Contents

Thermoforming QUARTERLY

TECHNICAL SECTION

DIVISION ACTIVITIES

A NOTE TO PROSPECTIVE AUTHORS

TFQ is an "equal opportunity" publisher! You will note that we have several categories of technical articles, ranging from the super-high tech (sometimes with equations!), to industry practice articles, to book reviews, how to articles, tutorial articles, and so on. Got an article that doesn't seem to fit in these categories? Send it to Jim Throne, Technical Editor, anyway. He'll fit it in! He promises. [By the way, if you are submitting an article, Jim would appreciate it on CD-ROM in DOC format. All graphs and photos should be black and white and of sufficient size and contrast to be scannable. Thanks.]

Thermoforming QUARTERLY

A JOURNAL PUBLISHED EACH CALENDAR QUARTER BY THE THERMOFORMING DIVISION OF THE SOCIETY OF PLASTICS ENGINEERS

Editor
Gwen Mathis
(706) 235-9298 • Fax (706) 295-4276
gmathis224@aol.com

Technical Editor
Dr. James Throne
Sherwood Technologies, Inc.
1797 Santa Barbara Drive
Dunedin, FL 34698-3347
1-800-273-6370 • Fax (727) 734-5081
throne@foamandform.com
jthrone@tampabay.rr.com

Sponsorships
Laura Pichon
(815) 678-2131 Ext. 624
Fax (815) 678-4248
lpichon@extechplastics.com

STRENGTH IN NUMBERS

BY CONOR CARLIN, MEMBERSHIP CHAIRMAN

As the new membership chairman, I would like to recognize the efforts of Mike Sirotnak over the past decade. During Mike's tenure, the SPE Thermoforming Division has become one of the most successful divisions within SPE. Our group has steadily grown over the years and is renowned for having members from a variety of industries. In recent times, we have expanded our efforts to recruit members from our burgeoning European Division and also to fill our ranks with the brightest minds from university programs.

I joined the SPE Thermoforming Division in 2000 and through every conference, meeting and seminar I have attended, I am constantly impressed by the amount of knowledge that is shared. From conference centers in Nashville to congress halls in Salzburg, the wealth and breadth of thermoforming skills and techniques on display allows me to learn something new every time.

MEMBERSHIP REPORT as of 6/1/06

Primary Paid	1,704
Secondary Paid	541
Total Membership	2,245
Goal as of 6/30/2007	2,500

When you participate as an SPE member, you are joining the ranks of the experts. Polymer scientists, process engineers, old sales hands and company executives are all in attendance at the annual conference. There is no better place to take the pulse of our thermoforming industry.

In addition to the benefits you receive as a member, you are also encouraged to contribute. We receive technical articles from universities in Europe as well as industry practice articles from seasoned formers. Your feedback on the contents of the Thermoforming Quarterly are important to the magazine's continued success.

It is my hope to build on the strong foundation left by Mike. Just looking at the new members every quarter is an inspiration as we continue to welcome people from around the country and around the globe. We are creating our own worldwide network and I am proud to be a part of it. I invite you to come and join us. ■

To Our New Members

Jay Abbott
Display Pack, Inc.
Grand Rapids, MI

Phillip J. Asker
Vitasheet Group
United Kingdom

Donald E. Bailey
Sun Tech
Tuscaloosa, AL

Bruce Belhoff
Whirlpool Corporation
Benton Harbor, MI

Phillip M. Bertrand
Nike IHM, Inc.
St. Charles, MO

Lamar A. Bost
Spartech Plastics
Warsaw, IN

Lou Calistro
Jetta Corporation
Edmond, OK

Adam Clark
Display Pack, Inc.
Grand Rapids, MI

Dakheel Al Dakheel
Kuwait Packing Materials Co.
Safat, Kuwait

Mike E. Carley
JSP
New Baltimore, MI

Leon R. Cole
GAFMC
Wayne, NJ

Randy Cook
Caro, MI

Olivier C. Coquerel
ABB Australia Pty Ltd.
Victoria, Australia

Chandrakant Doshi
Rajoo Engineers Limited
Veraval, India

Duane DeJong
Display Pack
Grand Rapids, MI

Fernando Moura Duarte
University of Minho
Guimaraes, Portugal

John L. Durfey
Dekalb, IL

Debra Gilmour
American Standard
Ontario, Canada

Thomas A. Goates
Baxter Health Corporation
Mountain Home, AZ

Laurence Goddard
Bonar Plastics
Ontario, Canada

Luke Gross
Mullinix Packages, Inc.
Fort Wayne, IN

Robert Guldi
Stryker Instruments
Kalamazoo, MI

Paul Harris
TriEnda
Portage, IN

Chris J. Hendryk
Plastic Package, Inc.
Sacramento, CA

Ming L. Ho
Pactiv Corporation
Canandalgua, NY

Marcus Holden
Evans, CO

Daigo Ishiyama
American Standard
Piscataway, NJ

Timothy J. Jandrow
Tripod Data Systems
Corvallis, OR

Mark Kishel
Arrowhead Plastics Products
Eaton, IN

Randall K. Loga
Tek Packaging
Huntley, IL

Dan P. Longhenry
Tennant Company
Golden Valley, MN

Jean Christophe Mercier Durand
Maquinaria Envapac SA De CV
Ed, Mexico

Pamela Marks
Sumitomo Corporation of America
Houston, TX

John W. Meriton
DuPont Australia
Richmond, Australia

Michael Pastelak
AAI Corporation
Hunt Valley, MD

Parimal K. Patel
Fremont, CA

Meng Y. Pun
Texchem Polymerds Sdn Bhd.
Prai, Malaysia

Brenda S. Richmond
Printpack, Inc.
Williamsburg, VA

Dennis Shimmell
Corvac Composites
Bryon Center, MI

Tony Straub
Mercury Marine
Fond Du Lac, WI

Ron Starnes
Alto
Albany, New Zealand

Bayne Upton
GE Healthcare
Waukesha, WI

Cory S. White
GN Plastics Co. Ltd.
Chester, NS, Canada

Bob Whitish
Plastics Ingenuity, Inc.
Cross Plains, WI

Edward G. Wolk
Hampel Corporation
Germantown, WI

WHY JOIN?

It has never been more important to be a member of your professional society than now, in the current climate of change and volatility in the plastics industry. Now, more than ever, the information you access and the personal networks you create can and will directly impact your future and your career.

Active membership in SPE:

- ***keeps you current***
- ***keeps you informed***
- ***keeps you connected***

The question really isn't "why join?" but …

WHY NOT?

2006 SCHOLARSHIP WINNERS

SEGAN MEMORIAL SCHOLARSHIP

LUCUS D. STALLBAUMER

Pittsburg State University
Pittsburg, Kansas

Lucas Stallbaumer will be a graduate student in Plastics Engineering Technology at Pittsburg State University this fall. A member of SPE, Lucas attended ANTEC 2004, the 2005 Thermoforming Conference, and was featured in a *Plastics Engineering* magazine article on mentorship as a result of his internship with Joe Peters, President of Universal Plastics. At Universal Plastics, Lucas experienced all kinds of thermoforming applications and was charged with designing a package with holes in the bottom so that it still contained physical strength and durability. After graduation, Lucas would like to work in the automotive industry.

GRIEP MEMORIAL SCHOLARSHIP

KIM C. ACINGER

Pittsburg State University
Pittsburg, Kansas

Kim Acinger will be a senior at Pittsburg State University working toward a B.S. in Plastics Engineering Technology with a minor in Manufacturing Management. She had an internship in the summer of 2005 at Nike IHM in St. Charles, MO working primarily in the thermoforming department, processing twin-sheet. She plans to return to Nike this summer for a second internship, doing project work in thermoforming. She also interned in 2004 at Sika Corp. of Grandview, MO doing insert molding in the injection molding division. Kim has been a lab assistant at PSU since Fall 2005 demonstrating thermoforming, extrusion, compression, injection and blow molding, as well as testing equipment such as Instron, Izod, DSC, and Melt Flow Index. She plans to pursue a career in the thermoforming industry after graduation while simultaneously working on a Masters of Business Administration.

PAUL BERTSCH MEMORIAL SCHOLARSHIPS

KURTIS J. SCHULTZ

Western Washington University
Auburn, Washington

Kurtis Schultz will be a senior at Western Washington University this fall working toward a B.S. in Plastics Engineering Technology. A member of the Phi Theta Kappa Honor Society, Kurtis is also a SPE member and was the recipient of a scholarship from the SPE Foundation last year. Kurtis held an internship in the summer of 2004 at Northwest Kayaks, where he used the thermoforming process for bulkheads, hatch covers, and protective nose covers for kayaks. His senior project is to develop a thermoformed kayak seat/support system for people who have restricted use of their lower extremities (paraplegics, amputees, or those otherwise injured). Kurtis was also instrumental in writing a grant proposal on behalf of the WWU Engineering Technology Program for the Thermoforming Equipment Grant.

STEPHEN M. PROBERT

University of Washington
Woodinville, Washington

Stephen Probert will be a graduate student in Mechanical Engineering at the University of Washington this fall. An honors student, he is also active in the UW Karate Club, the UW Yacht Club and the Campus Crusade for Christ. Stephen's undergraduate research was a "cup project" – a successful attempt to thermoform a microcellular foamed coffee cup from recycled bottles. The experience of thermoforming a material that has not been commercially thermoformed will now be incorporated into Stephen's graduate research. His work at MicroGREEN Inc. included modifying an old lab-scale thermoformer, developing lab protocols and research objectives, and making thousands of test runs to develop the deep draw foam sheet process. The University of Washington plans to patent the process.

ADRIANE R. WILTSE

Pittsburg State University
Pittsburg, Kansas

Adriane Wiltse will be a senior at Pittsburgh State University this fall, majoring in Plastics Engineering Technology with an emphasis in manufacturing. Her interest in plastics was sparked, at age 11, by encouragement from a cousin who was graduating from PSU as a plastics engineer. Adriane, too, decided to attend PSU where she is a member of Student Government Association, University Ambassadors, and is currently serving as the president of SPE Student Chapter at PSU. Adriane spoke at the 2004 Thermoforming Conference and attended the 2005 Conference. She has also worked as a General Plastics laboratory assistant, introducing freshman students to the Plastics Engineering Technology program at the university. After graduation, Adriane hopes to work in the thermoforming industry.

JUSTIN J. DAMERON

Pittsburg State University
Pittsburg, Kansas

Justin Dameron will be a senior at Pittsburg State University working toward a B.S. in Plastics Engineering Technology. He had an internship in the summer of 2004 at Charloma, Inc. working primarily with thermoforming machines. An active member of the SPE Student Chapter at PSU, Justin attends many local Section meetings and has participated in a large number of plant tours to familiarize himself with all aspects of plastics processing. Justin's future plans include marriage to a fellow PSU student this fall and a career in a thermoforming or rotational molding processing plant upon graduation.

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.

Our mission is to facilitate the advancement of thermoforming technologies through education, application, promotion, and research. Within this past year alone, our organization has awarded multiple scholarships! Get involved and take advantage of available support from your plastic industry!

Start by completing the application forms at www.thermoformingdivision.com or at www.4spe.com. The deadline for applications is January 15th, 2007. ■

Thermo Forming Division

THERMOFORMER OF THE YEAR CRITERIA FOR 2007

Every year The SPE Thermoforming Division selects a individual who has made a outstanding contribution to our industry and awards them the Thermoformer of the Year award.

The award in the past has gone to industry pioneers like Bo Stratton and Sam Shapiro, who were among the first to found thermoforming companies and develop our industry. We have included machine designers and builders Gaylord Brown and Robert Butzko and toolmaker John Greip, individuals who helped develop the equipment and mold ideas we all use today. We have also honored engineers like Lew Blanchard and Stephen Sweig, who developed and patented new methods of thermoforming. Additionally, we have featured educators like Bill McConnell, Jim Throne and Herman R. Osmers, who have both spread the word and were key figures in founding the Thermoforming Division.

We're looking for more individuals like these and we're turning to the Thermoforming community to find them. Requirements would include several of the following:

- Founder or Owner of a Thermoforming Company
- Patents Developed
- Is currently active in or recently retired from the Thermoforming Industry
- Is a Processor – or capable of processing
- Someone who developed new markets for or started a new trend or style of Thermoforming
- Significant contributions to the work of the Thermoforming Division Board of Directors
- Has made a significant educational contribution to the Thermoforming Industry.

If you would like to bring someone who meets some or all of these requirements to the attention of the Thermoforming Division, please fill out a nomination form and a one- to two-page biography and forward it to:

Thermoforming Division Awards Committee
% Productive Plastics, Inc.
Hal Gilham
103 West Park Drive
Mt. Laurel, NJ 08045
Tel: 856-778-4300
Fax: 856-234-3310
Email:
halg@productiveplastics.com

You can also find the form and see all the past winners at www.thermoformingdivision.com in the Thermoformer of the Year section.

You can submit nominations and bios at any time but please keep in mind our deadline for submissions is no later than December 1st of each year, so nominations received after that time will go forward to the next year.

Thermoformers of the Year ...

1982
William K. McConnell, Jr.
McConnell Company

1983
E. Bowman Stratton, Jr.
Auto-Vac Corp.

1984
Gaylord Brown, Brown Machine

1985
Robert L. Butzko
Thermtrol Corp.

1986
George Wiss, Plastofilm Industries

1987
Dr. Herman R. Osmers
Educator & Consultant

1988
Robert Kittridge
Fabri-Kal Corporation

1989
Jack Pregont, Prent Corporation

1990
Ripley W. Gage, Gage Industries

1991
Stanley Rosen
Mold Systems Corp.

1992
Samuel Shapiro
Maryland Cup
Sweetheart Plastics

1993
John Grundy, Profile Plastics

1994
R. Lewis Blanchard
Dow Chemical

1995
James L. Blin, Triangle Plastics

1996
John Griep
Portage Casting & Mold

1997
John S. Hopple, Hopple Plastics

1998
Lyle Shuert, Shuert Industries

1999
Art Buckel, McConnell Company

2000
Dr. James Throne
Sherwood Technologies

2001
Joseph Pregont, Prent Corp.

2002
Stephen Sweig, Profile Plastics

2003
William Benjamin
Benjamin Mfg.

2004
Steve Hasselbach, CMI Plastics

2005
Manfred Jacob
Jacob Kunststofftechnik

2006
Paul Alongi, MAAC Machinery

THERMOFORMER OF THE YEAR 2007

Presented at the September 2007 Thermoforming Conference in Cincinnati, Ohio

The Awards Committee is now accepting nominations for the 2007 THERMOFORMER OF THE YEAR. Please help us by identifying worthy candidates. This prestigious honor will be awarded to a member of our industry that has made a significant contribution to the Thermoforming Industry in a Technical, Educational, or Management aspect of Thermoforming. Nominees will be evaluated and voted on by the Thermoforming Board of Directors at the Winter 2007 meeting. The deadline for submitting nominations is December 1st, 2006. Please complete the form below and include all biographical information.

Person Nominated: ______________________ Title: ____________

Firm or Institution: ______________________________

Street Address: ______________ City, State, Zip: ____________

Telephone: ________ Fax: ____________ E-mail: ________

Biographical Information:

- Nominee's Experience in the Thermoforming Industry.
- Nominee's Education (include degrees, year granted, name and location of university)
- Prior corporate or academic affiliations (include company and/or institutions, title, and approximate dates of affiliations)
- Professional society affiliations
- Professional honors and awards.
- Publications and patents (please attach list).
- Evaluation of the effect of this individual's achievement on technology and progress of the plastics industry. (To support nomination, attach substantial documentation of these achievements.)
- Other significant accomplishments in the field of plastics.
- Professional achievements in plastics (summarize specific achievements upon which this nomination is based on a separate sheet).

Individual Submitting Nomination: ____________ Title: ____________

Firm or Institution: ______________________________

Address: ______________________ City, State, Zip: ____________

Phone: __________ Fax: ____________ E-mail: ________

Signature: ______________________ Date: ____________

(ALL NOMINATIONS MUST BE SIGNED)

Please submit all nominations to: Hal Gilham,
Productive Plastics, 103 West Park Drive
Mt. Laurel, New Jersey 08045

THERMOFORMING DIVISION FALL BOARD MEETING SCHEDULE

September 13th - 16th, 2006
Renaissance Nashville Hotel
Nashville, Tennessee

FOR RESERVATIONS: Call 615.255.8400
Request SPE Thermoforming Rate of $143.00

Wednesday, September 13th, 2006
Executive Committee Arrives

Thursday, September 14th, 2006
7:30 am – 8:00 am – Breakfast – Executive Committee, Bluegrass Room
8:00 am – 9:00 am – Technical Chairs Meet with Executive Committee
12:00 pm – 12:30 p.m. – Lunch – Executive Committee
2:00 pm – James Alongi, Finance Committee Meet with Executive Committee

Friday, September 15th, 2006
9:00 am – 10:00 am – Machinery Committee Meeting, Jazz Room
9:00 am – 10:00 am – Materials Committee Meeting, Classical Room
9:00 am – 10:00 am – Processing Committee Meeting, Belmont One Room
10:00 am – 4:00 pm – Committee Meetings, Belmont Three Room

BOARD ON THEIR OWN

Saturday, September 16th, 2006
7:30 am – 8:00 am – Breakfast – Board of Directors, Music City Ballroom
8:00 am – Noon – Board of Directors Meeting, Music City Ballroom
12:00 pm – 1:00 pm –Lunch Buffet, Music City Ballroom Foyer
6:00 pm – 8:00 pm – BOARD OF DIRECTORS SPECIAL EVENT – "An Evening at the Blue Bird Cafe," Music City Ballroom

Sunday, September 17th, 2006
6:15 pm – 6:30 pm – Ribbon Cutting Opening Exhibits, Convention Center
6:30 pm – 8:30 pm – Welcome Reception, Exhibit Floor, Convention Center

September 18th, 19th & 20th, 2006
16th Annual Thermoforming Conference

These sponsors enable us to publish Thermoforming QUARTERLY

A Solution for Warpage in Polymeric Products By Plug-Assist Thermoforming[1,2,3]

BY H. HOSSEINI AND B. V. BERDYSHEV
MOSCOW STATE UNIVERSITY OF ENVIRONMENTAL ENGINEERING, MOSCOW, RUSSIA

Abstract

The thermoforming process is one of the most popular techniques in polymer process. The broad spectrum of applications is because of its high performance, simplicity, compactness, and relatively low-cost equipment. The fundamental defect inherent in thermoforming technology is warpage of the products during their applications. This is particularly apparent when the products are used at high temperatures. The warpage defect is understood as the process of non-uniform or heterogeneous change of the geometric dimensions of product with time, resulting in a change or distortion of their original form. The results of this work allow thermoformers to find the causes of this warpage and to ascertain the processing conditions that give rise to this defect. This makes it possible to work out valid recommendations for the partial, and in some cases complete, elimination of warpage.

Introduction

Polymer processing production of all forms of polymeric articles has found great application in chemical industries. The thermoforming process is one of the most popular techniques in this field. Thermoplastic sheet or film-forming techniques are applied to various packaging applications such as medical devices, food containers, and pharmaceuticals [1-4]. The broad spectrum of thermoforming is because of its high performance, simplicity, compactness, and relatively low-cost equipment. These factors make it possible to produce complex, large-scale configurations and free-form shapes. In thermoforming, a heated plastic sheet is stretched into a mold cavity by applying pressure, eventually assisted by direct mechanical loading [5,6]. When the sheet contacts the cold surface of the mold, it is prevented from further deformation. As a result, the forming sequence yields a thickness variation in the final part. In addition to wall thickness variation, there is another problem that the thermoforming industry must overcome. The sheet during inflation may have physical instabilities such as sheet rupture and shrinkage that is exhibited in the final products.

Another inherent fundamental processing defect in the thermoforming technology is part warpage that occurs during use. This is particularly apparent at high temperatures, Figure 1. The warpage defect is understood as the process of non-uniform or heterogeneous change of the geometric dimensions of product with time, resulting in a change or distortion of their original form. Unfortunately, this problem has been overlooked or ignored in thermoforming literature [2].

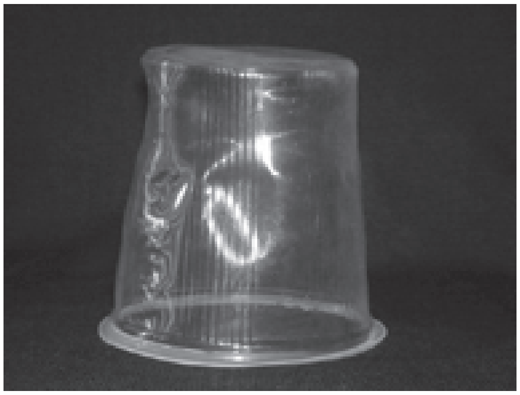


Figure 1. The warpage of a polymeric product during its use.

The results of this work allow thermoformers to find the causes of this warpage and to ascertain the processing conditions that give rise to this defect. This makes it possible to work out valid recommendations for the partial, and in some cases complete, elimination of warpage.

Mathematical Description and Rheological Model

An analysis of the results obtained shows that warpage is caused by relaxation of the residual or frozen-in stresses produced during the thermoforming process. Consider the after-effects of the deformation process of a viscoelastic polymer that had been subjected to the direct deforming influence of a fixed degree of intensity under pure shear.

The kinematics of the direct deformational influence on a polymer has not been randomly chosen. It completely corresponds to the deformation kinematics of a polymeric product at the initial

(continued on next page)

[1] Paper was published in the 2006 ANTEC proceedings and was presented at ANTEC on 8 May 2006.

[2] Paper retyped, partially rewritten, and edited by J. L. Throne,Technical Editor, who is solely responsible for any omissions, commissions and other blunders.

[3] Ed. Note: The mechanical deformation of plastic sheets, called "plug assist," has been the subject of previous Tech Articles in this Quarterly, at recent Thermoforming Conferences, and in a very important paper being given at the upcoming 2006 Conference in Nashville. The Editor believes that the approach given in this paper deserves further scrutiny by those examining the fundamentals of plug assist.

(continued from previous page)

stage of pre-stretching with a plug [1]. In this case, the kinetics of the development of general viscoelastic and elastic deformations resulting from the direct deforming effect on the polymer is given in the literature [1].

Assume that at a certain point in time, $\tilde{t}_\phi$, the direct deforming effect on the polymer is instantly removed by the removal of any external effects on it. At that time, as a result of the deformation, certain levels of general viscoelastic and elastic deformations have been accumulated: $\varepsilon^H(\tilde{t}_\varphi), \varepsilon_e^H(\tilde{t}_\phi)$

This condition corresponds to the free or unconstrained condition of the polymer in the molded product. Now, in accordance with the rheological model [1], for a polymer medium in the unconstrained condition, the relaxation process will occur at rates that relate to the reduction in the level of accumulated elastic deformation. This is characterized by the following natural kinetic conditions:

(1) $\bar{e} = -\bar{e}_f$

Where $\bar{e}$ is the strain rate tensor and $\bar{e}_f$ is the flow strain rate tensor.

The meaning of this condition is that in the absence of an external influence on the polymer, the rates of deformation changes in the latter are determined only by the typical rates of the relaxation processes themselves.

Applying this condition of the rheological model [1,7] to the kinematically determined process of deformation after-effects in a viscoelastic sheet or formed shape, the following system of differential equations that describe the kinetics of the procession are obtained[4]:

(2a) $$\frac{dc}{dt} = -(c^2 - 1)\frac{1}{2\theta_0(T)} e^{[-\beta(c + c^{-1} - 2)]}$$

(2b) $$\frac{d\varepsilon^H}{dt} = -(c - c^{-1})\frac{1}{4\theta_0(T)} e^{[-\beta(c + c^{-1} - 2)]}$$

Where $c \equiv \lambda_e^2 = e^{(2\varepsilon_e^H)}$, c is the Cauchy strain, $\theta_0(T)$ is relaxation time, β is the flexibility parameter of the molecular chain, ϵ^H is the Hencky strain, ϵ_e^H is the elastic Hencky strain, λ_e and is the elastic strain ratio.

The initial conditions for solving the system of equations $\varepsilon^H(\tilde{t}_\varphi), \varepsilon_e^H(\tilde{t}_\phi)$ are determined by solving the deformation influences on the polymer. From an analysis of these equations, it follows that the elastic deformation, ϵ_e^H, accumulated during the deformation sequence on the polymer, relaxes at a rate dependent on the removal of the mechanical field – in this case, the plug – from the polymeric sheet. This leads to the reduction in accumulated general deformations as given by the second equation[5].

For rigid chain polymer, $\beta \to 0$, or for a low level of accumulated elastic deformation, $e^{(\varepsilon_e^H(\tilde{t}_\phi))} \to 1$, the following solutions follow:

(3a) $$\varepsilon_e^H(\tilde{t}) \approx \frac{1}{2}\ln\frac{\frac{1+e^{(2\varepsilon_e^H(\tilde{t}_\phi))}}{1-e^{(2\varepsilon_e^H(\tilde{t}_\phi))}}e^{(\tilde{t}-\tilde{t}_p)} - 1}{\frac{1+e^{(2\varepsilon_e^H(\tilde{t}_\phi))}}{1-e^{(2\varepsilon_e^H(\tilde{t}_\phi))}}e^{(\tilde{t}-\tilde{t}_p)} + 1}$$

(3b) $$\varepsilon^H(\tilde{t}) \approx \varepsilon^H(\tilde{t}_\phi) - \frac{1}{4}\int_{\tilde{t}_\phi}^{\tilde{t}}\left[e^{(2\varepsilon_e^H(\tilde{t}))} - e^{(-2\varepsilon_e^H(\tilde{t}))}\right]d\tilde{t}$$

Now $\tilde{t} = \frac{t}{\theta_0(T)}$, the dimensionless time and $\tilde{t}_\phi$ is the dimensionless time of plug-assist forming. Figure 2 represents the kinetics of the process of free relaxation of elastic deformations in a viscoelastic polymer resulting in the uniaxial process of changing its original dimensions[6].

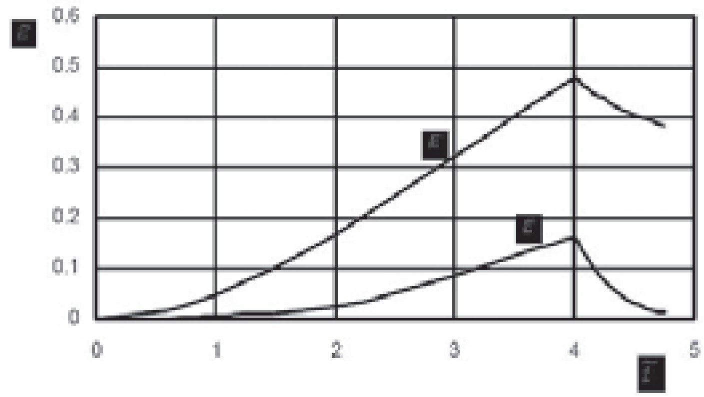


Figure 2. The kinetics of the process of free relaxation, $\tilde{t}$ > 4, of elastic deformations in viscoelastic polymers resulting in the process of changing its original dimensions, $\tilde{t}_\phi$ = 4. [Ed. note: It appears that the vertical scale is ϵ, the top curve is ϵ^H, the second curve is ϵ_e^H, and the horizontal scale is $\tilde{t}$.]

Results and Discussion

As shown above, the cause of molded part warpage during use is the accumulation of elastic deformations in the polymer. Because the accumulated elastic deformations in the polymer are usually non-uniformly distributed throughout the formed part, the relaxation process occurs at different rates across the part. This results in noticeably different rates of dimensional change in different regions of the part, that is, the warpage as evidenced by the last set of equations above. On the basis of our analysis, we find that the defect of warpage originates under the condition of the accumulation of heterogeneous elastic deformations in the polymer during thermoforming, and it manifests itself through the relaxation process of these deformations.

The equations above show that warpage is essentially determined by one of the fundamental rheological characteristics of polymers, the typical relaxation time, $\theta_0(T)$, which is temperature-dependent. Relaxation processes increase in rate, and, consequently, the rate of warpage increases with increasing polymer temperature.

Consider a quantitative characterization of the time-dependent warpage. A coefficient of dimensional change, $k_{u\phi}$, that integrally

[4] Ed. Note: The analysis that follows implicitly assumes uniaxial deformation and relaxation. For multiaxial deformation and relaxation, the scalar Cauchy, Henky, and elastic Henky strain terms must be replaced with the equivalent tensors.

[5] Ed. Note: Again, keep in mind that the authors appear to assume that the mechanical deformation of the sheet with a plug is a uniaxial deformation process.

[6] Ed. Note: Unfortunately, the labels for the curves on in this figure are obscured in the original paper. Those given in the figure caption are those proposed by this Editor.

characterizes the relative change in the original dimension of the product is defined as:

(4) $$k_{u\phi} = 1 - \frac{S(\tilde{t})}{S(\tilde{t} = \tilde{t}_\phi)}$$

Where $S(\tilde{t})$ and $S(\tilde{t} = \tilde{t}_\phi)$ are the current and original area of the lateral surface of the distorted part, respectively.

Using well-known mathematical equations and the equations given earlier, we obtain the following:

(5) $$S(\tilde{t} = \tilde{t}_\phi) = 2\pi r_3 \sqrt{b} \int_0^{\tilde{H}} \frac{\sqrt{(\sqrt{b} + \tilde{z})^4 + b}}{(\sqrt{b} + \tilde{z})^3} d\tilde{z}$$

(6) $$S(\tilde{t}) = 2\pi r_3 \sqrt{b(\tilde{r}_0 = 1, \tilde{t})} \int_{\tilde{r}_0 = \tilde{r}_p}^{\tilde{r}_0 = 1} \frac{e^{(\varepsilon^H(\tilde{r}_0, \tilde{t}))}}{\tilde{r}_0} d\tilde{r}_0$$

Where $b(\tilde{t} = \tilde{t}_\phi) \equiv \lambda^2(\tilde{z} = 0) - 1 = \left(\tilde{H} \frac{\tilde{r}_p}{1 - \tilde{r}_p}\right)^2$, $\tilde{r}_p \equiv \frac{r_p}{r_3}, \tilde{H} \equiv \frac{H}{r_3}, \tilde{z} \equiv \frac{z}{r_3}$, and $b(\tilde{r}_0 = 1, \tilde{t}) \equiv \lambda^2(\tilde{r}_0 = 1, \tilde{t}) = e^{(2\varepsilon^H(\tilde{r}_0 = 1, \tilde{t}))} - 1$, where r_p is the plug radius, r_3 is the initial radius of the sheet, r and z are the horizontal and vertical axes, respectively, and H is the depth of the deformed sheet. The function, $\varepsilon^H(\tilde{r}_0, \tilde{t})$, is determined from solution of the set of earlier differential equations (2a and 2b).

Using equations (5) and (6) from equation (4), we obtain an expression that describes the kinetics of warpage as shown in Figure 3. If we now assign an allowable value of the coefficient of dimensional change of the product, $\lfloor k_{u\phi} \rfloor$, with which the part is considered suitable for its use, the maximum permissible time of its use is given as:

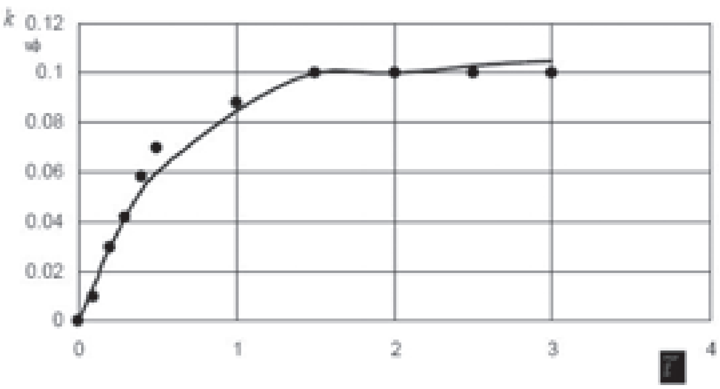


Figure 3. The kinetics of the warpage of PS at T=353K. Curve is from equation (4) and the points are experimental data. [Ed. note: The vertical scale is $k_{u\phi}$ and the horizontal scale appears to be $\tilde{t}$.]

(7) $$\lfloor k_{u\phi} \rfloor = k_{u\phi}(\tilde{t})$$

Where $k_{u\phi}(\tilde{t})$ is determined from equation (4).

It is now apparent from the above analysis that the use period of a polymeric product under the given temperature conditions, with the allowable coefficient of dimensional change, is essentially determined by the elastic deformations, $c(r_0, \tilde{t}_\phi)$, accumulated in the product during its formation. The smaller they are, the longer will be the operational period of the product.

Therefore, it is apparent that the practical task is organizing the plug-assist thermoforming methods so that the total level of elastic deformations – that is, the accumulated deformations during both the plugging and the forming stages of the molding process – is minimized. This means that the profile of the pre-stretched sheet should be maximized to approximate the profile of the final product.

The Concept of Relaxation Pause

Unlike the forming process, the mechanical plug pre-stretching process can be regulated through control of the plug motion. This provides an opportunity to organize, at the plug stage, the relaxation process of elastic deformations accumulated in the sheet because of the stretching action of the plug. The simplest of many possible scenarios to achieve this is to create a relaxation pause between the pre-stretching step and the vacuum forming step. During this pause, the accumulated elastic deformations can completely or partially relax. The problem here is that during this pause, the pre-stretched sheet may cool too much, making the forming step of the process difficult or impossible. Consider the necessary duration of this pause that would allow realization of the relaxation process.

During the relaxation pause, a plug holds the stretched sheet. One of the kinematic conditions of this process, corresponding to the absence of an external deforming influence, is:

(8) $$\bar{e} = 0$$

Using this condition, from the rheological model for the kinematically determined process of the relaxation in a viscoelastic polymeric medium [1], we obtain the following equation that describes its kinetics:

(9a) $$\frac{dc}{dt} = -(c^2 - 1)\frac{1}{2\theta_0(T)} e^{[-\beta(c + c^{-1} - 2)]}$$

(9b) $$\frac{d\varepsilon^H}{dt} = 0$$

Figure 4 presents the kinetics of change of elastic deformations during the relaxation pause in a sheet stretched with a plug[7].

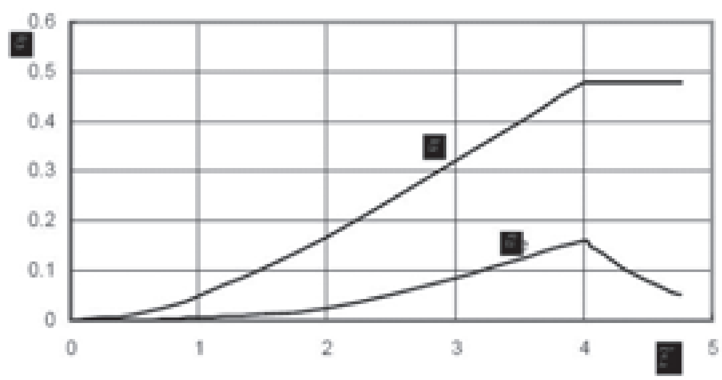


Figure 4. The kinetics of the relaxation process, $\tilde{t}$ > 4, of elastic deformations in viscoelastic polymers during the relaxation pause, $\tilde{t}_\phi$ = 4. [Ed. note: It appears the vertical scale is ϵ, the top curve is ϵ^H, the second surve is ϵ_e^H, and the horizontal scale is $\tilde{t}$.]

Comparing the differential equation systems (9a and 9b) and (2a and 2b), it is seen that the relaxation processes in polymers under the conditions of limited and free after-effects vary only by their rates.

7 Ed. Note: Again, unfortunately the labels for the curves in this figure are obscured in the original paper. Again, those given in the figure caption are those proposed by this Editor.

(continued on next page)

(continued from previous page)

This is quite logical, considering that the limited conditions of the relaxation after-effects do not completely correspond to the removed mechanical field, superimposed on the polymeric medium. This also slows the development of the relaxation process. For rigid-chain polymers, $\beta \to 0$, or at a low to moderate level of accumulated elastic deformation, $e^{\left(\varepsilon_e^H\left(\tilde{t}_\phi\right)\right)} \to 1$, the analytical solution of equations (9a and 9b) is:

$$(10a) \qquad \varepsilon_e^H\left(r_0, \tilde{t}\right) \approx \frac{1}{2}\ln \frac{\dfrac{1+e^{\left(2\varepsilon_e^H\left(r_0,\tilde{t}_\varphi\right)\right)}}{1-e^{\left(2\varepsilon_e^H\left(r_0,\tilde{t}_\varphi\right)\right)}} e^{\left(\tilde{t}-\tilde{t}_\phi\right)} - 1}{\dfrac{1+e^{\left(2\varepsilon_e^H\left(r_0,\tilde{t}_\varphi\right)\right)}}{1-e^{\left(2\varepsilon_e^H\left(r_0,\tilde{t}_\varphi\right)\right)}} e^{\left(\tilde{t}-\tilde{t}_\phi\right)} + 1}$$

$$(10b) \qquad \varepsilon^H\left(r_0, \tilde{t}\right) = \varepsilon^H\left(r_0\right) = const$$

The analysis of the equations obtained by numerical solution of the differential equations (9a and 9b) for common cases shows that even in the most unfavorable conditions, $\beta > 1$ and $c(t_\phi \approx 3)$, the accumulated elastic deformations are practically completely relaxed in a time period not exceeding approximately $9\theta_0(T)$. In thermoforming, most thermoplastic materials have typical relaxation times in the range of $\theta_0(T_\phi) \approx 0.2$ to 0.5 seconds. Thus, even in the most unfavorable situations, the maximum time necessary for the relaxation process would not exceed about 4.5 seconds.

From [8], it was determined that for a Bi=0.04 and Fo=1.75, within this time frame, a polymer sheet with thickness of, for example, 1.0 mm and a temperature of T=140°C, cools only about 10°C. This time is not considered critical when comparing the time spent during the pre-stretching phase of the process.

For thinner sheets, the maximum duration of the relaxation pause will obviously become critical. But this will occur only under the very strict requirements concerning the quality of the final product, according to the admissible criterion of their distortion, viz, $\lfloor k_{u\phi} \rfloor \to 0$. In less strict conditions, when some level of distortion is admitted, as determined the value of $\lfloor k_{u\phi} \rfloor$, t, the time necessary for the relaxation pause, is determined as follows:

The minimum duration of the relaxation pause should be a value that guarantees an infinitely large use time for a product with the allowable coefficient, $\lfloor k_{u\phi} \rfloor$. Nominally, considering equation (4), this is given as:

$$(11) \qquad S\left(\tilde{t} \to \infty\right) \geq S\left(\tilde{t}_\phi\right)\left(1 - \lfloor k_{u\phi} \rfloor\right)$$

From the analysis of equation (6), the function $S\left(\tilde{t}\right)$ is determined by solving the differential equations (2a and 2b). Solving the equations under different initial conditions, $\varepsilon^H\left(r_0\right), \varepsilon_e^H\left(r_0, \tilde{t}_\phi\right)$, will always yield a solution that will satisfy the condition of equation (11). The results obtained in this work provide the following expressions for determining the initial conditions specified above:

$$\varepsilon^H\left(\tilde{r}_0, \tilde{t}_\varphi\right) = \frac{1}{2}\ln\left\{\frac{1}{2}\left[\frac{c_0\left(\tilde{t}_\phi\right)-1}{c_0\left(\tilde{t}_\phi\right)} \bullet \frac{1}{1+b\left(\tilde{t}_\phi\right)} \bullet \frac{\tilde{r}_0^4 + b\left(\tilde{t}_\phi\right)}{\tilde{r}_0^3} + \sqrt{\left(\frac{c_0\left(\tilde{t}_\phi\right)-1}{c_0\left(\tilde{t}_\phi\right)} \bullet \frac{1}{1+b\left(\tilde{t}_\phi\right)} \bullet \frac{\tilde{r}_0^4 + b\left(\tilde{t}_\phi\right)}{\tilde{r}_0^3}\right)^2 + 4}\,\right]\right\}$$

$$\varepsilon^H\left(r_0\right) = \frac{1}{2}\ln\left[\left(\frac{\tilde{H}\tilde{r}_p}{\left(1-\tilde{r}_p\right)\tilde{r}_0^2}\right) + 1\right]$$

It follows from these equations that the procedure of the equation systems (2a and 2b) that satisfies equation (11) is reduced to a search of the critical maximum value of the elastic deformation, $c_{*0}\left(\tilde{t}_\phi\right)$. This value should not be exceeded in a given section of the stretched sheet at the end of the relaxation pause. This value must satisfy the condition in equation (11).

When this value is found, the duration of the necessary relaxation pause is determined by solving the differential equation (9a). For the special case given above, when the obtained value is substituted as the current one, corresponding to the end of the relaxation pause in equation (10a), an expression is obtained that determines the operational factors of the duration of the relaxation phase:

$$(13) \qquad t_{pn} = \theta_0(T)\ln\left\{\left(\frac{c_0\left(\tilde{t}_\phi\right)-1}{c_0\left(\tilde{t}_\phi\right)+1}\right)\left(\frac{c_{*0}\left(\tilde{t}_\phi\right)+1}{c_{*0}\left(\tilde{t}_\phi\right)-1}\right)\right\}$$

The level of elastic deformation in the sheet can also be reduced by decreasing the speed of the plug. This effect can be determined directly from the results in this work. However, in certain cases, the time of sheet stretching will exceed the sum of the time spent stretching at a normal plug speed and the relaxation pause. This is apparent because, in the plug-assist stage, a much greater mechanical force is imposed on the polymer than the effect of the relaxation pause. As a result, the rate of the relaxation step in the plug assist step will be less than that in the forming step.

Note also that the necessary time for the relaxation process during the relaxation pause can be reduced by raising the temperature of the sheet. This results in a reduction in the typical relaxation time. However, as noted earlier, the thermoforming operating range, $T_g < T < T_m$, limits the practical use of this option.

Summary

The analysis conducted on the causes and conditions of warpage in thermoformed products under specific applications has yielded:

- A method for calculation the operating conditions for forming products that would ensure operation of the final product with warpage not exceeding admissible values.
- A method for calculating the maximum admissible period for the use of polymeric products within which the warpage would not exceed allowable limits.
- Uneven strain recovery, caused by non-uniform orientation in the trim area is the major cause of long-term part distortion and warpage. In some cases, 24-hour annealing at mold temperature prior to trimming can reduce warping[8].

Acknowledgments

This word was supported by the Laboratories of Moscow State University of Environmental Engineering and Moscow State University of Chemical Engineering.

---

[8] Ed. Note: The authors do not explicitly address this conclusion in this paper.

References

1. H. Hosseini and B. V. Berdyshev, Structural Plastics 2005, Society of Plastics Industry, Orlando, Florida.
2. J. K. Thoren, *Thermoforming*, Hanser Publishers, Munich, 1987.
3. J. K. Lee, T. L. Virkler, and C. E. Scott, Poly. Eng. Sci., 41, 2001, pg. 1830.
4. G. J. Nam, K. H. Ahn, and J. W. Lee, Poly. Eng. Sci., 40, 2000, pg. 2232.
5. Rush et al., U.S. Patent 5 641 524, 1997.
6. A. Wineman, Jnl. Non-Newt. Fluid Mech., 4, 1987, pg. 249.
7. A. I. Leonov, Rheol. Acta., 15, 1976, pg. 85.
8. B. N. Udaev, *Engineering Thermodynamics*, in Russian, Moscow, 1988.

News from PennState, Erie, The Behrend College

SPE Grant Will Help Purchase Thermoformer

Students in Penn State Behrend's plastics engineering technology program will have access to the latest thermoforming equipment, thanks to a grant from the Society of Plastics Engineers Foundation.

The Brookfield, Conn.-based foundation for the support of plastics and polymer education has awarded Behrend's program a $10,000 matching grant for the purchase of a Formech 660 vacuum forming machine. Vacuum forming is a technology that forms sheets of plastic into a desired shape and is used to create products that range from clamshell take-out food containers to automotive body panels.

Penn State Behrend will match the gift equally, and Formech, which is headquartered in Harpenden, England, has agreed to a discounted flat price of $20,000 for the 660, three reducing plates, and an optional cooling system.

"We were very fortunate to get this grant from the thermoforming division of the SPE. This piece of equipment will go a long way to improving the quality of education our students will receive in the area of thermoforming," Brian Young, assistant professor of Engineering, said. "I have several students who are interested in starting research projects on this equipment as soon as it hits the floor."

The Formech 660 will be installed into the new 160,000-square-foot Research and Economic Development Center (REDC) opening on campus in fall.

"We were very fortunate to get this grant from the thermoforming division of the SPE. This piece of equipment will go a long way to improving the quality of education our students will receive in the area of thermoforming," Brian Young, assistant professor of Engineering, said. "I have several students who are interested in starting research projects on this equipment as soon as it hits the floor."

In addition to being used by student researchers, the Formech 660 will permit the college the add a technical elective in thermoforming, develop training seminars and applied research projects that support local industry, and enhance the employment prospects of plastics engineering technology graduates by exposing them to a growing technology.

Penn State Erie's plastics engineering technology program boasts 100 percent job placement; more than 300 inquiries were received in 2005 from companies interested in hiring the year's 40 graduates.

Contact: Christine Palattela, 813.899.6063, crm3@psu.edu. ■

How Much Data is Enough?[1]

BY RICHARD KNEBEL, CARL ZEISS IMT CORP., MINNEAPOLIS, MN

Coordinate Measuring Machines or CMMs come in many types, but one important area of distinction is the method of data acquisition.

There are two basic types of CMMs – touch-trigger probing and scanning. Today, the touch-trigger CMM is most common. It measures features by contracting individual points on the workpiece. The scanning probe SCMM uses a probe sensor that is, by itself, a small measuring machine. Linked to the larger CMM with advanced control technology, it continuously scans the contour of the workpiece surface. Scanning CMMs can collect hundreds or even thousands of independent points to define a part feature in the same time it takes touch-trigger probe CMMs to measure only four to eight points.

When choosing a CMM, it is common practice to obtain the machine's measurement uncertainty from the manufacturer. The data are compared to part size and tolerances to determine the suitability of a particular CMM for a given application. There is, however, once potential shortcoming. Specifications for measurement uncertainty are made relative to traceable artifacts such as gage blocks and ring gages.

One might ask, what's wrong with that? It's common practice to specify a system's capability relative to known artifacts. But it must be understood that these known artifacts are produced to have nearly perfect form. They are actually gages that are used to measure the CMM's performance. The fact that they have near-perfect form makes them a relatively easy target to measure using low data density.

In day-to-day use, CMMs must inspect imperfectly formed features. This task is much more difficult than inspecting artifacts with near-perfect form, because results can vary significantly depending on where the CMM samples the feature.

Most people are aware of the need for high data density when evaluating form, but there is less awareness of this need when evaluating location and size. It is easy to assume that if a particular feature has no specific form requirement, data density is not an issue. But it is important, and especially so when form isn't controlled separately. Form deviation exists in all measured features, only the magnitude of deviation varies. When form is not controlled separately through the use of a modifier such as circularity or roundness of a bore, then limits of size control the allowable form deviation.

Studies show that a minimum of 300 points are required to approach the correct result for form such as circularity of a diameter in the 25 to 70 mm range. Only above this level of data density will you begin to approach 90% or more of the correct form value. Any method that uses lots of data will see a more complete "picture" of the surface, and gain a better understanding of the true high-to-low variation. Low data density most likely will miss this variation and has the potential to be somewhat more repeatable.

In other words, if repeatability of form was the primary objective, one could measure only four points and calculate, for example, flatness. In general, however, the benefit of high density data is obvious when looking at the average results for many features.

You may have heard the saying "form follows function." Ad agencies often use it to describe a product with a very functional appearance. The inverse of this saying, "function follows form," is true in metrology. You cannot know the functional size and location without understanding the form of a feature.

When evaluating a CMM, consider the influence that form has on size and location. It can be greater than any error inherent in the CMM. Select a system and method that can accurately measure production parts, not just perfect artifacts. If a CMM must pass a gage repeatability and reproducibility or GR&R study, high data density is the best defense when challenged to repeat readings on imperfectly formed elements.

High data density also provides better functional results that lead to fewer problems in assembly, lower warranty costs, and improved overall production processes. ■

[1] This article has been edited from an article appearing in ***Manufacturing Engineering***, November 2002, pg. 15. It is used with permission of Society of Manufacturing Engineers, www.sme.org, and cannot be recopied without permission of the copyright holder. The Technical Editor is responsible for any rewriting, omissions, or errors in transcription.

THERMOFORMING DIVISION DVD'S STILL AVAILABLE

The first DVD is titled:

"WHAT EXACTLY IS THERMOFORMING?"

This six-minute DVD introduces the viewer to the thermoforming process with examples of parts produced and a video of the process. Both thin gauge roll fed and heavy gauge cut sheet fed aspects of thermoforming are illustrated. It is for students, industry and anyone who wished to learn more about thermoforming.

The second DVD is titled:

"FORMING EDUCATIONAL OPPORTUNITIES: GRANTS AND SCHOLARSHIPS OFFERED BY THE SOCIETY OF PLASTICS ENGINEERS – THERMOFORMING DIVISION"

This six-minute DVD discusses the 13 matching equipment grants of up to $10,000 and 20 scholarships up to $5,000 for college students. Information is provided for applying to these grants and scholarships. The Thermoforming Division of SPE has contributed over $150,000 in equipment grants and scholarships as of this date.

Both DVDs are free of charge and available from SPE through **Gail Bristol** at phone number 203-740-5447 or **Gwen Mathis**, Thermoforming Division, at phone number 706-235-9298.

IR Scanning With Closed-Loop Feedback for Thin-Gauge Thermoforing[1]

BY C. P. CARLIN, SENCORP, INC., AND C. CASALE, LAND INSTRUMENTS

When Lexus introduced their slogan, "The Relentless Pursuit of Perfection®," they made a simple and bold statement. They explicitly stated what most businesses strive to achieve – the reduction in errors. Whether it is a program of continuous improvement or lean manufacturing, businesses today in North America understand that in order to remain competitive, they must reach for perfection. This is a principle that has implications for today's thermoforming industry.

It has long been assumed that practice makes perfect. But what happens when outside factors influence what you've been practicing? In a process filled with variables, it is not always possible to have complete control. In thermoforming, if we focus on just the material (and assume there is no in-house extrusion), we find several factors that are outside the processor's control. These factors include:

- Basic material type/properties,
- Thickness,
- Material storage, and
- Ambient room temperature.

If we focus on what the processor can control, the first stage of thermoforming is heating the sheet.

Oven temperature is both easy to control and easy to define. Whether the heating elements are quartz, ceramic, or other, all machines are equipped with a means of reading temperature. However, what is easily forgotten at this stage of the process is what really matters is the temperature of the sheet. Infra-red sensors, pyrometers, and heat guns provide a limited reading of the sheet. The latest technology that allows for a more complete visualization of the sheet is an infra-red line scanner, Figure 1.

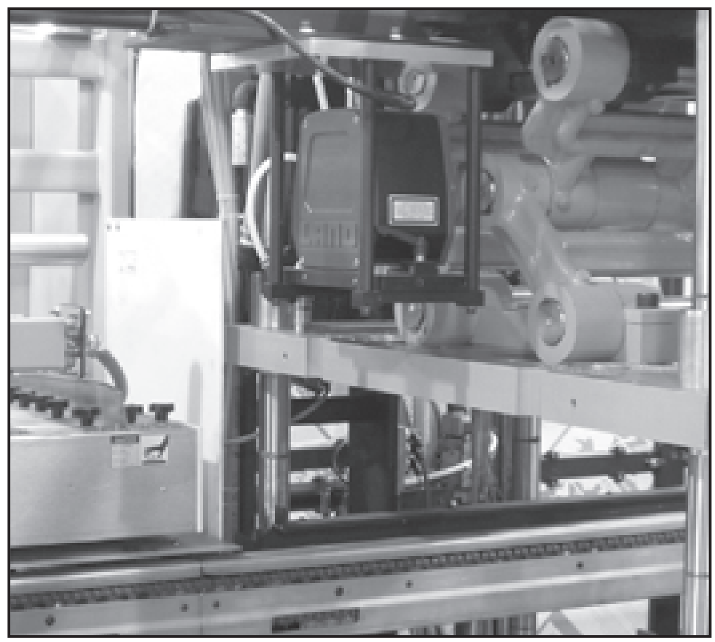


Figure 1.

When taken by itself, the line scanner provides a graphical image of an entire index length of the sheet, scanning through a window of less than one inch or 25 mm, Figure 2.

When coupled with a powerful closed-loop system, this method of scanning becomes a serious advantage for the custom thermoformer. The process now becomes more mathematical and rigorous, allowing the operator to analyze and

(continued on next page)

[1] This article is based on a case-study using a Land Instruments LFP7 line scanner and a Sencorp Series 2500SD in-line thermoformer.

(continued from previous page)

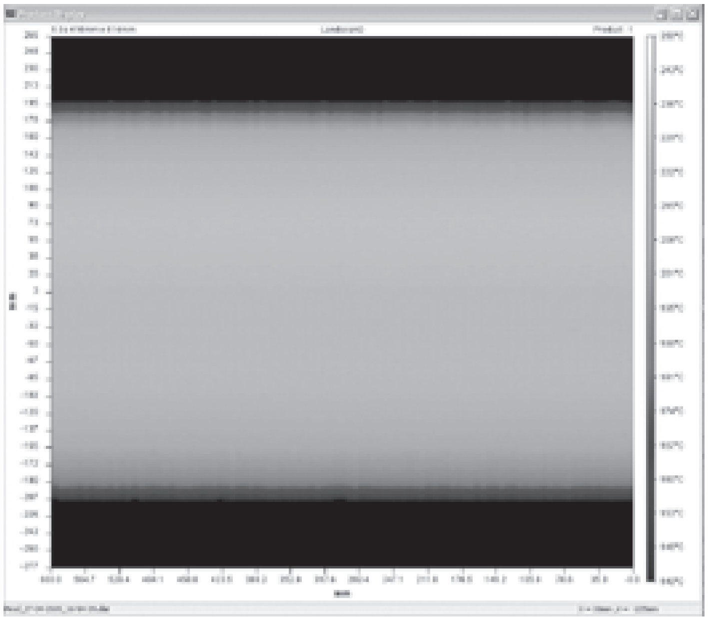


Figure 2.

monitor sheet temperature in a way that was previously unavailable. By scanning up to one hundred lines per second, a line scanner provides one thousand data points per line, or one hundred thousand temperature points per second (100,000/sec), Figure 3.

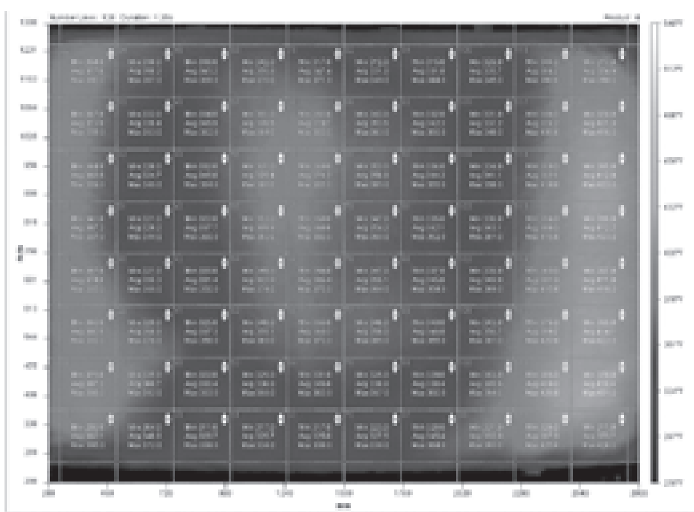


Figure 3.

The current system of heating the sheet relies on operator skill and savoir faire. Assuming a new job, the machine is set up and run until acceptable parts are formed. Then, the heater controls are calibrated to a set-point and the operator is alerted if the oven temperature is above or below this point. The operator only has control of the heater elements.

When the closed-loop system is integrated, the situation changes dramatically. When setting up a job, the operator can start the scanner and view the sheet temperature profile on the control system screen. Next, the tolerance range of the sheet is entered into the program so that if a change in temperature is detected, the closed-look system will determine whether a single zone or the entire oven needs to be adjusted. The operator also has control of the number of indexes required before making any change, Figure 4.

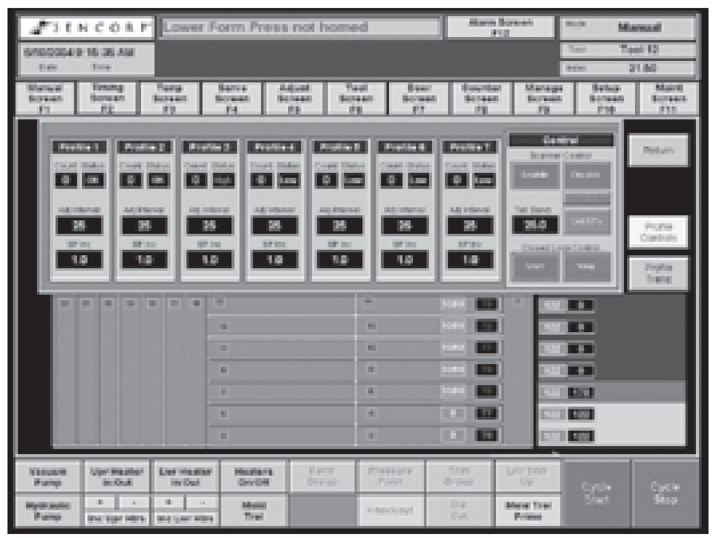


Figure 4.

Trial and error can be costly, especially when using expensive and complex materials. We are not thermoforming ovens, we are thermoforming sheet. Scarp, returns, and downtime all cost money. If all three of these variables can be reduced and/or eliminated, the thermoformer is one step closer to perfection. ■

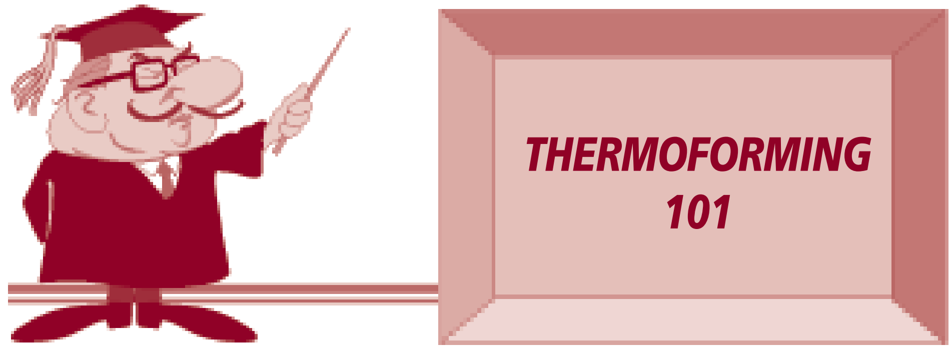
Twin-Sheet Thermoforming?

"This method is commonly used for making hollow articles. Two pieces of sheet are placed between the top and bottom dies of the mould, and compressed air or steam is blown in between them until the plastic has assumed the required shape. At the final stage of the moulding, extra pressure given to the edges of the mould causes the superfluous sheet to be cut away, whilst the effective edges fuse together so that the finished articles are removed in one piece. The die is ventilated with very fine air outlets so as to obviate airlocks with the resulting faulty mouldings. The sheets of plastic are usually slightly heated before being placed in the die. If steam is used for blowing, a pressure of about 50 lbs. per sq. in. is employed; if compressed air, the approximately double that pressure is necessary."

F. W. Kellaway and N. P. Meadway, ***Introducing Plastics****, The Scientific Book Club, London, 1945.*

The Cutting Edge

BY JIM THRONE, SHERWOOD TECHNOLOGIES, INC., DUNEDIN, FL



For those of you who came in late, we have been examining the various aspects of part design. In this lesson, we focus on the edge or periphery of the part. The first thing we need to realize is that the part we've just thermoformed is still attached to the plastic that held it in the clamp frame while it was being formed. This is true whether the entire assembly, formed part and edge material, is removed to a separate fixture or whether the formed part is punched from the trim material immediately after forming. We've discussed trimming in earlier tutorials. In this tutorial, we discuss the characteristics of the edge itself.

Registration

Trimming devices need to trim the part where the designer wanted it trimmed. This means that the trim line and the trim device must register. The accuracy of registration is a design issue. In heavy gauge forming, it is impractical to ask a trim device to trim within thousandths of the design trim line everywhere along the trim line. Heavy-gauge parts may be fixtured between the time they are formed and the time they are trimmed. Fixturing allows for some residual stress relaxation and often improves the trim registry. In thin-gauge forming, the trim device should be able to trim very close to the design trim line. Because many thin gauge parts are axisymmetric, meaning that the trim line is round, registration focuses on the degree of ovality of the formed trim line prior to the trimming step. Thin-gauge parts are often trimmed within minutes of being formed. Certain polymers such as polypropylene continue to crystallize after forming. As a result, the design trim line and the final part edge peripheral location may be quite different.

Heavy-Gauge Cut Edge

The nature of the final cut edge depends strongly on the trimming device. In many robotic trimming steps, the edge is rough-cut initially. This edge finish may be adequate if the cut edge of the part is completely hidden in the final assembly. Polycarbonate skylights that are edged in aluminum are examples. Often the product requires a smoother edge. For robotic trimming to achieve the desired edge, the rough-cut edge is routed a second time while the part remains on the trim fixture.

In some applications, the edge must be as smooth as the overall plastic surface. Here are some ways of achieving a very smooth, even polished edge.

- Fine grit sanding followed by Crocus cloth or 1200-grit polishing
- The above method, followed by pumice polishing
- For certain plastics, a light wipe with a mild solvent will smooth trim cuts. Care must be taken to minimize the amount of solvent that is absorbed into the polymer.
- Flame-polishing is popular with transparent amorphous plastics such as acrylics and polycarbonates. Flame-polishing is not recommended with plastics such as PVC.
- Laser cutting. The laser is a high-intensity beam that cuts plastic by melting and vaporizing it. The cut line is usually very smooth.

Thin-Gauge Cut Edge

Thin-gauge trimming is substantially simpler than heavy-gauge trimming. Nevertheless, the trim edge characteristics can be quite important to the customer. There are three major issues with the cut edges of thin-gauge parts:

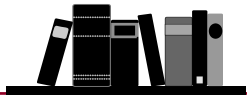
- Trim dust and fibers, known as angel hair and fuzz.
- Microcracks that can grow into the formed part as it is flexed
- Jagged edges that can cut or abrade the user

Edge and surface contamination are often the results of problems in the trimming step. But not always. It is very difficult to trim polystyrene without generating very tenacious trim dust. It is often difficult to trim polypropylene pr PET without generating fibers and fuzz. Adding antistatic agents to PS, either as an additive that is compounded into the polymer or as a topical coat to the sheet prior to forming, helps the trim dust problem. If fuzz and fibers are objectionable to the customer, they are often minimized by passing the container edges through a hot air knife. The heat shrivels the fibers to microscopic size.

Microcracks and jagged edges can also be "healed" by heating the edges with hot air. One approach is to collect and nest a stacked, counted number of parts and pass the stack though a hot air tunnel prior to packaging or boxing for shipment. ■

Keywords: registration, flame polishing, laser cutting, trim dust, microcracks

BOOK REVIEW



V. Capasso, Ed., **Mathematical Modeling for Polymer Processing: Polymerization, Crystallization, Manufacturing**, Springer Verlag, Berlin, 2003, 74.85 euro ($94), 320+xiv pages, 90 figures, in English.

All right, let's get the bellyaching out of the way first. "Oh, Jeez, another technical book!" "Who the heck reads all this stuff, anyway?" "Why can't this guy review a practical book, like 'Thermoforming for Dummies'?" Okay, are you done? Can I proceed? Thank you! (After all, this is my column, not yours!)

This is a technical book. Jam-packed with equations, most of which appeal only to people of the ilk[1] of the particular author(s). The title intrigues – ***Mathematical Modeling in Manufacturing!*** Wow! If we can mathematically model, maybe we can predict. And if we can predict, maybe we can eliminate many trial-and-error steps as we bring a new polymer/product to production. So, let's see what's between the covers.

First off, the book is a translation of an edited collection of mostly European papers. The translation seems to flow well. In certain cases, the equation jumps[2] omit critical intermediate steps. In at least one case, the authors tacitly make a major, very questionable assumption between equations which the reviewer believes calls into question their conclusions.

There are seven chapters. There are many references to earlier, less complex efforts. The first chapter considers the math of polymerization.

The next three chapters focus on crystallite nucleation and the next two on the mechanisms of crystallization. The last section, 44 pages long, is entitled "Manufacturing," and consists of one chapter, entitled "Modeling of Industrial Processes for Polymer Melts: Extrusion and Injection Molding." Yep, you're right! Nothing on thermoforming! "So," you ask. "Why the heck are you reviewing this thing, anyway?" Well, don't get your britches in a bunch just yet. Let's keep in mind that some of the most challenging polymeric materials that we deal with are crystalline in nature – polyethylene, polypropylene, TPO, PET … Typically, we form these materials in their amorphous, melt state. And then we wait for them to crystallize … Or, with PET, maybe not. So chapters 2 through 6 form a basis for understanding the various crystallization mechanisms. (Yes, Virginia, there are many mechanisms!)

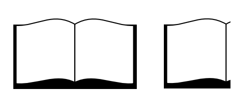
The early chapters focus on variations in Gibbsian cluster theory. In short, how many molecules need to collect in a given region before a crystallite forms? How do they get there? And why? There's a nice section by the late A. Ziabicki, considered the father of modern crystallization theory, on the free energy of aggregation and … Oh … You're not following along, are you?

Well … Let's see. Are you interested in the theoretical reasons why crystallization ceases for many polymers? No? Figgers. How about mechanisms that promote pure spherulitic crystallization rather than shish-kebabs? You know, the difference between quiescent[3] crystal growth and shear-induced crystal growth? Not that, either?

Okay, then. Let's jump right to the manufacturing chapter. As I said, there's nothing in here on thermoforming. If you want to learn about the parameters that affect the cooling rate of your just-formed-and-still-sitting-on-the-mold waiting-to-be-crystalline-eventually part, you'll need to read the chapters you just skipped over. On the other hand, if you want to know what kinds of issues face your sheet supplier, you might want to listen up (or in this case, read up)! Unfortunately, the authors theoretically address only one extrusion processing issue – flow instability, often called 'melt fracture.' (The astute[4] and well-educated reader should have learned some of this arithmetic some time ago.) The authors add an additional term to the traditional KBK-Z constitutive model to handle a newly-defined effect the authors describe as 'spurt.' (Your reviewer is not comfortable replacing the traditional 'stick-slip' concept with the authors' 'Newtonian, latency, and spurt phases,' though.)

Again, this is a collection of mathematical treatises that is obviously not bedtime reading. And it is not a book that will engender heated debate on the Conference floor. Nevertheless, many of us deal daily with semicrystalline polymers and we should have at least get a warm, fuzzy feeling that there are underlying theories that describe why our polymers behave the way they do. (And not necessarily the way we want them to do!)

Because the book title purports to discuss the theory of processing (but doesn't) and because the work focuses extensively on crystallization kinetics but fails to apply same to sheet extrusion, this reviewer gives it only one-and-a-half books out of five.



~ Jim Throne

[1] Ilk = type or kind.

[2] An 'equation jump' means that the text goes between two equations with little explanation. Typically authors resort to the phrase, "therefore, …"

[3] Quiescent = quiet, still, tranquil, not moving.

[4] Astute = discerning.

THERMOFORMING DIVISION TO FUND THE SPE STRETCH AWARD

The Thermoforming Division Board agreed to fund a program to reward SPE Student Chapters who win the STRETCH Award. The STRETCH stands for "Students Reaching Excellence Through Chapters." Application forms are on the SPE website: www.4spe.org.

The total amount is $5,000 and will be split among the Student Chapters who win the STRETCH Award with a $500 limit per Chapter.

Students lead busy lives and we hope to motivate them to complete all the requirements of the STRETCH Award.

If they do that, they are truly an active chapter!

Council Report …
Charlotte, North Carolina

BY LOLA CARERE, COUNCILOR

This summary is intended to help you review the highlights of the Council Meetings held in Charlotte on May 7th, 2006.

ANTEC

Registration at ANTEC was 2,063 (including registrants in the seminars). A total of 206 registrants attended 24 Society seminars.

Incoming President Tim Womer's SPE mantra is "Are You In? (Internationally Networked)."

From the Council Floor

Each of the Society's officers and vice presidents provided a brief update on their recent activities and liaison work.

• Senior Vice President Vicki Flaris reviewed the International Awards, Fellows, Honored Service Member, and the other SPE award programs and noted that the process has been completed for 2006. Dr. Flaris also encouraged the submission of names of additional candidates for the coming year.

• Kishor Mehta provided an update on the Constitution and Bylaws Committee (newly renamed going forward as the Bylaws and Policy Committee) and the work on the revision to Bylaws and dissolution of the Constitution. He reviewed the success of the recent vote on the dissolution. The motion to dissolve the existing SPE Constitution passed by an overwhelming majority: 4,808 for, 153 against. Therefore, effective Monday, April 10th, the new Bylaws previously approved by Council became the official governing document for the Society.

• Dr. Roger Corneliussen gave an update on the Sections Committee meeting. Issues discussed and pursued included regionalization and Section revitalization. Dr. Corneliussen recognized past Chairs Barbara Arnold-Feret and Alan Arduini as well as Vice Chair Helen Basso.

• Bill Arendt provided an update on the activities and plans for the Divisions Committee. Goals include revamping/expansion of the Speakers List, sponsoring new Divisions/SIGs, and supporting Sections through MiniTecs.

• John Szymankiewicz provided an update on ANTEC and the ANTEC Operating Committee. The update included some details on the preparation for and results to date on ANTEC 2006 in Charlotte, NC.

• Jon Ratzlaff provided an update from the International Committee on the work with headquarters and local Sections to grow globally. Mr. Ratzlaff gave details on the plan(s) to grow individual Sections/areas/regions. Mr. Ratzlaff also indicated that the International Committee is publishing a semi-annual newsletter with additional details and summaries of activities throughout the world. Mr. Ratzlaff reminded the group of the Spanish-language series for one set of seminars at NPE, formation of the India Advisory Board, and network expansion with local Sections in Mexico and the Asia/Pacific rim area.

Governance Restructuring

Prior Past President Donna Davis presented data and progress on the process for reviewing the current governance structure. Ms. Davis reviewed the mission statement of the Society and the philosophy the team has adopted in reviewing and evaluating potential changes to the current governance structure.

New Charters

A Student Chapter was established at the University of Houston.

Awards and Recognitions

In addition to the recognition of the retiring administration, the Michael Cappelletti Excellence Award was given to Hector Dilan. (Note: The James Toner Service Excellence Award was awarded at the Brookfield headquarters on May 19th, 2006 to two recipients this year: Yetty Pauwels and Doris Thoren.)

Outgoing President Len Czuba thanked his Executive Committee for their hard work. Incoming President Tim Womer introduced his Executive Committee. New Executive Committee Vice Presidents are: Barbara Arnold-Feret, Ken Braney, Dan Cykana and Bill O'Connell. Paul Anderson is the 2006-2007 Secretary and John Szymankiewicz is the 2006-2007 Treasurer.

Contributions and Donations

It is with grateful appreciation that the Society would like to acknowledge the following contributions and donations by its Sections and Divisions:

• Bartlesville-Tulsa Section – Vivek Rohatgi presented a check for $1,000 to SPE.

• Color & Appearance Division – Returned its $2,684 rebate payment for the 1st and 2nd quarters.

• Detroit Section – Tom Powers presented a check for $35,519 to the SPE Foundation for the Robert G. Dailey Scholarship, Hurricane Katrina Relief, International Award for Education, International Essay Award, and conferencing proceeds.

• Electrical and Electronic Division – Amod Ogale presented a check for $946 to SPE, representing the Division's rebate from SPE for 2006.

• Extrusion Division – Presented a check for $2,500 to the SPE Foundation Scholarship Fund.

• Mid-Michigan Section – Ken Kerouac presented a check for $500 to the SPE Foundation for the Robert Cramer Scholarship Fund.

• Plastics Environmental Division – Dennis Denton presented a check for $13,000 from their GPEC proceeds.

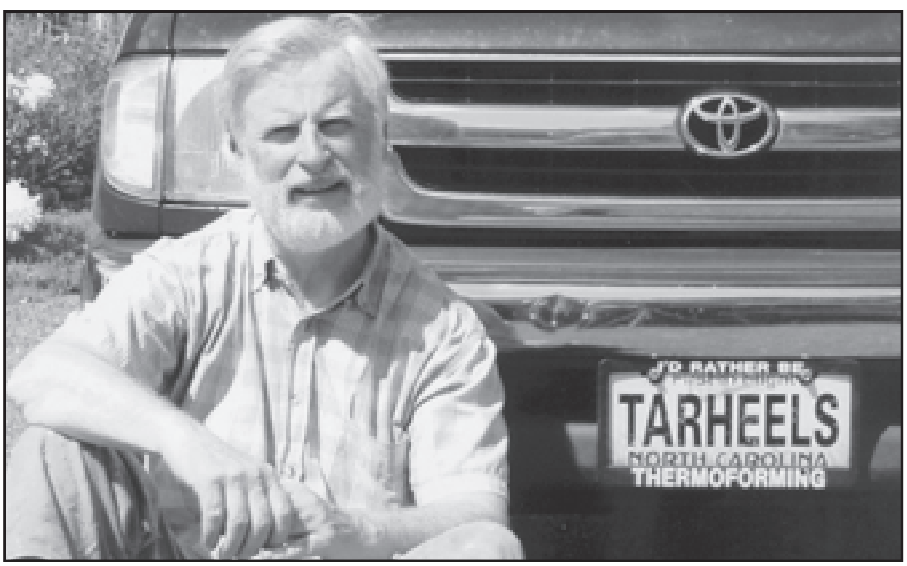
• South Texas Section – Prior Past President Donna Davis presented a check for $6,663 to SPE representing new membership fees collected at the Polyolefins Conference.

• Tex-La-Gulf Section – Rick Wagner presented a check for $32,308 to the SPE Foundation to begin a fund to provide scholarship and relief to victims of hurricanes Katrina, Rita, and Wilma. The contribution to the Foundation represents the entirety of the Tex-La-Gulf Section's budget.

• Thermoset Division – Paid TopCon profits of $2,572. The Thermoset Division also returned its 2006 rebate check to SPE earlier this year.

• TPM&F Division – Sal Monte presented a check for $5,000 to the SPE Foundation.

• Vinyl Division – Presented a check for $1,000 to the SPE Foundation Scholarship Fund and a check for $1,000 for the Student Author Travel Fund. ■



Dr. Peter Mooney, renowned economist on global developments in the plastics industry, displays his allegiance to the Thermoforming Division.

Thermo Forming Division

Help Sponsor

THERMOFORMING® QUARTERLY

ONE YR. SPONSORSHIPS

****Please note the increase in sponsorship rates. This is the first increase since the inception of the Thermoforming Quarterly in 1981. We appreciate your continued support of our award winning publication.**

Patron - $625

(Includes 2.25" x 1.25" notice)

Benefactor - $2,000

(Includes 4.75" x 3" notice)

Questions?

Please Contact:
Laura Pichon
Ex-Tech Plastics
815/678-2131 Ext. 624
lpichon@extechplastics.com

We Appreciate Your Support!

From The Editor

Thermoforming Quarterly welcomes letters from its readers. All letters are subject to editing for clarity and space and must be signed. Send to: Mail Bag, Thermoforming Quarterly, P. O. Box 471, Lindale, Georgia 30147-1027, fax 706/295-4276 or e-mail to: gmathis224@aol.com.

"FORMING EDUCATIONAL OPPORTUNITIES: GRANTS AND SCHOLARSHIPS OFFERED BY THE SOCIETY OF PLASTICS ENGINEERS – THERMOFORMING DIVISION"

The Thermoforming Division of SPE has produced a new six-minute DVD for educators.

The DVD discusses the 13 matching equipment grants of up to $10,000 and how to apply for the grant. The 20 scholarships to college students are discussed and information is provided as how to apply for a scholarship. The Thermoforming Division of SPE has contributed over $150,000 in equipment grants and scholarships as of this date.

The DVD is free of charge and available from SPE through Gail Bristol at 203-740-5447 or Gwen Mathis, Thermoforming Division, at 706-235-9298.

Thermoformers, have you discovered a forming tip that you are willing to share with your fellow formers?

A time saver?

Or a cost saver?

Or something that will save wear and tear on your machine?

Or your employees?

Then the

Forming TIPS

column is for you!

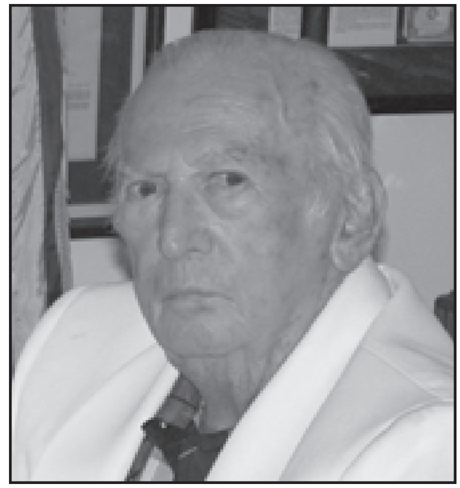
Just send Jim Throne a fax at 727-734-5081, outlining your tip in less than a couple hundred words. You can include drawings, sketches, whatever. Thanks!

The Thermoforming Division Salutes a Pioneer Thermoformer … Glenn Blackburn

Most of Glenn Blackburn's life was dedicated to the Thermoforming Industry. His life ambition was to be a veterinarian like his Dad. While Glenn was only able to achieve an 8th grade education in a one-room school house before going to war, he enlisted in the army with hopes of receiving veterinarian training. His hopes were dashed when horses were not used during World War II. As a Staff Sergeant in the First Calvary Division of the Army, he served in Australia, New Guinea, The Admiralty Islands, The Philippines and Japan. He was a liberator of the Japanese- held prison camp at the University of Santo-Thomas in Manila. Fighting malaria that he had contracted from the war made it difficult to work for a period of time after the war. Upon returning to the United States, he worked and received training as a chemical bacteriologist. Working with groups in companies such as BF Goodrich, Doebeckman and Dow Chemical, he assisted in the development of a plastic film that would be used to enhance the longevity and storage of prepackaged cheese. Mr. Blackburn also worked on the development of equipment to cut, slice and vacuum pack cheese precisely. Mr. Blackburn obtained many patents during his work. He received 13 claims, allowing the laminating and gluing of a mass of cartons all at one time by means of steam and vacuum under precise timing and control. After two years of development work, many pieces of equipment became available to the prepackaging industry. Some of the equipment was tested and put to use in the sliced bacon department of Armour and Company. Mr. Blackburn totally developed and directed the use of this equipment, which was the first to produce marketable sliced bacon with a stairstep appearance.

During the 1950s, Mr. Blackburn was recognized and awarded the responsibility to manage the operations of a small plastic processing company in Portage, Wisconsin. Only a few types of thermoplastic existed during those days. Working long days and nights, he learned fast and gained an education in plastic processing through trial and error. The challenge was immense with the company operating at a loss. One year later the company was profitable and after years the plant grew to sales of $12 million. This plant was Portage Plastics, later becoming Portage Industries and finally Spartech Plastics Portage facility. He hired many people from outside of the plastics industry, all of which became successful in the extrusion, thermoforming and compression molding industries.

In 1966, Mr. Blackburn was offered an opportunity to become one-third partner in a small company in Winter Haven, Florida. His goal was to build machinery and thermoformed plastic field boxes for the citrus industry. The company also did hand lay-up of fiberglass for many different products. With little or no money, 10 years soon slipped away as Mr. Blackburn developed a full line of containers for agricultural use in harvesting and material handling. During this time the company was reorganized several times as it tried to find new markets in the South. Winter Haven Plastics was dissolved in 1975 as Mr. Blackburn left his partners and formed Artec Plastics, Rebel Plastics and Blackburn Industries. All of these companies carried on the agricultural line of formed containers while developing new markets. Mr. Blackburn was one of the first to develop a low profile wheeled refuse container for municipal garbage pickup and installed this system into many cities in the U.S. and as far away as Brisbane, Australia. As Blackburn Industries grew, the name was changed to Progress Plastics Inc. Progress Plastics grew to be the largest custom thermoforming company in the Southeast U.S. with 9 Rotary thermoformers, several CNC routers, 13 compression molding presses and several rotational molding machines. PPI had many reputable customers who chose Progress Plastics because of the high quality standards and immaculate plant that Mr. Blackburn demanded. His business always had a competitiveness that was fueled by ingenuity. Mr. Blackburn strongly believed in structured training of his employees. A five-year plan put emphasis on specific training each year in areas such as Safety, Quality, Efficiency and Communications. Training took place continuously for skills in thermoforming and other manufacturing methods. Mr. Blackburn believed in sharing techniques,



Mr. Glenn Blackburn

technology and systems with customers as well as competitors. The doors of Progress Plastics were opened several times for seminars and tours for customers, competitors and the local SPE chapter. Mr. Blackburn was one of the founders of the Central Florida Chapter of SPE and encouraged his employees and others to join.

Since the sale of Progress Plastics to Triangle Plastics, Mr. Blackburn has been enjoying an active retirement. He spends a lot of his time in his local community helping neighbors with home and garden projects. He has returned to the Philippines Islands twice to visit WWII sites. He frequently travels and speaks at Veterans of Foreign War meetings. He has worked on his life memoirs from childhood days through WWII. As one of the most knowledgeable in the Thermoforming Industry, he is not wasting that talent either. Besides producing oil paintings and other arts and crafts with his wife Eunice, he still finds time to consult and help startup companies as well as established thermoforming companies. Glenn has always been respected for coming up with a way to thermoform something when others said it had to be done by another process. He is often called upon for his ideas in part, tool or process design. It wasn't until after his retirement and in 2001 that Mr. Blackburn was awarded a High School Diploma at a graduation ceremony for WWII Veterans.

Glenn's three children – Dennis, Wanda and Wendy – all live close to his central Florida home.

Some of Glenn Blackburn's Accomplishments:

1. Developed a process for vacuum packaging and sealing of cartons of food products in stacks.
2. Worked with development of packaging films, Dow Chemicals (Saran Wrap), Doebeckman (Cellophane), B.F. Goodrich (Polyfilm).
3. Developed tooling and procedures for manufacturing a 5 gal. plastic pail liner. The material was .060 HDPE and a four cavity female mold with plug assist was used in this difficult project.
4. After other companies failed, Mr. Blackburn developed tooling and process to thermoform the 18" x 18" x 32" McDonald's waste receptacle using a female mold.
5. Developed a method for impregnating anti-static solution onto HDPE extruded sheet prior to vacuum forming. This material was used to form several million trays for Johnson & Johnson and surpassed the required static decay factors.
6. Developed 7 thermoforming companies: Portage Plastics, Haines Industries, Winter Haven Plastics, Artec Plastics, Rebel Plastics, Blackburn Industries, and Progress Plastics.
7. Set up 2 different companies with equipment which included over 26 compression molding presses, blenders, extruders and other machining equipment to manufacture fiberglass flower pots as well as low- and high-voltage electrical housings. ■

Thermoforming with Style

Technology advances have increased designers' flexibility.

Designers who think that injection molding is the only way to fabricate stylish plastic parts are behind the times and need to take a second look at thermoforming. While it's true that thermoforming is ideal for large, flat parts, the capabilities of the process extend much farther, due to many technology innovations and the availability of new sheet materials.

"There's a huge amount of education that needs to take place among designers," says Richard Freeman, president of Freetech Plastics, Fremont, California. "I think we are just scratching the surface of its potential."

Freetech Plastics has been a leader in stretching the design limits of thermoforming and in developing an approach that's become known as the West Coast Style of thermoforming.

The West Coast Style concentrates on more dramatic shapes with sweeping curves, deeper draws, larger undercuts, and the use of rib structures. Because this approach relies on painting after forming, it eliminates the need to mold in texture and color, a need that can restrict part design to a more conservative style.

A number of designers have already gotten the message and are working with Freetech to provide their customers with creative concepts. For example, Lunar Design, Palo Alto, California, has won five design awards from ID Magazine for projects on which Freetech thermoforms the enclosures. Frog Design, Sunnyvale, California, and Ziba Design, Portland, Oregon, have also each won a design award using parts formed at Freetech.

"For the most part, we can duplicate any part design that you can do with injection molding," Freeman says. "We've never turned away a customer because the part shape was too complex."

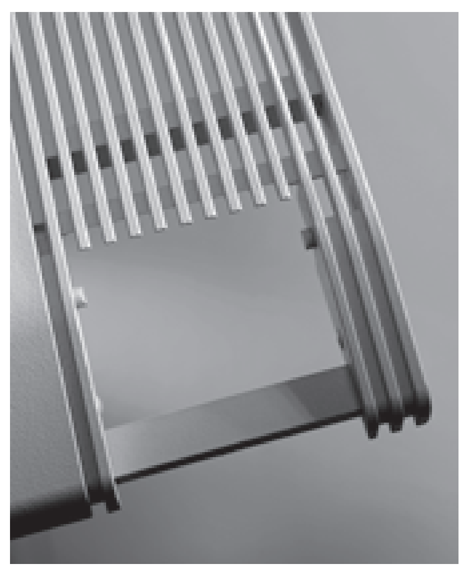
Thermoforming also gives designers the freedom to use significantly fewer parts, notes Freeman, and new techniques are allowing them to do things they couldn't do before. For example, Freetech can perform insert forming, which it does to produce the Xenogen enclosure (see photo on next page).

"For structural purposes, we inserted some machined corner blocks and formed the material around them," Freeman says.

Such secondary machining is a frequent means of executing complex part designs. For example, even though the thermoforming process can only mold precise features on one side, additional structural support and part nesting type features can still be added to the back side by bonding machined parts after forming. Vent openings on parts can be achieved by designing in deep drawn rib structures, then machining the openings off the backside.

Freeman also refutes the myth that thermoformed parts cannot achieve the same level of aesthetic quality of injected molded parts.

"We not only can achieve injection molding standards, we often exceed them," Freeman notes. "A Class A finished, molded-in-texture, thermoformed part generally looks better than an injected molded part because we don't have their issues with swirls, sink marks, weld lines, gate marks, etc. On cars, plastic bumpers and plastic lower side panels are typically thermoformed because we can consistently achieve



This is an example of a pressure-formed grille that demonstrates the design flexibility that can now be achieved with thermoformed parts.

Life Measurement's Pea Pod air displacement plethysmograph assesses infant body composition. The top part of the machine enclosure is pressure formed by Freetech Plastics.

the Class A finish on a big part where injection molding night not."

Depending on a particular part design and size, thermoforming can often match, or even exceed, the productivity of injection molding by using inline or rotary machines.

Xenogen Ivis 200 Laboratory Imaging System also uses enclosure parts pressure formed at Freetech Plastics.

"With a rotary machine and a four-up tool, we can get four shots a minute," Freeman says. "You cannot get four shots a minute on large parts with injection molding."

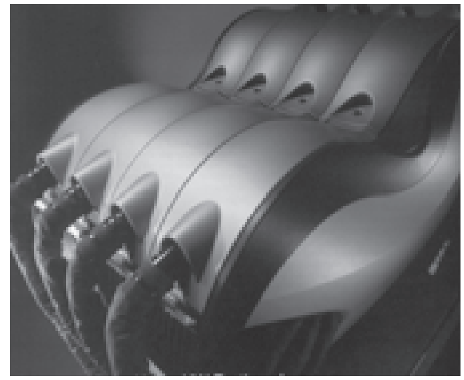
So when should someone use thermoforming instead of injection molding? There's not one simple answer. Volume plays a huge role, given the difference in tooling costs. Lower volumes favor thermoforming, since thermoforming tooling costs are only 10 percent to 15 percent the cost of injection molding tooling.

Part complexity and shape are big factors, since they affect tooling costs. And, of course, size is important. Very large parts favor thermoforming, while very small parts favor injection molding, where multi-cavity tooling can be used. For medium sized parts, all the factors must be considered together: complexity, size, and volume.

Material choices also affect the decision making process, since not all engineering resins are available in the extruded sheet form that is used by thermoforming machines.

However, resin suppliers continue to roll out new thermoformable materials every year. Available materials already include the olefins, ABS, polycarbonate, nylons, polyphenylene sulfide (PPS), and thermoplastic elastomerssuch as DuPont's Hytrel. Last year, DuPont also introduced a thermoformable version of its Delrin acetal.

Freetech Plastics was the first company to demonstrate the feasibility of thermoformed Delrin, which DuPont is aiming at



Credence Kalos XW Testhead uses pressure formed enclosure parts that illustrate the curvaceous aesthetic representative of the West Coast style of thermoforming.

the medical equipment segment because of the material's high chemical resistance.

Conventional thermoforming methods have long provided parts for commercial appliances such as refrigeration and vending machines, but the new techniques have also allowed thermoforming to provide innovative solutions in segments such as medical equipment, laboratory equipment, fitness equipment, business machines, and lawn and garden equipment. Some manufacturers of consumer electronics have even turned to thermoforming for the large housings used inprojection televion sets.Such parts were typically injection molded in the past.

Thermoforming may not be the best route for every application, but it should definitely be looked at first on large parts.

"The process has been too often overlooked in the past," Freeman says. "But it's a process that designers need to be aware of and keep in their tool kit." ■

MARK YOUR CALENDAR!

• • •

17th Annual Thermoforming Conference

2007 THERMOFORMING CONFERENCE

SEPTEMBER 16 - 19, 2007

CINCINNATI, OHIO
CINERGY CENTER
& MILLENNIUM HOTEL

CHAIRMAN:
KEN GRIEP,
PORTAGE CASTING & MOLD

TECHNICAL CO-CHAIRS:
BRIAN WINTON,
MODERN MACHINERY
AND
CONOR CARLIN, SENCORP

PARTS COMPETITION:
HAYDN FORWARD,
SPECIALTY MANUFACTURING

Society of Plastics Engineers
P.O. Box 403, Brookfield, CT 06804-0403 USA
Tel: +1.203.740.5403 Fax: +1.203.775.8490 www.4spe.org

MEMBERSHIP APPLICATION

Applicant Information

Name:

first last mi

Company Name and Business Address (or College):

company/college:

job title:

address:

address:

city: **state:**

zip: **country:**

Phone/Fax Format: USA & Canada: (xxx) xxx-xxxx All Others: +xx(xx) x xxx xxxx

Work Phone: **Fax:**

Email: *used for society business only*

Home Address:

address:

city: **state:**

zip: **country:**

Home Phone:

(✓) Preferred Mailing Address: ❑ **Home** ❑ **Business**

Gender: ❑ Male ❑ Female

Birth Date: (mm/dd/yyyy)

Demographics

Job Function *(choose only one)*

❑ Consulting
❑ Design
❑ Education (Faculty)
❑ Engineer
❑ General Management
❑ Manufacturing
❑ Marketing/Sales
❑ Other
❑ Purchasing
❑ Quality Control
❑ R & D
❑ Retired
❑ Self-Employed
❑ Student
❑ Tech Support

Materials *(choose all that apply)*

❑ Composites
❑ Film
❑ General Interest
❑ Nylon
❑ PET
❑ Foam/Thermoplastics
❑ Polyolefins
❑ Polystyrene
❑ TPEs
❑ Thermoset
❑ Vinyls
❑ No Interest

Process *(choose all that apply)*

❑ Blow Molding
❑ Compression
❑ Compounding
❑ Engineering Properties
❑ Extrusion
❑ Fabrication
❑ Foam
❑ Injection Molding
❑ Mold Making
❑ Product Design
❑ Rotational Molding
❑ Thermoforming
❑ General Interest
❑ No Interest

The SPE Online Membership Directory is included with membership. Your information will automatically be included.

❑ Exclude my email from the Online Member Directory
❑ Exclude all my information from the Online Member Directory
❑ Exclude my email from 3rd party mailings

Payment Information

New Member 1 Year	New Member 2 Years *	Student Member
❑ US ($122.00)	❑ US ($212.00)	❑ US ($28.00)
❑ Canada ($162.75)	❑ Canada ($282.00)	❑ Canada ($37.50)
❑ Euro (€125.00)	❑ Euro (€219.00)	❑ Euro (€25.00)

Students must supply graduation date: ______

Membership Amount ______

My Primary Division is (choose from below) ______

Primary Division FREE

Additional Divisions are available for a fee. Check below to select Additional Divisions.

❑ Additives & Color Europe (D45)
❑ Automotive (D31)
❑ Blow Molding (D30)
❑ Color & Appearance (D21)
❑ Composites (D39)
❑ Decorating & Assembly (D34)
❑ Electrical & Electronic (D24)
❑ Engineering Properties & Structure (D26)
❑ Extrusion (D22)
❑ Flexible Packaging (D44)
❑ Injection Molding (D23)
❑ Marketing & Management (D37)
❑ Medical Plastics (D36)
❑ Mold Making & Mold Design (D35)
❑ Plastics Environmental (D40)
❑ Polymer Analysis (D33)
❑ Polymer Modifiers & Additives (D38)
❑ Product Design & Development (D41)
❑ Rotational Molding (D42)
❑ Thermoforming (D25)
❑ Thermoforming, European (D43)
❑ Thermoplastic Materials & Foams (D29)
❑ Thermoset (D28)
❑ Vinyl Plastics (D27)

Additional Division(s)
costs for each Additional Division

	1yr.	2 yrs.
US	$6.00	$12.00
Canada	$8.00	$16.00
Euros	€5.00	€10.00

______

TOTAL ______

❑ CHECK ❑ VISA ❑ AMEX ❑ MASTERCARD

card number

expiration date (mm/yyyy)

PAYMENT MUST ACCOMPANY APPLICATION
Sorry, No Purchase Orders Accepted

Checks must be drawn on US or Canadian banks in US or Canadian funds.

Dues include a 1-year subscription to *Plastics Engineering* magazine.
SPE membership is valid for twelve months from the month your application is processed.
*save over 10%

By signing below I agree to be governed by the Constitution and Bylaws of the Society and to promote the objectives of the Society. I certify that the statements made in the application are correct and I authorize SPE and its affiliates to use my phone, fax, address and email to contact me.

signature date

recommended by member (optional) Id #

D

These sponsors enable us to publish Thermoforming QUARTERLY

INDEX OF SPONSORS

These sponsors enable us to publish Thermoforming QUARTERLY