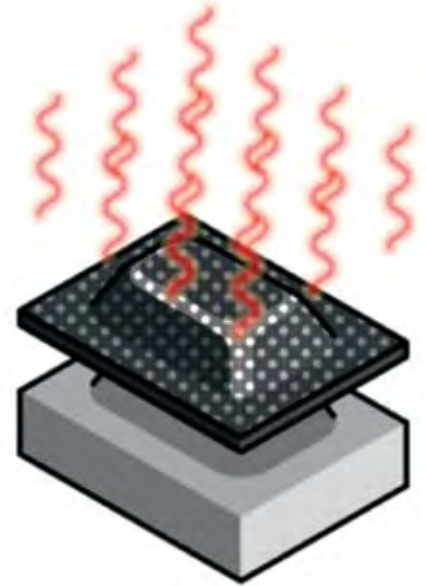
Technical Recommendations for Decorated Thermoformed Parts

By Olivier Hilmarcher, Market Manager
Protechnic Hélioplast Division

Use of PMMA printed films laminated to ABS Sheets can really offer new perspective in terms of design: metal aspect, brushed aluminum, chrome aspect, carbon aspect, wood aspect, marble & stone aspect. This is also exciting to know that those sheets of ABS + printed PMMA films are still easily vacuum formable; there are no limitations, just new opportunity to get ultra-innovative aspects on thermoformed parts.

Thermoformed sheets of ABS + printed PMMA films are already used in many different fields: automotive, public transportation, mobile homes, yachting, bikes, sanitary, luggage, etc.

During the presentation, a focus will be made on a few technical points to be considered to get a nice final decorated thermoformed part. Each processing step is important: film lamination should respect a few basic rules and vacuum formed settings may be slightly modified to be really successful. |



Heating and Cooling the Plastic Sheet

By Joseph LeBlanc, Ph.D.
Pennsylvania College of Technology

The initial step in thermoforming is to heat the core of the sheet to the forming temperature in the shortest time without overheating the surface. The appropriate method will depend on the type of plastic and the thickness. The material characteristics for heat transfer are Thermal Conductivity,

Specific Heat Capacity, and Thermal Diffusivity; the mechanisms of transferring heat into the material are Conduction, Convection, and Radiation. Conduction is useful to heat a very thin sheet. Radiation is used for thin to medium sheets, and in most applications. For very thick sheets, Convection might be the most applicable, and it is more efficient if the air is forced.

Radiation absorption is sensitive to temperature, distance, view angle, type of plastic, and surface quality. Polymers will be transparent or opaque to infrared in various degrees at different wavelengths. An FTIR analysis of the sheet material is useful to match the emitted peak wavelength to the absorbed wavelengths.

The last step is to cool the part uniformly to prevent warps and surface defects. As soon as the hot sheet touches the mold and the plug, it is being cooled by Conduction, and this mechanism will dominate while the part is in contact with the mold. The mold will be cooled by water forced through channels and the efficiency of cooling will increase if the flow in the channels is turbulent, rather than laminar. When the part is separated from the mold, it is cooled by Convection currents forced over the part; radiation from the part is minimal because of its relatively low temperature. |



Thermoforming Can Meet the Demand for Stronger, Higher-Quality Packaging at Lower Cost, Source Reduction and Recycling

By Kent T. Johansson, President and CEO, OMV-USA, Inc., Machine Division
Elkhorn, Wisconsin

ABSTRACT:

Today's thermoforming technology can comply with all of the above demands. It also provides safe and hygienic packaging for fresh food and the convenience of disposable cups and tableware to fit the recycling stream.

The new, modern, fully-automatic, fast running thermoforming machines are designed for electronic optimization with minimum energy cost, highest level of repeatable process cycle, in-mold trim and mold utilization. The unique "shuttle" mold technology especially designed for increased cooling time will assure the highest level of tolerances using polyolefin materials. This together with our lid forming option will complete a package suitable for tight lid fit inside and outside (3x point seal) and optional tamper evidence.

Build in rim rolling, automatic counting/stacking, bagging and carton packaging will assure clean/hygienic handling (no humans touch the product) and labor savings. In addition, OMV technology offers thermoforming IML of rectangular, round containers and lids. Big savings comparing to injection molded IML.

The combination of the in-line extrusion/thermoforming system and described forming and decoration methods will give the most economical process today for the production of plastic food and disposable packaging. With quality and tolerances similar to or better than what is normally experienced in injection molding, the old issue of "less quality in thermoformed products" has been resolved by using this technology and that the end users can see the big advantages in thermoformed products. |

Optimization of Flat Sheet Extrusion

By Tim Womer, CPlasT

Flat sheet extrusion can be a very complex process depending on the resin, the tolerance required for the final product and everything in between. It is necessary for the engineering manager, the process engineer and the extrusion operator to understand several basic and fundamental requirements in order to produce good quality flat sheet.

The basic components for producing a quality flat sheet are:

- the resin being processed
- the screw which will feed, melt, pump and mix the resin
- the screen changer which will filter the resin after it leaves the extruder and before it enters into the melt pump
- the die that is used to give the resin the desired width and thickness
- the heat transfer rolls which will cool the sheet and give the resin its final finish and dimension

It is not only necessary to understand the function of each component of a sheet extrusion system, but also the interaction among each. For example, how does understanding the melt rheology of the resin being processed affect how the barrel zone temperature profile is optimized to produce the best melt quality that is delivered from the extrusion screw? Or, how can optimizing the type of screen changer that has been installed in the system affect the optimization of the extruder screw or the function of the melt pump that is after the screen changer?

Each of the components in the sheet extrusion system represents a science within itself. A good basic understanding of each component is necessary for a company to produce a flat sheet product of high quality that will provide the most profit.

This one-day seminar will teach the important fundamentals of each of these components. People who should attend this seminar are engineers, technicians and managers who design, fabricate and manufacture flat extruded sheet. |

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The McConnell Thermoforming Heavy Gage Workshop

Presented by: Robert Browning and Don Hylton

WORKSHOP PRESENTATIONS

Thermoforming 101: The Basics We Tend To Forget **Robert Browning**

Get The Basics Right - The Rest Will Follow

A brief presentation will be conducted on the "Basics of Thermoforming" and why we have to re-examine them on a regular basis. Problems are solved by getting back to basic knowledge and experience.

Material Behavior in Thermoforming: **What You Should Know** **Don Hylton**

Thermoformers use time, effort, material and money compensating for inconsistencies in sheet materials. This session explains the root causes of those inconsistencies and how sheet production, resin selection, regrind, extrusion conditions and calendaring influence thermoforming. Learn to establish proper sheet specifications for cost effective Thermoforming. Additionally, methods to trouble shoot and remedy sheet problems, quality control and sheet consistency will be covered. The outcome will be insight on how to establish proper sheet specifications for cost effective Thermoforming.

Thermoforming Case Studies: The Good, The Bad & The Ugly - Robert Browning

Do You Ever Feel That Your Sole Purpose In Life Is To Serve As A Bad Example For Others?

Here is your opportunity to witness case studies of the successes, failures and really bad problems other thermoformers have had with processes, designs, and why. Things can go wrong. Successful thermoforming must be able to analyze, understand, and know how to correct problems. The keys to successful operations are to learn from problems and mistakes and not repeat them.

Afternoon Panel Discussion: Thermoforming Questions and Answers

Bring questions, sample parts and problems for discussion and free help from the experts. In the past years, the open panel questions and answers have produced some very intense and diverse discussions.

Moderator: Stephen Sweig, Profile Plastics

Tooling: Ken Griep, Portage Casting & Mold

Material/Extrusion: Chris Willis, PMC

Machinery: Paul Alongi, MAAC Machinery

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Thick Sheet Thermoforming With FDM Tooling

A detailed overview for using Fused Deposition Modeling tooling for heavy-gauge thermoforming

By Rob Winker, Stratasys

***Editor's Note:** This article has been adapted and re-formatted from a "Technical Application Guide" for thermoforming using FDM technology, a novel application. Its focus is on the details of how the FDM tools were used successfully.*

1. OVERVIEW

- 1.1.** FDM patterns provide custom tools directly from CAD models.
- 1.2.** Using Insight, interior fills can be processed with varying levels of porosity allowing for vacuum to be pulled throughout the tool without the need for drilling vacuum-assist holes.
- 1.3.** CAD data and FDM provide coordinated tooling solutions for thermoforming by coordinating the parent geometry to output forming tools, scribe or offset trim tools, and vacuum-holding jigs.



FIGURE 1



FIGURE 2



FIGURE 3

2. CAD CONSIDERATIONS

- 2.1.** Most types of forming plastics will contain some level of shrink during the thermoforming process. It is recommended that shrink compensation be applied during tool design. If the native CAD file is not available, the STL file can be scaled to provide the required compensation.
 - 2.1.1.** Mold shrinkage for male molds is 0.4%-0.6% and female molds, 0.5%-0.7%
- 2.2.** Drafting side walls is recommended to assist in tool extraction. Minimum draft of 1-3 degrees should be designed into the tool. Additional draft angles of 5-7 degrees will greatly assist tool extraction, along with the added benefit of minimizing the likelihood of webbing.
- 2.3.** Minimum radius for tool design is generally equal to the nominal thickness (i.e. 0.71mm [0.028" in.] thickness).
- 2.4.** Additional technical information for Kydex can be found at http://www.kydex.com/uploads/files/tb-116_021011-368.pdf

- 2.5.** CAD output files will be in the STL file format. For a simple model, such as the box shown in Figure 1, its surfaces can be approximated with twelve triangles, two on each side, as shown in Figure 2. The more complex the surface, the more triangles produced, as shown in Figure 3.

2.5.1. STL files should be exported as binary.

2.5.2. If your part was rougher or smoother than you had hoped, you can change the angle, deviation and chord height to create the right outcome. Faceting is determined by the relative coarseness of curved areas of the adjoining triangles. The most common variables are deviation or chord height, and angle control or angle tolerance. Coarse faceting is almost always caused by the angle setting being too high, or the deviation/chord height settings being too large, or a combination of both.

- 2.6.** Several benefits to both build time and material cost savings can be incorporated into the CAD design of the tool. Insight preprocessing software provides for automatic support generation. This calculation scans the geometry and automatically generates support structures needed to build geometry such as cavities and overhanging structures. Traditional tools used for thermoforming are typically built out of solid materials. This is not required when building with FDM and can be optimized through a couple of different processing styles. One way to optimize the tool is to design in ribbing. This topic will be explained further in the next section. Another method is to build the tool using the Insight™ sparse-fill build style. This technique is explained in Section 4.

3. TOOL DESIGN OPTIMIZATION AND CONSIDERATIONS

- 3.1. Tool Optimization Using Ribbing:** If your CAD program allows for Finite Element Analysis (FEA) of the tooling design, this is the best way to calculate potential tool deflection under forming loads. Using the conversion from -inHg to PSI, most thermoforming machines are only able to achieve -25 - -28inHg. This would equate to 15 PSI that could be used to calculate the pressure load on the surfaces of the tool in the analysis tool. Other considerations that could influence tool design are the life expectancy of the tool and whether the tool will be fixtured in the framing system of the thermoforming machine or free floating on the bottom foundation plate. For tools that will be fixtured to the forming machine, it

is recommended to use a minimum of 0.25-in. ribs and walls. Rib spacing is a complex parameter that is geometry dependent and the use of FEA tools is recommended to optimize spacing requirements. For a conservative structure, rib structures should be placed on a 1-in. centerline spacing. As a general rule, spacing can be increased as tool height and surface area is reduced.

- 3.2. Tool Fixturing:** If the tool will be fixtured into the framing system of the thermoforming machine, hardware inserts or hard points for drilling and tapping locations should be accounted for in the CAD design of the tool. The FDM process can be paused during the build to allow for the insertion of nuts or other fastening hardware. (Higher temperature FDM materials such as PC, ULTEM 9085 and PPSF tend to show a witness line of a shrink point at the insertion point on the part due to temperature fluctuation of the build envelope during insertion. Insertion should not be practiced if high tool accuracy is required. Tools built with PPSF should not incorporate insertion, as there is high potential of the foundation sheet to lose vacuum during insertion due to temperature change.)

4. INSIGHT PROCESSING

- 4.1.** The primary benefit of using FDM tools is the ability for the tool to be processed and built with porosity throughout the entire tool. Traditional tools require drilling vacuum-assist holes throughout the tool to allow for vacuum transfer through the tool. With FDM, this is automated with the Insight software and the processing style of building with positive air gaps in the raster fills throughout the build. This enables channels throughout the entire tool for the vacuum to be drawn through. If an FEA tool is not used in the design of the tool to calculate surface loads, the best recommendation to ensure tool integrity would be to process the tool in Insight using the Part interior style of Solid-normal under Modeler Setup and then add the internal porosity through one of two methods:

4.1.1. In the Toolpaths main menu, choose Setup. Once in the Toolpath Setup menu, click on the advanced parameters button. Once in this menu, locate the internal raster airgap parameter and set it to +0.010 in. (+0.254 mm). This is a key parameter that allows for vacuum to be pulled throughout the tool.

4.1.2. A second way to build porosity into the tool build is through custom groups. Under the Toolpath menu, click the New button. This will open the Create New Group window. Under "Air gap between," enter +0.010 in. (+0.254 mm) in the Adjacent rasters box.

Next, select all curves on the model so that they become highlighted on the screen, then click the Add button under the Custom groups menu. Additional information on this feature can be found by searching "custom groups" in the Help Menu.

- 4.2. System mode selections with ULTEM material:** Tools should be built using the Normal system mode. This allows for increased oven temperature to prevent part curling from the base.
- 4.3.** When processing tools with PPSF material, it is highly

recommended to use the "Auto Cool Down" mode on the FDM machine to prevent temperature shock to the tool during removal, which could result in fracturing.

5. POST PROCESSING THE FDM TOOL

Generally the only post processing needed on FDM tools is a light sanding. All tools used for test in this application were sanded with 120-grit aluminum oxide sand paper using a 5.5-in. dual-action sander. The main concentration of the sanding was blending the area of the seam to match adjacent surfaces.

- 5.1. Fillers:** Fillers are not recommended, as this blocks the FDM tool's natural porosity

6. RELEASE SPRAYS

Two types of spray release were used during testing:

- 6.1.** The first release tested was Sprayon S00206 all-purpose silicone lubricant. This worked with acceptable results on all FDM materials tested. A light coat was sprayed on the tool on every other pull.
- 6.2.** The second release tested was Sprayon S00708, which is formulated with P.T.F.E. and was found to release better than the silicone formula on all FDM materials tested. A light coat was sprayed on the tool on every other pull.
- 6.3.** Other untested considerations are
- 6.3.1.** Zyxax
- 6.3.2.** Miller Stephenson

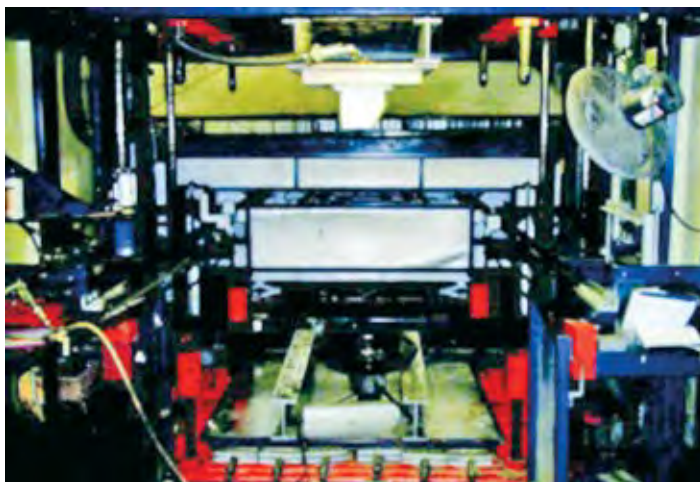


FIGURE 4: FDM tool mounted in the thermoforming machine

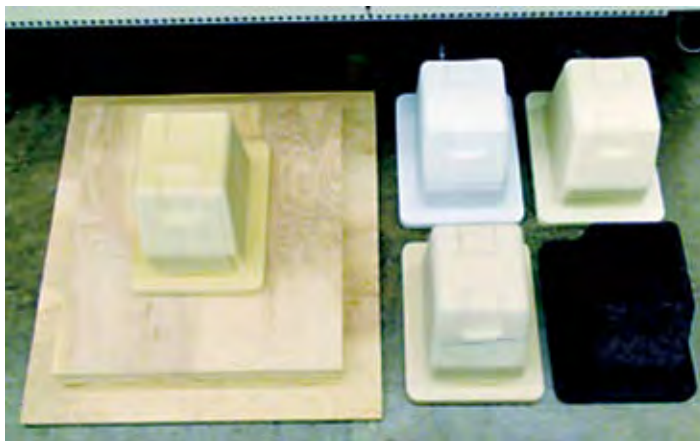


FIGURE 5: FDM heavy gauge thermoform tooling

7. TESTING

All testing and thermoforming design expertise was in partnership with Kintz Plastics Inc., Howes Cave, New York (www.kintz.com).

- 7.1. All test pulls were processed with Kydex T in 0.250 in. (6.35 mm) sheet stock. Kydex T is a fire-retardant thermoplastic sheet for general thermoforming, commonly used in aerospace applications. Drying is generally not required except in high humidity. If the material must be dried, it should be dried at 68 C (155 F), or about 15 C below the product's HDT for 16 hours for 3.20 mm (0.125 in.) thickness. Two-sided (sandwich) heaters are recommended above 2.00 mm (0.080 in.) nominal thickness. Additional Kydex material information can be found at: www.kydex.com/technical-data/technical-briefs.aspx.
- 7.2. All test pulls were processed on a Monark SPF Series thermoformer with LP heating. The Monark system uses both top and bottom heaters that allow for more uniform heating of the plastic sheet.
- 7.3. As shown in Figure 4, our test tools were invert mounted on the top frame of the machine to allow for the natural draping of the heated plastic to compliment the deep draw. This helps to minimize chill spots on the pulls by minimizing the time of contact between the sheet and tool, prior to vacuum being pulled. The FDM tool was bolted to a plywood base consisting of 5 layers of 0.75-in. plywood that was glued and screwed together to coordinate with the thermoforming framework. Tooling is shown in Figure 5. This configuration enabled the tool to be extracted from the sheet form using the pneumatic lift of the machine, once the plastic had adequately cooled. This configuration duplicated a production setup, which allowed for repeated processing of the tool |

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SPE 2013 Thermoforming Conference Keynote Speaker

Dr. Peter Mooney, PCRS | Wednesday, September 11, 2013

Thermoforming in the New Normal Economy

The first dozen years of the new millennium have been marked by tremendous turbulence. There was a mini-recession in 2001, followed by a period of strong economic growth fueled in part by expansionary monetary policy. Yet by 2007 the regional and global economies were showing signs of an impending financial crisis. The Great Recession ensued over the period 2008-2009, and to date, the rebound from this setback has been unusually tepid.

Virtually every segment of the North American plastics industry experienced this pronounced convulsion of economic activity. This was certainly true for the industrial product thermoformers. And contrary to the notional the single-use packaging market is recession-resistant, the packaging thermoformers also endured a temporary sales downdraft in 2009.

What lies ahead? The notion of a "new normal economy" has gained currency. What does it mean? And to the extent it's relevant, what does it portend for regional thermoformers of industrial and packaging products?

Peter's presentation distills data and insights drawn from his thermoforming research programs. He provides an economist's perspective on recent patterns of growth and technological change in this business, highlighting some of the opportunities and challenges that lie ahead. |



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COUNCIL SUMMARY



The PlastiVan Outreach Education Program

In the Q1 2013 issue of *TQ*, I reported that the SPE Foundation is now home to the **PlastiVan Outreach Education Program**. This program plays a vital part in our “plastics manufacturing alliance with education”. In order to promote a future interest as plastics engineers, technicians and professionals, the excitement of plastics needs to be communicated to middle school students and teachers. The van program provides that energy into education. This article will update members on the program, how it can benefit all of us, and what is taking place to manage and grow the program moving forward.

The PlastiVan Outreach Education program is a hands-on science and technology program that excites middle- and high school students, as well as the general public, about the vast opportunities offered by our industry. This is a traveling program that visits schools and companies throughout North America. The program educates people of all ages about the chemistry, history, processing, sustainability, and application of plastics. This program has been easily and successfully integrated into school curricula for over 15 years. PlastiVan provides sound science and educational programs which spark scientific and “how’s that done” curiosity in students, while increasing their knowledge of how plastics contribute to modern life. This knowledge and curiosity has encouraged many past PlastiVan students to seek careers in plastics.

The PlastiVan program is designed to visit one school per day. The maximum

class size is 40 and up to 5 classes will be taught in that school day.

The middle school lab (with groups ages 12-14 and the most popular program) provides a fun learning experience introducing the students to polymers involving them in experiments that will pique their interest in science and technology.

The high school (ages 15-18) and adult labs are an advanced experience where students delve into the chemistry, history, and sustainability of plastics and how they are designed to have distinct properties. At this level students are also introduced to a wide array of career opportunities as well as college programs that focus on plastics engineering. With 50% of the plastics industries technical professionals retiring over the next 5 years, work force development cannot start too soon.

Plastics industry companies and other organizations are encouraged to bring the PlastiVan to their communities for the introduction of the marvels of plastics to students and adults. Time can be allotted for a company representative to address the groups about their products, processes and career opportunities. Sponsoring companies nurture development of their future workforce by opening minds to the science and engineering related careers available. A PlastiVan visit further benefits the sponsoring company by increasing their visibility in the community, uplifting the public’s perception of the industry, and positively affecting the lives and minds of young people.

Moving forward the SPE Foundation is evaluating the current state of the PlastiVan program. The complete understanding of current strengths and weaknesses with identification of the threats and opportunities for the PlastiVan program are in process. This knowledge will lead to a 5-year business development

strategy designed to assure continuing success of the program.

The exciting part of this process is recognizing the opportunities for the future. In closing, I want to share some of those possibilities for the PlastiVan program with you.

- An expanded presence throughout North America and internationally
- Expansion of content
- Content updates and refreshing
- Multilingual program availability
- Webinars
- YouTube videos
- Support of expanded scholarship applicants
- SPE Student Section involvement
- Parents increased understanding of the industries opportunities
- A PlastiVan app

Thank you for taking an interest in the future of our industry through your membership and support of SPE. Furthering our industry success through support of the PlastiVan Outreach Education Program can be initiated by contacting Margie Weiner at 978-618-5496.

Plastics Education on the Move!

The SPE Foundation is now the home for the “Plastics Van Program”. SPE is applying pressure on SPI for further Van Program funding relating to the transfer agreement. The Foundation will be developing the final budget and planning for the Van at our next meeting Friday the 22nd. The Thermoforming Division may want to consider some grant funding to the Van program instead of additional scholarships when we have added scholarship memorial funding. Just food for thought as the Van touches many students. |



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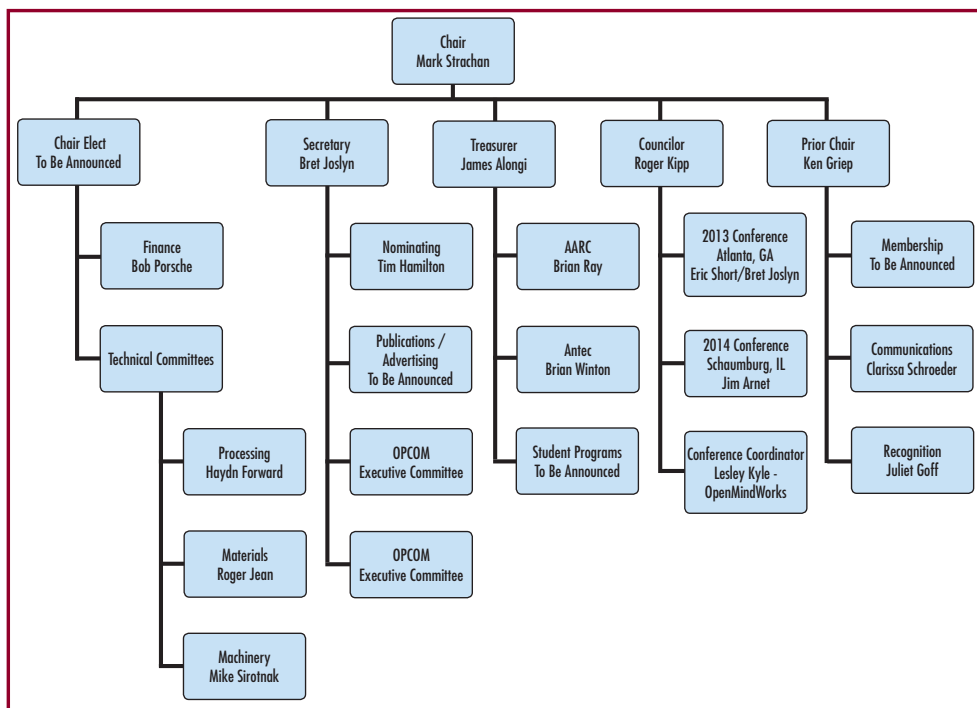
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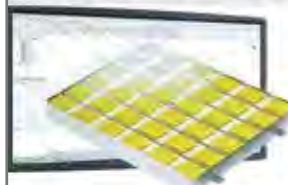
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New Process Monitoring Technology for Thermoforming

By Robert Borse, President, Angle Tool Works Inc.
Burr Ridge, IL

Abstract

The evolution of thermoforming plastics continues. Every year, thermoformers are challenged with an array of new products and resins. Quality control systems boasting continual improvement seek higher performance standards. Supply chain systems remain focused upon backwards traceability and cost containment. Meanwhile, thermoforming product designs and manufacturing techniques continue to become ever more complex. Managers drudge through manufacturing records in search of techniques to meet higher efficiency goals. More than 30 years ago, Philip Crosby wrote an astounding book called *Quality is Free*. The quality principles found in Crosby's book remain unchanged. The only real changes have been in technology. Modern quality systems must be designed for today's modern processing environments. In other words, who would think of making quality claims of absolute precision using a plastic slide rule and a wooden yard stick? Crosby's philosophy included internal system reviews through regularly scheduled internal audits. This is where quality control management questions the system in place.

- Does your manufacturing process support qualitative judgment?
- Is your system the traditional periodic snapshot or is it a true continuous monitoring system?
- Are data records actual processing parameters or only simply documentation of machine settings?
- Is the manufacturing processing data automatically archived?
- Does your process decision support efficient and effective operations management?
- Does your data detect risk issues within the process?
- Does your data provide a means to detect weak or poorly designed process controls?
- Does your data system include a procedure to correct or replace ineffective operational controls?

Now the concept of continual process monitoring and recording begins to take hold. Process monitoring technology begins the transformation of thermoforming from art to science. Among the many advantages of process monitoring are increased efficiency, reduced costs and improved quality assurance.

Process Efficiency

As new thermoformed products continue to increase in complexity, so do the costs associated with producing those products. Thermoforming relies on upstream sheet extrusion before forming the product. Most extruded sheet requires expensive additives and colorants which add to sheet costs.

Efficient utilization of extruded sheet is the thermoformer's first major cost hurdle. The second is transforming that very expensive sheet into quality products that will meet or exceed the demanding product expectations of their customers.

Today's competitive market structure is found at every stage of the thermoforming process. The pure competition marketplace requires that firms compete for business. Generally, firms must operate at top efficiency to out-produce the competition while maintaining profitability. Here, all the basic fundamentals of pure competition remain the same. Firms with production models operating with a cost advantage generally prosper while firms with production models operating at a cost disadvantage most often perish. Therefore, businesses are in constant search of technologies offering cost advantages. What if a new technology were recently developed that could be easily adapted to existing capital equipment? What if the new technology had the potential to differentiate your firm from your competition, giving you a competitive advantage?

The scientific approach is the basic protocol of all researchers. Scientists and chemists have developed and utilized laboratory testing equipment for centuries to achieve today's advances in technology. It is this effective utilization of laboratory testing equipment that has fostered the development modern plastic polymers. What if laboratory technologies could be economically adapted to rigors of today's production floor environments?

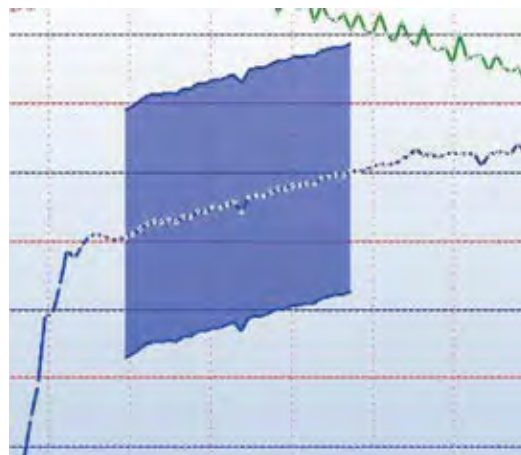


Figure 1: Process Monitoring Graph

Process Confidence and Predictability

Thermoforming machine technology has improved dramatically with such developments as the microprocessor and servo drives. Today's machines are absolutely more mechanically advanced than their predecessors. Then again, many of today's products are more difficult to process so this makes sense. While the machine controls have become more advanced, they have also become more difficult for operators to interpret. Modern control panels offer multiple screen views, requiring the operator to step through several display windows while adjusting the machine settings. Here lies the operator's difficulty in assessing the machine settings.

- Which machine settings are correct?
- Which machine settings are most optimal?
- Is the process fully predictable?
- Would different settings provide a higher level of confidence?
- What settings would improve quality?
- Are there variations between different thermoforming machines that need compensation?
- It now works, but why?

The new concept of continual process monitoring provides the answers to these questions. Continual process monitoring of events during the thermoforming cycle provides real-time quantitative and qualitative data. That data may then be used to support changes to the thermoforming machine settings.

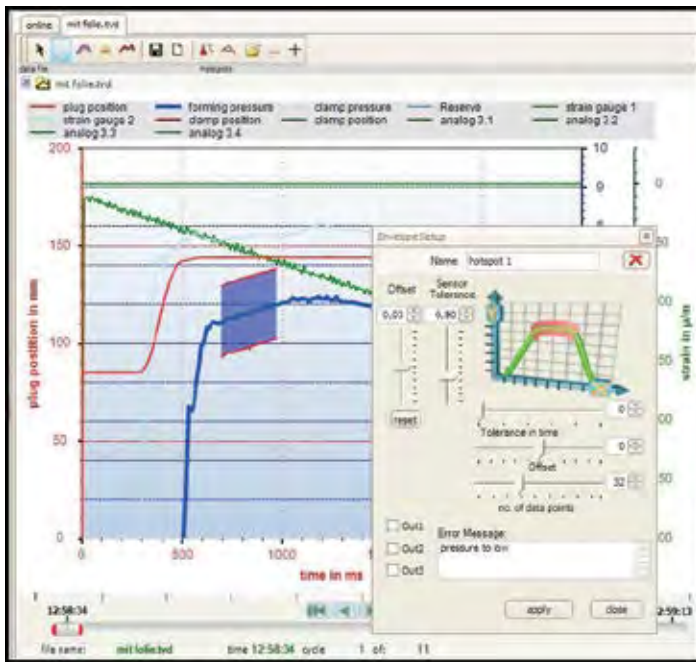


Figure 2: Process Monitoring 3D Graphics

ToolVu® Continuous Process Monitoring System

The ToolVu® system is a process monitoring system that can interface with any thermoforming machine. The system provides multiple graphic displays of various process events. The display provides charts and graphs in real-time as they are occurring during the machine cycle. The system was recently demonstrated at SPE Thin Wall Thermoforming Workshop at Penn State College. The live onsite process monitoring demonstrations offered all those attending the workshop an opportunity to better understand the dynamic conditions that occur during the thermoforming process. Here, the advantages of the continual process monitoring become quickly apparent.

The ToolVu® system incorporates process monitoring features that are new to the plastics industry. Sensors monitor process events in microseconds. The system is so accurate that it identifies even the slightest process variations created by different machines, sheet or tools. Most importantly, it provides the operator with real time usable information that is easy to interpret.

Adding the ToolVu® monitoring system to any thermoform machine and tooling will allow precise measurement of many specific thermoforming events. Here are a few of the most basic events that may be measured and recorded:

- Form Air Cycle: volume, velocity, and duration
- Vacuum Cycle: volume, velocity, and duration
- Plug Assist Speed: proximity, forces generated, velocity, acceleration/deceleration
- Temperatures across the sheet as the sheet enters the forming station
- Stress and Strain sensors located on the trim tooling record the pressures exerted, along with tool flex during the trim cycle.

The system empowers the operator to base decisions on operating data and allows him to visually disseminate that data in real-time.



Figure 3: Process Error Report

The proprietary ToolVu® system is a complete process monitoring platform. The package includes everything required for successful installation:

- Computer
- Monitor
- Sensors
- Cables
- Hardware
- Software
- Installation

Customization of the system allows users to select from a wide range of sensors that best suit their individual processing requirements. Data from sensors may be selected for display and recorded to any computer hard drive. Best of all, the continuous computer archiving system makes quality control retention indefinite and permanent.

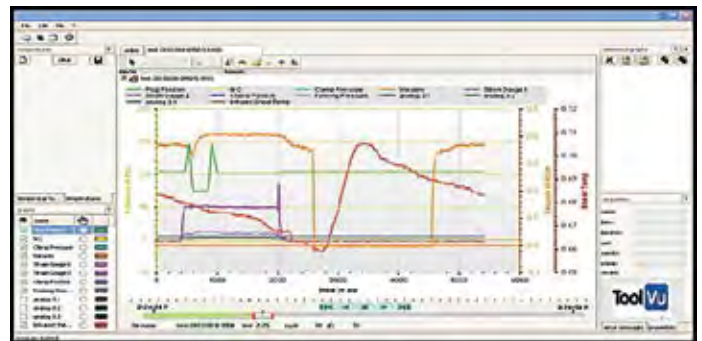


Figure 4: Process Monitoring Graph

Benefits of Continuous Process Monitoring Process Improvement

- Continuous monitoring actively identifies, quantifies and reports control failures

- Reduces startup time and improves machine and sheet production efficiencies
- Reduces process trouble shooting time and saves valuable production machine time
- Provides more effective and higher quality understanding of the thermoforming process
- Process monitoring enables the processor to precisely identify the process parameters
- Process monitoring enables the processor to identify new process parameters not previously understood, available or known to the processor
- Setting sensor parameters help manage risk while providing continuous qualitative and quantitative production process data

Quality and Control Improvement

- Continuous monitoring typically meets all three operational disciplines of quality control standards:
 - Continuous Audit
 - Continuous Controls Monitoring
 - Continuous Transaction Inspection
- Sensor parameters may be set to warn operators when process conditions fall below or rise above preset limits
- Reduces defective products and waste sheet
- Reduces defective product due to process variations not previously monitored
- Reduces inferior product cross contamination
- Reduces rejected products in the final packaging
- Reduces sorting, grinding and quarantine of rejected products
- Reduces returned goods
- Provides continuously recorded data for quality control systems
- Continuous Monitoring Computer data record retention meets requirements and integrates into modern Quality Control Systems / Continuous Improvement Systems

Cost Reduction

- Increased process efficiency allows the processor to save machine time, labor, materials and energy.
- Constant process control increases machine sheet efficiencies throughout the thermoforming process runs.
- Data recordings are paperless, computer data is stored on hard drives, so the records are easily retrieved for review and audits.
- Sensors mounted to the machine and tooling monitor the stress and strain during the trim cycle. These measurements are helpful in assessing when the machine or tooling is ready to be serviced.
- Sensors help in establishing service intervals for wear components. Historical data provides the ability to assess actual processing conditions.
- Stress and strain sensors may be set to warn when extreme conditions with alarms and lights. These alarms may even provide enough time to prevent a catastrophic failure, possibly preventing damage to the machine or tooling.
- Warning sensor parameters may be set to hard stop the thermoforming machinery when extreme conditions exist.

Return on Investment

- Real time experience with the system has clearly demonstrated that the system can ensure substantial cost savings when setting up

and running production on any thermoform machine and tooling.

- The cost savings resulting from the ability to monitor and control the process as detailed above have clearly shown the total investment can be recovered in as little as 6 months.

Most Common Hardware and Sensors Installed:

The standalone system is completely independent of the machine's controller and existing sensors. Therefore, the system may be installed on any new or existing thermoforming equipment.

- **Main Interface Box** – Main interface between the sensors and the software via a LAN Connection
- **Strain Gauge Sensors** – used to acquire data about the stresses on the machine presses and/or tool
- **Infrared Sensors** – used to gather real time sheet temperature data
- **Form Air Pressure** – used to monitor air pressure inside plug mold during production
- **Clamp Air Pressure Sensor** – used to monitor air pressure applied to the clamp or other components
- **Clamp Position Sensor** – monitors the clamp displacement throughout the cycle in high resolution
- **Plug Displacement Sensor** – monitors the plug motion travel in real time within the tool
- **Tool Temperature Sensors** – monitor up to 16 temperature sensors on the tool
- **Plug Force/Pressure Applied to Sheet** – measures the load between the plug drive and the plug plate on the tool
- **Visual Display** – provides visual graphs to view all sensors and data in real time
- **Signal Light Tower with Audible Alarm** – monitors may be preset to parameters that warn the user via 3-tier light tower with audible alarm

This novel system that applies real-time IT to thermoforming is geared specifically towards the processor. This system integrates directly into the production environment and provides immediate manufacturing process advantages. The marginal cost versus the marginal benefit decision model provides the methodology. Here, the more the system is utilized and integrated into the manufacturing process, the greater the marginal benefits resulting from improvements in product quality, process predictability, and production efficiency.

About the Author

Robert Borse is President of Angle Tool Works Inc, in Burr Ridge, IL. His professional career includes forty years of advanced tooling, manufacturing processing, quality control and supply chain management experience in the plastics industry. It encompasses all phases from concept and product development thru production of thermoformed products. His thermoforming experience includes virtually all the types of thermoforming processing equipment. His thermoforming knowledge base includes; high speed inline flat bed, wheel forming, cut sheet inline, cut sheet single and twin sheet heavy gage rotary, cut-in-place, trim-in-place, and form-fill-seal processes.

Sources:

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Step 1: Select the *right* base resin.

Mytex Polymers' custom formulated MetaForm 7200 brings uniformity and physical properties you can trust, from excellent melt strength over a wide temperature range to consistent sag behavior. Special attention is given to the design of this product to allow for a broader processing window and varying levels of draw depth parts.



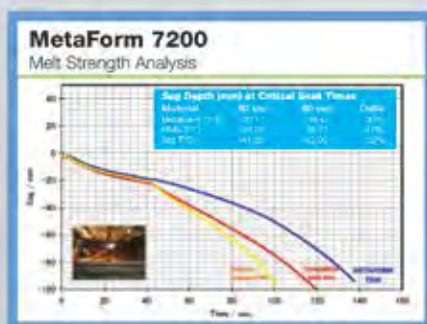
Step 2: Select the *right* extruder.

PMC has the technical know-how, TPO expertise and engineering support to produce high-quality sheet filling just the right criteria. They will consistently meet your performance objectives and expectations at a great value to you. With the operational capacity to produce one, two and three-ply custom sheet materials up to 120" wide and in gauges up to .375" thick, PMC will have the right product for you.



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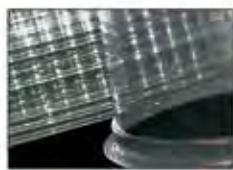
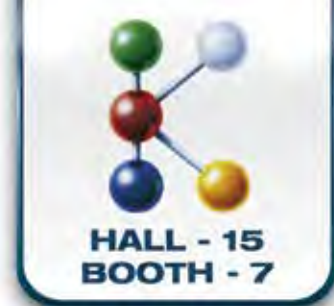


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