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September 23-25, 2012
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Ken Griep

20th Annual Conference is Huge Success!!

As we close yet another year, there are so many people and companies our Division needs to thank that a simple note in this columns cannot do it justice. This past year's conference in Schaumburg was a huge success. I first need to thank all of our sponsors, exhibitors and attendees who participated in this year's "Being Prepared to Meet Future Opportunities" conference.

Everyone agreed that the September conference is still the best event our industry offers. I want to thank to James Alongi, Conference Chair, for his dedication and drive to deliver excellent value for attendees. We also owe a round of applause for his staff members, Paul Alongi, Jay Waddell, and Mark Strachan, for their involvement and direction to ensure quality technical content. A special thanks is due to Brett Joslyn for putting together yet another a well-run Parts Competition. Last but not least, I want to acknowledge and thank Gwen Mathis for her untiring devotion to our Division and to the success of these conferences. Thank you so much again!

I would like to acknowledge and congratulate our scholarship winners: **Brian L. Rupnow**,

University of Wisconsin, Stout – "The Segen Griep Memorial Scholarship" ($5,000); **Martha M. Brundage**, University of Akron – "The Thermoforming Division Memorial Scholarship" ($2,500); and **Kevin W. Rudy**, Ferris State University – "The Mathelin Bay Scholarship of Excellence" ($1,000). We wish them continued success in their current academic pursuits and their future careers in thermoforming.

As we drive forward to the end of 2011, I want to recap some of the areas where the Board is particularly active. A new and dynamic interactive website is under construction. This newly designed site will be your go-to site for a comprehensive listing of all exciting events within the industry. Stay tuned, as we plan to roll this out in early 2012. We have also launched a LinkedIn Group both to continue the great conversations we had at Schaumburg and to create a new forum for division communications and technical exchanges. We encourage you to join our Thermoforming Division Group on LinkedIn and start a new discussion or post questions. If you are not a LinkedIn member yet, I encourage you join us and join the conversation.

This year marked the 20th year of the Thermoforming Division's annual conference. We have really matured over these 20 years,

evolving from a casual get-together discussing business matters, to the now familiar well-orchestrated event with 1000+ attendees talking about in-depth issues in thermoforming and sharing highly technical presentations on polymer science. From simple table top displays to full blown machinery demonstrations, there is no other venue where you can rub shoulders with colleagues and peers, suppliers and customers, academics and professionals in one place at one time. More importantly, the twenty years have tightened the professional and personal relationships that are a hallmark of our group. I am not the only one who notes that this special conference has helped to grow our division and to propel our industry forward. SPE President Russell Broome offers distinct praise for us all in his letter, published in these pages. Nowhere else can you find such a conference the delivers such an impact to your success. Congratulations again to all involved!

On behalf of the Thermoforming Board, we wish you all a safe and enjoyable holiday season and continued success in 2012.

If you have any view points or comments, please feel free to contact me. I would like to hear from you! |

ken@pcmwi.com

Bilo Bautista
Lucite International
Cordova, TN

Steve Zamprelli
Formed Plastics
Carle Place, NY

Eric John Krohn
Formall, Inc.
Knoxville, TN

Edward Passno
Speck Plastics Inc.
Nazareth, PA

Bernard F. Yurko
Speck Plastics Inc.
Nazareth, PA

Dan Mohs
Placon
Madison, WI

William B. Hiltz
Ontario Die Co. Ltd.
Waterloo, ON

Vicki Holt
Spartech Corp.
Clayton, MO

Chris Palmer
Spartech Plastics
Sheboygan Falls, WI

Gary Orenstein
Spartech Plastics
Cape Girardeau, MO

Sang-Kook Kim
LG Electronics
Pyeongtaek

Janet Mann
Spartech Corp.
Clayton, MO

John Hirsch
Spartech Corp.
St. Louis, MO

Jana M. Gessner
Spartech Corp.
Clayton, MO

James Sorensen
CMPG
Gladwin, MI

Joseph A. Hartmann
C M Packaging Inc.
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ABC Group
Toronto, ON

Paul R. Lamont
Printpack Inc.
Williamsburg, VA

Shyam N. Singh
Thermoplastec Inc.
Rockford, IL

Frank A. Menichini
Custom Pack Inc.
Exton, PA

Gary McClain
ALP Lighting
   Components, Inc.
Olive Branch, MS

Brian Toliver
ALP Lighting
   Components, Inc.
Olive Branch, MS

Blake Miller
Hart Plastics
Elkhart, IN

Chris Dolny
Moore Tool Co.
Bridgeport, CT

Paul Uphaus
Primex Plastics
Richmond, IN

Keith Sawatsky
WD Plastics Limited
Saskatoon, SK

Alejandro Miguel Vasquez
Lamiempaques S.A.S.
Itagui Antioquia

Carlos Humberto Fernandez
Lamiempaques S.A.
Itagui

Robert McNeal
McNeal Enerprises
San Jose, CA

Joseph M. Scarpy
TEQ
Huntley, IL

Martin Larsen
Minimizer
Blooming Prairie, MN

Stephen Oseguera
Profile Plastics Corp.
Lake Bluff, IL

Brian Deeken
Global Body & Equipment
Wooster, OH

Tom Jankowski
Allied Plastics Inc.
Twin Lakes, WI

Oktay Ekinci
Isik Plastik
Gebze-Kocaeli

Cathleen B. Duthie
3M
St. Paul, MN

Hani Omran
Lund International, Inc.
Lawrenceville, GA

Peter Hazenberg
Nike, Inc.
Beaverton, OR

Ronald Pardee
Golden Plastics Corp.
Oakland, CA

Jim Cavezza
The Fabri-Form Co.
New Concord, OH

Milliard Davis
Lund International
Lawrenceville, GA

Janelle Shruhan
Trelleborg Offshore
   Boston Inc.
Mansfield, MA

Alex Nunez
Tegrant Corp.
Dekalb, IL

Andy Flint
Gauge Works
Dulles, VA

Greg Day
Gauge Works
Dulles, VA

John Slocum
Concord, MA

Damian Gouff
Quick Cable Corp.
Franksville, WI

Brad Bollard
Plastic Fabricating
Salt Lake City, UT

Adam Shepherd
Plastic Fabricating
Salt Lake City, UT

Chris Shively
Barger Packaging
Elkhart, IN

Domenic Baggeppa
ABC Group
Toronto, ON

Doug Newman
Profile Plastics Inc.
Lake Bluff, IL

Martin Schad
Bose
Framingham, MA

Roger Bord
Ex-Tech Plastics
Richmond, VA

Patrick Fanning
Panoramic Inc.
Janesville, WI

Jerry Sutton
PMC
Findlay, OH

William R. Cohn
Southtech Decorative
   Laminations
Trenton, NC

Mike Cardwell
Southtech Plastics
Raleigh, NC

Phil Noakes
Premier Material Concepts
Findlay, OH

Christopher E. Toler
Southtech Decorative
   Laminations
New Bern, NC

Mark Bohler
Plant Engineering
   Services, Inc.
Fort Wayne, IN

Peeter A. Leis
Husky Injection Molding
   Systems
Etobicoke, ON

Keith Teague
Norcold
Sidney, OH

Michael Hoppes
Brentwood Industries
Reading, PA

Yan Zhang
Solo Cup
Lake Forest, IL

Nick Garrard
Cox Wokingham
   Plastics Ltd.
Berkshire

Lori Slugocki
MAAC Machinery
Carol Stream, IL

Miguel Angel Avila
Impersealco
Mexico

Fernando David Avila Muñoz
Impersealco
Mexico

Mike Keifer
Jay Visual Packaging
Elkhorn, WI

David Avila
Impersealco
Mexico

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, and keeps you connected.

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

Why Not?

Thermoforming in the News

Placon Acquires Barger

MADISON, WI – November 1, 2011

Placon Corporation of Madison, Wisconsin announces the acquisition of Barger Packaging, Inc., a thermoform manufacturer of packaging for the medical and pharmaceutical industries. With the acquisition, family-owned Placon becomes one of the top three medical thermoformers in the U.S.

"Barger has a strong reputation in the industry for its array of high quality products and focused customer service," said Dan Mohs, CEO of Placon Corporation. "These strengths, combined with Placon's innovative product design and operational depth, will enable us to deliver greater value to customers."

Scott Duehmig, Barger General Manager adds, "Placon's technical expertise, material offerings, and in-house tooling will enhance our ability to support our customers and the medical packaging market."

Placon is a market leader in packaging design and technology. Barger's diverse offerings include thermoforms, protective packaging, Tyvek® lidding and cartons. A standout in the Barger product group, BargerGard® is an innovative alternative to replace foam and vinyl protective packaging. Together, by combining their strengths and offerings, the Placon/Barger team will be a powerful resource for the design, development and production of sterile and non-sterile medical packaging systems.

Barger Packaging was founded in 1887 and began developing medical packaging 40 years ago. They employ 67 employees who will continue to work out of the Elkhart, Indiana facility. Placon plans to maintain the Barger name and operate it as a division of Placon Corporation. Placon will combine the sales teams into one medical sales organization and continue to operate both the Madison and Elkhart ISO Class 8 (100,000) clean rooms. They also plan on reinvesting in the Elkhart plant to modernize and improve their operational capabilities.

ABOUT PLACON

Headquartered in Madison, WI, Placon has been a leading manufacturer of thermoformed packaging for over 45 years. Serving the medical, retail and food markets, the privately-owned company offers custom-designed packaging, stock products and raw materials. According to *Plastics News*, Placon ranks among the top 25 thermoformers in the United States. |

Mid Oaks Investments Acquires CM Packaging Group Through D&W Fine Pack Business

By Clare Goldsberry, Plasticstoday.com – November 14, 2011

Privately held Mid Oaks Investments LLC continues its 25-year history of investing in the food packaging industry with its agreement to acquire CM Packaging Group, through D&W Fine Pack LLC, a Mid Oaks portfolio company. This acquisition will move forward D&W Fine Pack's strategy to become a nationwide distributor of disposable containers and other food packaging for away-from-home and at-home foodservice markets.

CM Packaging, headquartered in Lake Zurich, IL, is comprised of three business units: CM Packaging, Stone Plastics and Packaging Direct Inc. CM Packaging Group is a manufacturer of rigid plastic containers and aluminum containers serving the restaurant, grocery, bakery, produce and food processor markets. The CM Packaging business will complement the D&W product offering, with both stock and custom thermoformed products, and add five manufacturing locations.

CM Packaging Group's CEO, Mark Faber, stated in a release that the "combination of CM Packaging Group and D&W Fine Pack and their collective production and supply network will strengthen the customer service of CM Packaging Group." CM Packaging Group has manufacturing locations in Central Islip, NY; Gladwin, MI; Miami, FL; and Cadiz, KY; and a distribution facility in City of Industry, CA.

D&W Fine Pack's President and CEO, Mark Staton, commented that the company is "focused on being a complete-service provider of foodservice packaging products for its customers. Integrating CM Packaging Group's products will enable the company to offer broad options and versatility to its customers in order to fulfill the emerging needs in the food packaging and foodservice industries."

Following the acquisition, revenues will approach $400 million, and the company will employ 1,600 and operate from 11 locations in the U.S. and Canada. |

Celebrating 20 Years

Ken Braney was elected President of SPE in 2010, becoming the first member of the Thermoforming Division to hold the office. Ken's career in thermoforming spans several decades and multiple continents. A true global professional, Ken's contributions to the Division and the Society are well-known. He reflects on his time at the conferences.

My recollections date back to the early 1990's when I first attended the Thermoforming Conference as a member of the Brown Machine contingent, representing the European arm of the company. It was at the time when leaders such as John Griep, Roger Kipp, Art Buckel, Bill McConnell were in their prime. After attending one of the famous Art/Bill pre-conference seminars, I invited both gentlemen to come to the UK and put on similar training seminars. These events were well-received, following the format of the seminars in the USA. Subsequently, they then spread not only to continental Europe, but also to India and the Far East.

As a result of attending these early conferences, I had the opportunity to meet industry professionals and to develop lasting friendships with a number of US thermoformers. I had developed such a friendship with John Griep that Dick Roe (rotary/twin sheet guru from Brown Machine) and I made a number of visits and presentations to companies who originally had sent their employees to the conferences.

I had the pleasure of being involved in a number of celebration dinners when the Thermoformer of the Year was announced and there are two special occasions that stand out in my mind. Of course, all Thermoformers of the Year are unique, but as everyone will appreciate, when good friends are acknowledged by peers, it makes it an occasion to remember.
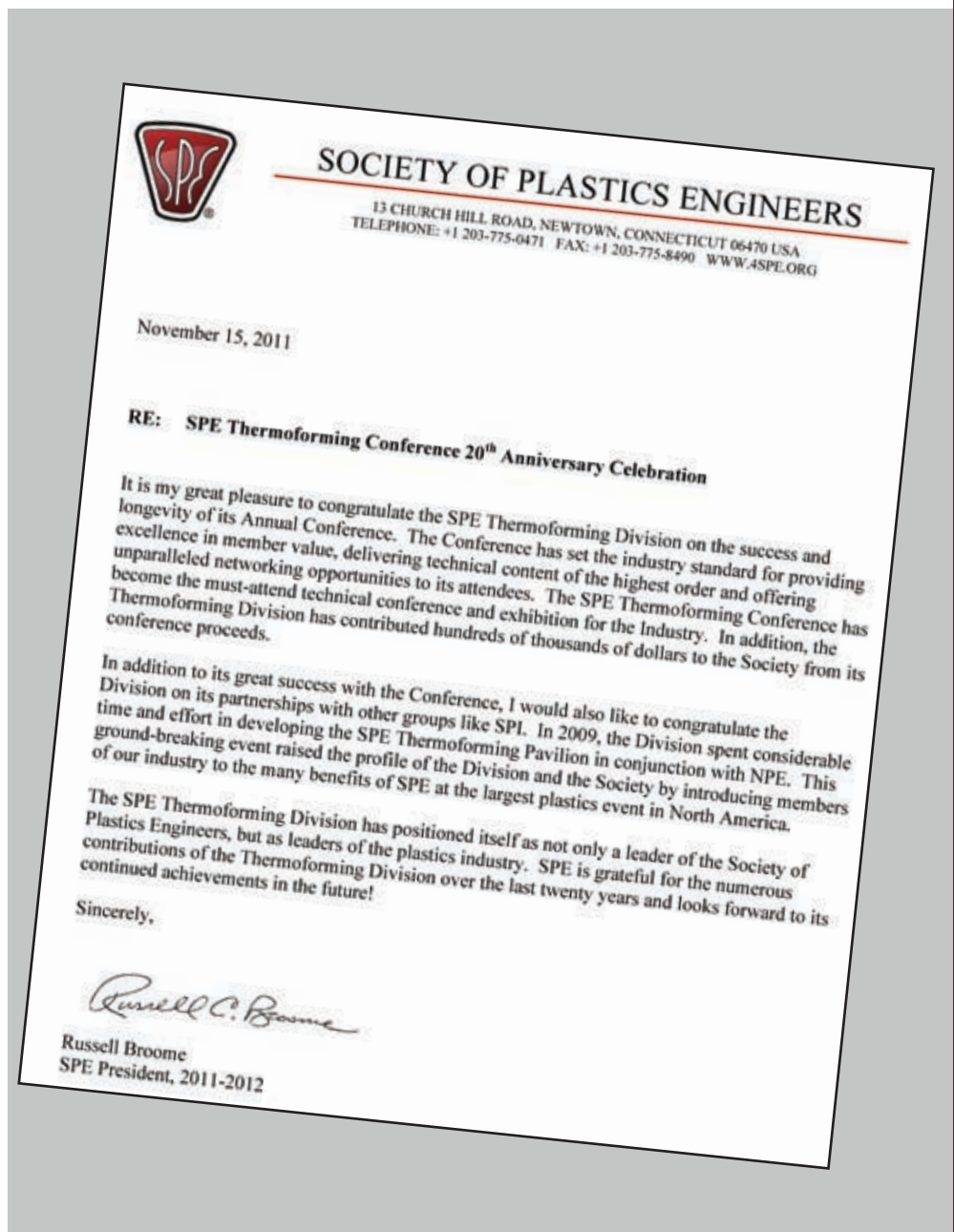
The first occasion was when my good friend (and the "Father of the SPE European Thermoforming Division") Manfred Jacob was recognized for his achievements. This was in 2005 and I was invited to the celebration dinner, as Chair of the European Thermoforming Division, to make the presentation. It

was even more special as we had a few of his colleagues from the ETD also in attendance.

The second occasion that stands out was more recent, just last year in Milwaukee. As President of SPE 2010-2011, I had the pleasure of being at the conference to fulfil various functions. One of these duties was to say a few words at the official lunch when, to my great pleasure, I was introduced by Ken Griep, the son of my good friend John. That evening, I had been asked

to say a few words about the 2010 Thermoformer of the Year, who was my very good friend Roger Kipp.

On both occasions, it was both rewarding for me to see colleagues recognized for their achievements and to play a small role in the evolution of the conference from a small gathering of peers to an annual event that draws professionals from across the globe. The conference goes from strength to strength and I plan to attend for many more years. |

SOCIETY OF PLASTICS ENGINEERS
13 CHURCH HILL ROAD, NEWTOWN, CONNECTICUT 06470 USA
TELEPHONE: +1 203-775-0471   FAX: +1 203-775-8490   WWW.4SPE.ORG

November 15, 2011

RE: SPE Thermoforming Conference 20th Anniversary Celebration

It is my great pleasure to congratulate the SPE Thermoforming Division on the success and longevity of its Annual Conference. The Conference has set the industry standard for providing excellence in member value, delivering technical content of the highest order and offering unparalleled networking opportunities to its attendees. The SPE Thermoforming Conference has become the must-attend technical conference and exhibition for the Industry. In addition, the Thermoforming Division has contributed hundreds of thousands of dollars to the Society from its conference proceeds.

In addition to its great success with the Conference, I would also like to congratulate the Division on its partnerships with other groups like SPI. In 2009, the Division spent considerable time and effort in developing the SPE Thermoforming Pavilion in conjunction with NPE. This ground-breaking event raised the profile of the Division and the Society by introducing members of our industry to the many benefits of SPE at the largest plastics event in North America.

The SPE Thermoforming Division has positioned itself as not only a leader of the Society of Plastics Engineers, but as leaders of the plastics industry. SPE is grateful for the numerous contributions of the Thermoforming Division over the last twenty years and looks forward to its continued achievements in the future!

Sincerely,

Russell Broome
SPE President, 2011-2012

Thermal Radiant Absorption in Thin Semi-Transparent Plastics[1]

By Jim Throne, Dunedin, FL

Author's Note: Energy input to plastic sheet is usually through a combination of radiant and convective sources. One model that is often used to predict the rate at which a specific plastic of a specific thickness heats is called the transient one-dimensional heat conduction model. For thick-gauge sheet (greater than approximately 0.120 inch or 3.0 mm in thickness), the standard model assumes that the sheet is radiopaque, meaning that all the inbound energy is absorbed on the surface of the sheet. The conduction of this energy into the sheet from the surface is the controlling heat transfer factor. For thin-gauge sheet, conduction is no longer as major a factor. Instead, the ability for the sheet to absorb the inbound energy becomes significant.

Abstract

Infrared absorption characteristics of three thin semi-transparent plastics are examined, using their Fourier Transform Infrared scans. Their heating characteristics are analyzed using the transient one-dimensional lumped parameter mathematical model.

In the first part of this paper, the rationale for using transmissivities and absorptivities of sheet at least 0.010 inches thick was presented. In the concluding part of this paper, an example of energy absorption into thin semitransparent plastics is given.

The Development of the Sheet Heating Model

How can the information in Part I be used to determine the rate of heating of semi-transparent sheet? Consider the simple example of infinitely parallel plates. The radiating plate considered a black body with an emissivity =1 and its temperature is T_r*. The absorbing plate temperature is $T_{plastic}$*. [*Asterisks denote absolute temperatures.*]

The inbound heat flux is given as:

$$q_{inbound} = \sigma T_r^{*4} \tag{7}$$

Where σ is the Stefan-Boltzmann constant. The amount of energy absorbed by the sheet is given as:

$$q_{inbound} = \alpha_T(l)\sigma T_r^{*4} \tag{8}$$

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[1] This paper was published in two parts. Part I was published in TQ3 Vol. 30, No. 3. The references, table numbers and equation numbers are continued from Part I.

The total energy interchange is thus:

$$q_{interchange} = \sigma\left[\alpha_T(l)\left(T_r^{*4}\right) - T_{plastic}^{*4}\right]$$ (9)

It is apparent that the amount of energy absorbed is linearly dependent on the thickness-dependent absorptivity, $\alpha_T(l)$.

The arithmetic above assumes all the radiant energy is entering one surface of the plastic sheet and exiting the other. Most plastic sheets are heated from both sides. So the total energy uptake of the sheet is given as:

$$q_{interchangex2} = q_{interchange1} + q_{interchange2}$$ (10)

$$q_{interchangex2} = \sigma\left[\alpha_T(l)\left(T_{r1}^{*4} + T_{r2}^{*4}\right) - T_{plastic}^{*4}\right]$$ (11)

For thin plastic sheets, where the conduction through the sheet is less significant than the energy exchange with the heating source, the sheet temperature can be approximated by the lumped-parameter model:

$$V\rho c_p dT = Q_{convection} + Q_{radiation}$$
$$V\rho c_p dT = hA\left(T_{air} - T_{plastic}\right)d\theta + q_{interchange}Ad\theta$$
$$V\rho c_p dT = hA\left(T_{air} - T_{plastic}\right)d\theta + \sigma\left[\alpha_T(l)\left(T_r^{*4}\right) - T_{plastic}^{*4}\right]Ad\theta$$ (12)

This model includes the effect of convection heat transfer at the surface of the sheet. V is the volume of the sheet, V=Al, where A is the sheet surface area and l is the sheet thickness in compatible units. T_{air} is the air temperature, h is the convection heat transfer coefficient, and θ is the time.

The equation can be approximately solved in two ways: analytically after a linearization of the radiation term, and with finite difference analysis.

Approximate Analytical Solution

As a first step in linearization, a radiant heat transfer coefficient, h_r, is defined as:

$$h_r = \frac{q_{interchange}}{\left(T_r - T_{plastic}\right)} = \sigma\left[\frac{\left(\alpha_T(l)T_r^{*4} - T_{plastic}^{*4}\right)}{\left(T_r - T_{plastic}\right)}\right]$$ (13)

Now the lumped-parameter equation is approximated by:

$$l\rho c_p \frac{dT_{plastic}}{d\theta} = h\left(T_{air} - T_{plastic}\right) + h_r\left(T_{radiation} - T_{plastic}\right)$$ (14)

Replacing some of the terms:

$$C = \frac{\left|hT_{air} - T_{plastic}\right|}{l\rho c_p} \qquad B = \frac{\left[h + h_r\right]}{l\rho c_p} \qquad \frac{C}{B} = \frac{\left[hT_{air} + h_r T_r\right]}{\left[h + h_r\right]}$$

Where C, B, and C/B are (approximate) constants. (Keep in mind that h_r is really dependent on plastic sheet temperature, as shown in Table 9.)

$$\frac{dT_{plastic}}{d\theta} = -BT_{plastic} + C = B\left(C/B - T_{plastic}\right) \tag{15}$$

$$\frac{dT_{plastic}}{\left(C/B - T_{plastic}\right)} = Bd\theta \tag{16}$$

If the initial sheet temperature, $T_{plastic} = T_0$ when $\theta = 0$, then the first order equation can be integrated to yield an approximate analytical solution:

$$\ln\left[\frac{C/B - T_{plastic}}{C/B - T_0}\right] = -B\theta$$

$$\left[\frac{C/B - T_{plastic}}{C/B - T_0}\right] = \exp(-B\theta) \tag{17}$$

Because the radiant heater temperature, T_r, is usually much greater than the ambient air temperature, T_a, the value of the term C/B is on the order of the radiant heater temperature value. Thus, from the last equation, it can be assumed that as time progresses, the plastic sheet temperature, $T_{plastic}$, approaches the radiant heater temperature in an exponential fashion.

Difference Solution

Beginning with the one-dimensional equation, assume a forward difference:

$$l\rho c_p dT = h\left(T_{air} - T_{plastic}\right)d\theta + \sigma\left[\alpha_T(l)\left(T_r^{*4}\right) - T_{plastic}^{*4}\right]d\theta \tag{18}$$

$$dT \approx \Delta T \rightarrow T_i - T_{i-1} \tag{19}$$

Where T_i is the temperature at $\theta + \Delta\theta$ and T_{i-1} is the previous temperature at θ. Again, $T = T_0$ at $\theta = 0$. The difference equation now reads:

$$T_i = T_{i-1} + \left[\frac{h\left(T_{air} - T_{i-1}\right)}{l\rho c_p}\right]\Delta\theta + \sigma\left[\frac{\alpha_T(l)T_{rad}^{*4} - T_{i-1}^{*4}}{l\rho c_p}\right]\Delta\theta \tag{20}$$

Because of the strong influence of the fourth-power term, care must be taken in selecting a small enough value for the time step, $\Delta\theta$.

Arithmetical Values

Note that the terms in the brackets in equation (20) must have the units of temperature per unit time. In the first bracket, the ratio $\dfrac{h}{l\rho c_p}$ must have the units of reciprocal time.

Table 6.

Values for $\dfrac{h}{l\rho c_p}$ where l=0.030 inch and h = 1 Btu/ft^2 h ^{o}F

Plastic	c_p (Btu/lb ^{o}F)	ρ (lb/ft^3)	$l\rho c_p$	$h/l\rho c_p$ (h^{-1})
PS	0.5	65.5	0.0819	12.2
PVC	0.5	84	0.105	9.52
PE	0.9	60	0.135	7.41

For the radiation term, $\sigma = 0.1714$ x 10^{-8} Btu/ft^2 h ^{o}R^4, where ^{o}R = ^{o}F+460. By dividing the absolute temperature by 100, the arithmetic simplifies.

$$\sigma\left[\frac{\alpha_T(l)T_{rad}^{*4}-T_{i-1}^{*4}}{l\rho c_p}\right]=0.1714\left[\frac{\alpha_T(l)\left(\dfrac{T_{rad}+460}{100}\right)^4-\left(\dfrac{T_{plastic}+460}{100}\right)^4}{l\rho c_p}\right] \quad (21)$$

As illustration, consider T_{rad} = 700°F. The first parenthesis in the bracket is $\alpha_T(l)$ x $0.1714\times11.6^4 = 3103\,\alpha_T(l)$. For the three plastics above:

Table 7.

Terms in radiant bracket for l = 0.030 inch

Plastic	3103/ $l\rho c_p$	$\alpha_T(l)$	$\alpha_T(l)$ 3103/ $l\rho c_p$	0.1714 / $l\rho c_p$
PS	37890	0.905	34290	2.093
PVC	29500	0.822	24249	1.634
PE	23000	0.778	17894	1.273

Table 8.

Comparison of Inbound Radiant and Sheet Re-radiant Energy Terms
[units = h^{-1}] for l = 0.030 inch

Plastic	Radiant @ 700°F	Sheet @ T= 80°F	Sheet @ 380°F
PS	34290	1780	10420
PVC	24249	1390	8135
PE	17894	1082	6338

Two observations can be made regarding the energy input to thin sheet. First, it is apparent when comparing the relative values of convective and radiative heat transfer that convection effects are negligible. Second, it is apparent that the major thermal driving force is energy from the radiant heaters. For the calculations shown in Table 8, the energy give-back of the PS sheet at 380°F is only 30% of the total energy output of the heater. The value is less for lower sheet exit temperatures and the other plastics.

The radiation term can be linearized by creating a radiative heat transfer coefficient, h_r, as shown in equation (13). The radiative heat transfer coefficient concept is important when comparing the relative influences of convective and radiative energy transfer rates on the heating rate of semi-transparent plastics. Table 9 gives calculated values of radiative heat transfer coefficients for the three semi-transparent plastics at the two temperatures in Table 8.

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Table 9.

Radiative Heat Transfer Coefficient, h_r, Btu/ft^2 h °F
[Compare with Convective Value, h = 1]

Plastic	$\alpha_T(l)$	$h_r@T_{plastic}=80°F$	$h_r@T_{plastic}=380°F$
PS	0.905	4.29	6.11
PVC	0.882	4.18	5.89
PE	0.778	3.66	4.88

</div>

As is apparent and expected, radiant energy transfer rates are greater than convective energy transfer rates. (The reason the radiative heat transfer coefficient increases as the sheet temperature goes up is that the denominator of equation (13) decreases more rapidly with temperature than does the numerator.)

Calculated Heating Rates – An Example

Consider a comparison of the heating profiles for the three plastics in the above tables for sheet thickness, $l = 0.030$ inch, Figure 8. The radiant heater temperature is 700°F and the convective heat transfer coefficient, h = 1 Btu/ft^2 h °F.

It appears that the high transmissivity and high specific heat of PE strongly influence its slow heating rate. The higher density and slightly higher transmissivity of PVC are the apparent reasons why it heats at a slower rate than PS.

Sheet thickness=0.030 in, Radiant Heater Temperature = 700F, Initial Sheet Temp = 80F, Air Temp = 80F

Figure 8. One-dimensional radiant heating of semi-transparent thin-gauge plastic sheet. Sheet thickness =0.030 inch, Radiant heater temperature, T_r=700°F, Initial sheet temperature, T_0=80°F, Air temperature, T_{air}=80°F

Equation (20) and the arithmetic that follows it do not necessarily distinguish whether the energy in inbound from one or two energy sources, so long as T_{rad}, h, and T_{air} are the same on both surfaces of the sheet. Heating uniformly from both sides increases the rate of heating, as is expected (Figure 9).

One-dimensional Radiant Heating of Semi-Transparent Thin-Gauge Plastic Sheet
Thin Line - 2 Side Heating, Thick Line - 1 Side Heating

Sheet thickness=0.030 in, Radiant Heater Temperature = 700F, Initial Sheet Temp = 80F, Air Temp = 80F
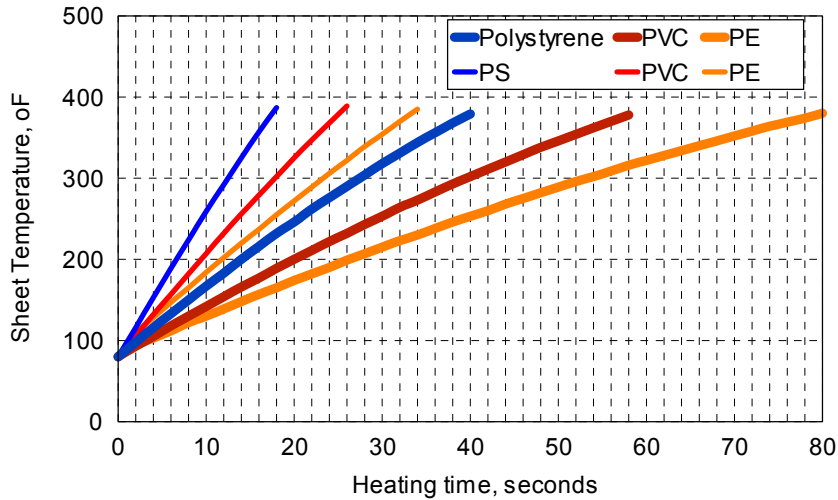
Aug2010graphic3.bas

sheet heating, Aug2010.bas

Figure 9. One-dimensional radiant heating of semi-transparent thin-gauge plastic sheet. Thin lines indicate heating on 2 sides. Thick lines indicate heating on one side (Figure 8). Sheet thickness =0.030 inch, Radiant heater temperature, T_r=700°F, Initial sheet temperature, T_0=80°F, Air temperature, T_{air}=80°F

Limitations on the Lumped-Parameter Concept

The lumped-parameter model should be applied only when the dimensionless Biot number, Bi < 0.1 [7]. Bi = hl/k, where h is the heat transfer coefficient, l is a sheet thickness dimension, and k is the thermal conductivity of the plastic. If the sheet is heated on only one side, l equals the actual sheet thickness. If the sheet is heated on both sides, l equals the actual sheet half-thickness. In the technical literature, h is always assumed to be the convective heat transfer coefficient. In the analysis below, the combined heat transfer coefficient, h_r + h, is also considered when determining the maximum allowable thickness for the lumped-parameter model.

For some bounds on the model, consider the three semi-transparent plastics used earlier. Note that the maximum allowable thickness decreases in proportion to the increase in heat transfer coefficient. For the illustration above, the convection heat transfer coefficient, h, was 1 Btu/ft^2 h °F. As seen in Table 10, for convection only, the maximum allowable thickness values are quite large compared with the thicknesses used in earlier discussions on transmissivity and absorptivity. This implies that the use of the lumped-parameter model is applicable to the above analysis.

On the other hand, if the effect of radiation is included, using the radiative heat transfer coefficient, h_r, given in equation (13), the lumped-parameter model may not be applicable at temperatures much above room temperature. Remember, however, that the maximum sheet thickness values in Table 10 represent half-thickness values when the sheet is heated equally on both sides[2].

Having said that, the lumped-parameter model is the easiest to use when illustrating the role transparency plays in heating of semi-transparent plastic sheet.

Table 10.
Thermal Conductivity and Maximum Sheet Thickness Values
For Lumped-Parameter Model, Bi < 0.1

Plastic	Thermal Conductivity, Btu/ft h °F	Maximum Thickness, l inches, h	Maximum Thickness, l in, h+h_r (80°F)	Maximum Thickness, l in, h+h_r (380°F)
PS	0.105	0.126	0.0218	0.0143
PVC	0.083-0.100	0.100-0.120	0.0207-0.0248	0.0119-0.0143
PE	0.183-0.292	0.220-0.350	0.0377-0.0600	0.0255-0.0405

Limitations on the Above Analysis

From even a casual glance at Figures 2 through 4, it is apparent that transmissivities are strongly wavelength-dependent. The analysis above assumes that it is proper to assume average values, at least through the wavelength range of 3 μm through 7 μm. Of course the proper method of analysis is to parse the values over a finite number of wavelength ranges [8]. Further, it was noted that the analysis above assumed that the emissivity values of the sheet and the heater were unity and that both the sheet and heater were planar and infinite in dimensions. These limitations can, of course, be removed, with the result being fine-tuning of the time-dependent heating curves depicted in Figure 9. |

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[2] It is important to keep in mind, however, that the lumped-parameter model contains no conduction component, meaning that thermal conductivity and thermal diffusivity are not included in the model. As a result, having thin sheet from both sides doubles the energy input but **does not affect** the functional sheet thickness. For transient one-dimensional heat transfer in thick sheet, conduction into the sheet is important. As a result, with equal energy input to both sides of the sheet, the functional sheet thickness is **one-half** the actual sheet thickness [7].

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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.

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: Juliet Goff,
Kal Plastics, 2050 East 48th Street,
Vernon, CA 90058-2022
Phone 323.581.6194, ext. 223 or email at: Juliet@kal-plastics.com**

The Growth of the SPE Thermoforming Division
20 Years Strong

By Stanley R. Rosen

The commercial thermoforming industry can be said to have its beginnings when a vacuum forming machine was demonstrated and sold at the Fifth National Plastics Exhibition in Philadelphia in March 1952. Prior to this event, vacuum forming was a proprietary process of a few firms and the U.S. Army Map Service.

The years 1950-1960 saw an incredible period of industrial expansion in the United States. We manufactured everything and exported many products to the war-torn countries around the world. At the end of World War ll, 12,000,000 men were discharged into the growing economy. Congress provided technical training or a full university education under the G.I. Bill of Rights for any veteran. Millions took this opportunity to become the engineers, scientists and businessmen that later would create many new industries.

One of the fastest growing segments in this economy was the relatively new plastics business. Most of the expansion in plastics was seen in injection molding and extrusion, where entrepreneurs and engineers were seeking substitutes for existing materials. These processes required heavy capital investment for equipment and molds. Those entrepreneurs who had fewer financial resources recognized the lower cost of entry to be found in the vacuum forming industry (the term in vogue at the time). For example, a businessman of my acquaintance borrowed $5000 from a Providence loan shark, started a successful vacuum forming firm, and within a year repaid his debt without suffering any physical damage to his person. Other early entrants to the vacuum forming field expanded existing businesses in packaging, advertising, displays and plastics fabrication.

Unfortunately, these early firms had no written texts or technical associations to explain the details of thermoforming, so they were continually reinventing the wheel. Any advances in knowledge in the thermoforming

process were painfully and expensively learned at each location. The only fresh and new technical information came from contacts with seller of plastic sheet and thermoforming mold makers. Plastics periodicals did not publish many articles of practical use for these start-up thermoformers. These were the dark ages for thermoforming, where witchcraft trumped science. The Society of Plastics Engineers tried to create a home for the thermoforming community during the years 1950

to 1975 without much success. During this era, small thermoformers were focused on building and strengthening their businesses. The large firms, producers of cups and lids, were secretive and insular Although the Thermoforming Division existed on paper, it had very few members. Dr. Jim Throne joined the Division in 1976 at which time it consisted of nine members, all of whom were on the Board.

In 1982 the Board began a concerted effort to build Division membership. It launched the "Thermoformer of the Year" award which was bestowed on Bill McConnell in that inaugural year.

At the time, the Board consisted of the following individuals:

Dick Osmers (Chair) – chemical engineer, educator-consultant, Rochester, NY

Bill McConnell – aeronautical engineer, businessman, educator-consultant, Forth Worth, TX

Dr. Jim Throne – chemical engineer, educator-consultant, Naperville, IL

Stan Rosen – mechanical engineer, President, Mold Systems, W. Nyack, NY

Pete Hughes – President of Hughes Plastics Corp., Redwood City, CA

John Griep - President, Portage Casting and Mold, Portage, WI

Al Scoville - Director of Sales for Ray Products, El Monte, CA

John Grundy – President, Profile Plastics, Chicago, IL

Charlie Hovesapian – Director of Sales, Innovative Plastics, Orangeburg, NY

Frank Palmer – Director of Sales, BMF Enterprises, Nashville, TN

Other very competent Board members joined as the Division's membership expanded. During the 1980s, Board meetings were often held at the O'Hare Airport Hilton in Chicago for easy travel access from any place in the U.S. Most of the Board members were non-political, independent and very capable individuals who wanted to improve the industry. They aimed to educate and communicate by interacting directly with individual members of the thermoforming community. The Board realized that to achieve this goal, the Division needed a stable financial base.

SPE headquarters rebated a small sum back to the Division for each member, so recruiting became a major priority. A very austere Division Quarterly newsletter was used to communicate with the membership and the Division derived income from vendor business cards printed in each issue. Commercial advertising was banned by SPE rules at the time and organizing an event which did not conflict with the SPE ANTEC proved to be difficult.

In 1989, Bill McConnell organized a two-day thermoforming seminar which was approved by the SPE and proved to be very popular. This event provided valuable practical, technical content to the participants and generated additional funding for other divisional projects. A thermoforming pavilion was organized within existing plastics shows with exhibits in a centralized venue. Successful thermoforming pavilions in the late 1980s in Las Vegas and Philadelphia generated further interest in created an annual event dedicated to thermoforming.

John Griep of Portage Casting and Mold and long-time Board member, hosted an open house at his thermoforming mold making plant in 1991. Bill McConnell and Art Buckel volunteered to conduct a free thermoforming seminar on this occasion. Attendance was expected to be about 30, but 180 showed up, confirming industry thirst for knowledge. This successful accomplishment encouraged the Board in 1992 to invest in the first SPE Thermoforming Division Conference at the Chula Vista Resort in The Dells, Wisconsin after much discussion about potential bankruptcy. Larger conference facilities were needed in each successive year as attendance and interest grew.

The Board was now in a position to finance many activities which promoted education and advanced thermoforming. Individual Board members advocated for and worked to create many of the following programs:

Thermoforming Student Activities

- Scholarships for students interested in plastics education

- Purchase of thermoforming equipment for college labs

- Funding for plastic exhibits to visit public schools via traveling vans

- Financial assistance for students to attend plastics conferences

- Cooperation with college-based thermoforming programs

Thermoforming Industry Programs

- Publishing the *Thermoforming Quarterly* Journal

- SPE Thermoforming Division Annual Conference provides educational opportunities through presentation of technical papers. Latest industry advances are available in visiting the exhibits at the show and through field trips to local thermoforming venues.

Honoring Outstanding Thermoforming Individuals

- Thermoformer of the Year Award
- Lifetime Achievement Award Winners
- Director Emeritus

Plastics News on February 25, 2008 published an article which aptly describes this division with the following headline: "**The Little SPE Division That Could; After Rocky Start, Thermoforming Group Growing.**" Since then, the Thermoforming Division has continued to evolve while continuing the mission to advance technology through "education, application, promotion and research." Long may it continue.

Stan Rosen is the author of "Thermoforming: Improving Process Performance" (SME 2002). He can be reached at the following: thermoipp@earthlink.net. Telephone: 702.869.0840. |

SPE Thermoforming Division
Chairs of the Board

1982-1984	Herman R. Osmers, Consultant, Rochester, NY
1984-1986	Peter Hughes, Hughes Plastics, Redwood City, CA
1986-1988	John Kelly, Hopple Plastics, Cincinnati, OH
1988-1990	Stanley R. Rosen, Mold Systems Corp., W. Nyack, NY
1990-1992	Charles Hovesepian, Innovative Plastics, Orangeburg, NY
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1994-1996	Phil Scalvin, James River Corp., Easton, PA
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PRIOR THERMOFORMERS OF THE YEAR

1982	William K. McConnell, Founding Division Member, McConnell Co.
1983	E. Bowman Stratton, Jr., Co-Founder, Auto Vac Corp.
1984	Gaylord Brown, Founder, Brown Machine
1985	Robert Butzko, Co-Founder, Thermtrol Corporation
1986	George Wiss, Pioneer Thermoformer, Plastofilm Corporation
1987	Dr. Herman Osters, Consultant
1988	Robert P. Kittridge, Founder, Fabri Kal Corporation
1989	Jack Pregont, Founder, Prent Corporation
1990	Ripley W. Gage, Founder, Gage Industries
1991	Stan Rosen, President, Mold Systems Corporation
1992	Samuel Shapiro, Founder, Sweetheart Cup Corporation
1993	John R. Grundy, Founder, Profile Plastics
1994	R. Lewis Blanchard, Researcher, Dow Chemical
1995	James L. Blin, Founder, Triangle Plastics
1996	John Griep, Founder, Portage Casting & Mold
1997	John S. Hopple, Founder, Hopple Plastics
1998	Lyle Shuert, President, Shuert Industries
1999	Arthur Buckel, Consultant, McConnell Company
2000	Dr. James L. Throne, Founding Division Member, Sherwood Technologies
2001	Joe Pregont, President, Prent Corporation
2002	Stephen Sweig, Technical Director, Profile Plastics
2003	Bill Benjamin, President, Benjamin Manufacturing
2004	Steve Hasselbach, Founder, CMI Plastics
2005	Manfred Jacob, President, Jacob Kunststoffechnick
2006	Paul V. Alongi, Founder, Maac Machinery
2007	Curt Zamec, President, Wilbert Plastics Services
2008	George Lueken, Founder, Mullinix Packages
2009	David Bestwick, President, Tran Pak Corporation
2010	Roger Kipp, Technical Director, McClarin Plastics
2011	Stephen Murrill, President, Profile Plastics

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Thermoformability of Radiation Cross Linked Polyamide 12

By Dietmar Drummer and Andreas Seefried, Institute of Polymer Technology, University of Erlangen-Nuremberg, Am Weichselgarten 9, D-91058 Erlangen/ Germany

Abstract

Most semi crystalline thermoplastics have a smaller processing range for thermoforming compared to amorphous thermoplastics, due to their narrow temperature window for the transition from viscoelastic to viscous material behavior. Otherwise they offer superior properties for applications like ductility or chemical resistance. Within this article modification of semi crystalline polyamide 12 by radiation cross linking with respect to its suitability for vacuum thermoforming is shown. Experimental thermoforming processing studies, thermo-mechanical and elongational rheometry were performed in order to point out the potential of cross linked semi crystalline thermoplastics for thermoforming.

Introduction

Besides injection molding, extrusion and blow molding, thermoforming is one of the most important techniques in polymer processing. With a high variety of process variants a heated thermoplastic sheet is three-dimensionally formed into a part by pneumatic and/or mechanical forces. Because of the large amount of process variants available, which are described e.g. by Gruenwald [1] or Throne [2], general statements about thermoforming are difficult without knowing the discussed process. Besides plug-assisted thermoforming, which is focused by several current research activities [3-5], vacuum thermoforming is one of the most common thermoforming variants. Here the preheated sheet is drawn over a male or into a female mold by applying a vacuum between sheet and mold. Therefore the available pressure for forming is limited.

Thus there are some requirements to the thermoformability of thermoplastics in vacuum thermoforming. First the material must supply sufficient stiffness during the heating step. The modulus up to forming temperature has to be high enough to avoid sagging or even destruction of the sheet. Hylton [6] states a modulus of about 10^6 Pa to be optimal for thermoforming. This is one of the reasons, why it is more difficult to vacuum thermoform semi crystalline polymers as Cormont [7] described. In contrast to amorphous thermoplastics they show a sharp drop in modulus at melting temperature. Thus the region of sufficient stiffness is narrow for semi crystalline polymers.

Besides stiffness during heating also elongational viscosity of the polymer during sheet stretching is of importance for its thermoformability. Takahashi et al. [8] and Münstedt et al. [9] found for thermoformable PP as well as Yamaguchi and Ken-ichi [10] for modified HDPE uniaxial elongational viscosities of 10^5 – 10^7 Pas at forming temperatures. According to Hylton [6] the ideal magnitude of elongational viscosity for thermoforming is 10^7 Pas. Additional to the amount of elongational viscosity also a strain hardening elongation behavior is important for thermoforming. As Münstedt et al. [9] showed by comparing a strain hardening and a linear non strain hardening PP, more homogenous wall thickness distributions are reached with strain hardening material.

Strain hardening was especially studied for polystyrene and polyolefins. At first strain hardening depends on the molecular weight of a polymer. Ramsey et al. [11] found for approximately monodisperse polystyrene with different molecular weight significantly stronger strain hardening for high molecular weight polystyrene. Besides average molecular weight also molecular weight distribution has an influence on strain hardening. Münstedt and Laun [12] described for polyethylenes a strain hardening effect of a broadening in molecular weight distribution and of high molecular weight components on elongational viscosities. Furthermore they showed the effect of chain branching which also increases strain hardening.

A potential approach in modifying polymers to meet the requirements of vacuum thermoforming is cross linking by high energy radiation. Since the first fundamental studies on the effects of irradiation on plastics by Charlesby [13] several advances where made in radiation processing of polymers. Charlesby's work was especially focused on polyethylene, which is radiation cross linkable by itself. In order to cross link technical thermoplastics like polyamides, cross linking agents are used to lower the required irradiation dose or to enable cross linking at all as Bernstein et al. [14] or Brocka et al. [15] demonstrated.

Radiation cross linking occurs by recombination of radiation induced polymer radicals and thus formation of covalent bonds between macromolecules. This process results in increasing molecular weight, chain branching and at higher degrees of irradiation to the formation of a molecular network. A well known effect of radiation cross linking is the improved strength of the material at elevated temperatures and rubber-elastic behavior above

melting temperature. Thus cross linking should provide increased stiffness for a polymer sheet during heating in thermoforming process. Moreover radiation treatment offers the potential to enhance strain hardening of a polymer. Chum [16] performed tensile tests at elevated temperatures with irradiated polyethylenes which showed increased strain hardening with cross linking. The general thermoformability of radiation cross linked polyethylene was demonstrated by Pausch and Wunsch [17] by deep drawing specimens below melting temperature.

Motivation

Semi crystalline thermoplastics normally have a smaller processing temperature window for vacuum thermoforming compared to amorphous thermoplastics, but have certain advantages for applications. Semi crystalline polyamide 12 for example, which is used for the investigations in this shown in this article, has superior electrical properties, high stress cracking resistance as well as excellent stability against greases, oils, fuel and alkaline substances [18].

Modifying technical semi crystalline thermoplastics, e.g. polyamides, with high energy irradiation has the potential to make these advantages accessible for vacuum thermoforming. This may result in novel applications for vacuum thermoformed parts.

Experimental

An overview of all investigations in this article is given in Table 1. PA12 films were fabricated via chill-roll extrusion and afterwards irradiated with high energy electrons. The influence of radiation treatment on thermoformability in general was investigated by experimental thermoforming studies. Digital image correlation was used to investigate strain distributions and modes of elongation in thermoformed parts. Rheological material behavior during thermoforming was characterized by oscillatory plate/plate measurements and unaxial elongational rheometry. Due to slippage of irradiated film specimens in the uniaxial elongational rheometer thinner films (0.3 mm) had to be used for these measurements.

Materials

A commercial radiation cross linkable Polyamide 12 (V-Rilsan-PA12-AECN 0 TL) compound produced by Plastic Technology Service, Adelshofen, Germany, was used for sample preparation. The compound has a content of 3.0 weight-% of the cross linking agent triallyl isocyanurate (TAIC) which allows optimal cross linking with an irradiation dose of 50 kGy.

Table 1. Experimental design; x: conducted experiment.

Material	PA12						
Irradiation dose [kGy]	0	15		33		66	
Film thickness [mm]	0.6	0.3	0.6	0.3	0.6	0.3	0.6
Experiments							
Thermoforming study	x		x		x		x
Digital image correlation			x		x		x
Plate/plate rheometry	x		x		x		x
Uniaxial elongational rheometry	x	x		x		x	

Film Extrusion

Films were fabricated from the cross linkable PA12 by flat film extrusion using chill-roll casting. The parameters of specimen extrusion are listed in Table 2. Using a single screw extruder, Collin E30M, with a 30 mm screw diameter and L/D-ratio of 25 and a coathanger die of 250 mm width in combination with a chill-roll, Collin CR136/350, films of 0.3 mm and 0.6 mm where processed with haul-off speeds of 2.4 m/min and 1.3 m/min.

Table 2. Parameters of film extrusion.

Parameter	Unit	Value
Temperature zone 1 (near hopper)	[°C]	235
Temperature zone 2	[°C]	245
Temperature zone 3	[°C]	250
Temperature zone 4	[°C]	250
Die temperature	[°C]	250
Chill-Roll temperature	[°C]	90
Screw rotation speed	[min⁻¹]	75

Electron-beam Irradiation

Electron-beam irradiation of extruded sheets was accomplished by Beta Gamma Service (BGS), Saal a.d. Donau, Germany, with a 5 MeV electron accelerator. Irradiation doses where set to 15 kGy, 33 kGy and 66 kGy. To excel a radiation dose of 33 kGy, the e-beam treatment was performed in repeated steps, each with a dose of 33 kGy, in order to keep thermal load low.

Thermoforming process studies

Thermoforming experiments, in order to analyze the general thermoformability of cross linked PA12, where performed using a vacuum forming machine, Berg Mini M3. Figure 1 shows the geometries of the modular male thermoforming molds for this study. The cylindrical, rounded aluminum inserts with an average surface roughness Rz of 14 μm provide areal draw ratios from 1.3 to 3.0 and thereby cover a wide range of draw ratios. Mold temperature was set to 70 °C, a usual value for PA12, for all experiments. Heating of the polymer film was achieved by an upper and lower bank of quartz radiant heaters. Film temperature was measured with thermocouples on the up- and downside of the specimen in combination with a pyrometer. PA12 films were dried 16 h at 70 °C in vacuum prior to thermoforming. The remaining water content was less than 0.15 weight-%.

In order to determine the strain distribution in thermoformed parts two different techniques were used. First a line grid of 10 mm spacing was drawn on the sheets. From the line distance measured after thermoforming in radial direction of the cylindric parts, the local strains in radial direction where calculated.

Areal draw ratio R_a	Height H [mm]
1.3	20
1.5	30
2.0	55
2.5	80
3.0	110
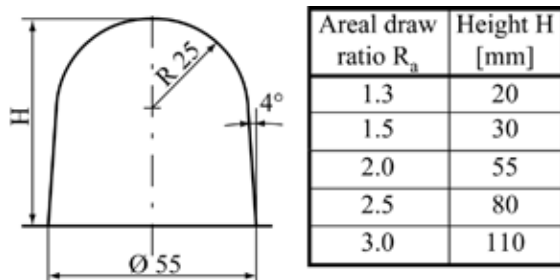
Figure 1. Mold geometries and areal draw ratios for thermoforming studies.

The second method of strain measurement used was digital image correlation [19]. A chaotic pattern of graphite speckles on PA12 sheets was simultaneously recorded with two cameras before and after thermoforming. Local deformations of the film were calculated from the images using the software Vic3D, Correlated Solutions, USA. Figure 2 illustrates the camera setup as well as the location of the evaluated measurement points. In order to improve image contrast, PA12 sheets were painted with a white acrylic paint before thermoforming. The average thickness of the painting layer was 20 μm. High temperature tensile tests indicated no influence of the painting on the elongational behavior of the PA12 films.
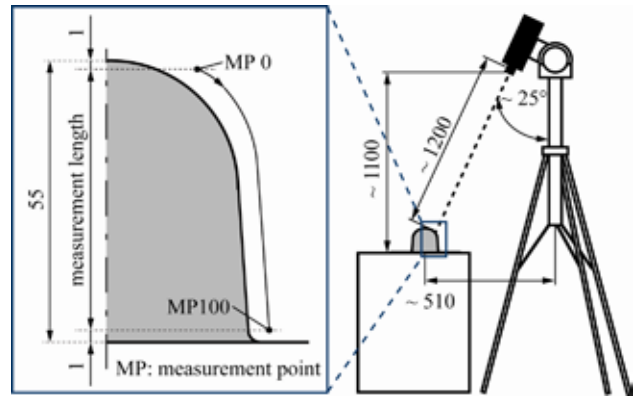
Figure 2. Camera setup and location of measurement points for digital image correlation.

Gel fraction analysis

Gel fraction analysis was used to determine the degree of cross linking achieved by irradiation. On the basis of DIN 16892 (Crosslinked polyethylene (PE-X) pipes - General requirements, testing) the irradiated films were boiled in a solvent (concentrated formic acid) for six hours, filtered (mesh size 0.12 mm) and then subsequently dried. The gel value results as the quotient of mass remaining after boiling and initial mass of the specimen.

Thermo-mechanical analysis

A Rheometer, AR2000, TA Instruments, was used to approximately characterize the stiffness of the specimens during heating step in thermoforming. Temperature sweeps with a plate/plate set up in oscillatory shear where performed with a frequency of 1 Hz, a strain of 0.2 % and a heating rate of 3 K/min.

Elongational viscosity measurements

Uniaxial elongational viscosity above the crystalline melting point was measured with an ARES-EVF, which is commercial Meissner type extensional rheometer. The ARES-EVF winds up the specimen on two cylinders instead of using the rotary clamps like the original Meissner [20] concept.

The specimens of 20 mm length and 10 mm width were cut from the extruded sheets, whereas the length direction corresponds with the extrusion machine direction. Their average thickness was 0.307 mm for irradiated and 0.543 mm for non irradiated samples. Due to the stiffness of cross linked specimens at the measurement temperatures thinner samples had to be used in order to avoid slippage of the films in the rheometer.

In order to take into account the thermal expansion of specimens during heating from room temperature to measurement temperature, their densities where measured. The densities at room temperature were measured using a

gas pycnometer Accu Pyc 1330, Micromeritics, according to DIN EN ISO 1183-3. The densities at higher temperatures where extrapolated from pvT-data measured at 200 bar and 400 bar with a pvT 100, SWO Polymertechnik. Table 3 shows the densities of PA12 with different doses for various temperatures.

Table 3. Densities of PA12 for various temperatures and radiation doses.

Temperature [°C]	Density [g cm^{-3}]			
	0 kGy	15 kGy	33 kGy	66 kGy
23	1.020	1.025	1.024	1.025
180	0.844	0.849	0.858	0.861
200	0.832	0.838	0.846	0.850
220	0.819	0.825	0.834	0.838
240	0.807	0.813	0.822	0.825
260	0.794	0.801	0.810	0.814

The testing was performed on an ARES-LS2, TA Instruments, under air atmosphere at different temperatures in the range of 180 °C to 260 °C with a hencky strain rate of 1 s^{-1}. The heating time for these measurements was 360 s. For evaluation, mean values of at least two matching measurements where calculated and are shown in the following.

Results and Discussion

Effect of Irradiation on Gel Fraction

The gel values for 15 kGy, 33 kGy and 66 kGy were found to be 47 %, 58 % and 53 %. Thus irradiation leads to the formation of cross links between the macromolecules. The lower gel value of 53 % for a dose of 66 kGy may be caused by radiation induced degradation or the general inaccuracy of the measurement technique.

Effect of Cross Linking on the Thermoforming Process

The temperature window which allows complete molding of the test geometries for different areal draw ratios is shown in Figure 3. The criterion for determining the lower temperature limit was precise molding of the mold geometry. The upper temperature limit was evaluated by ruptures in the sheet during forming process. Thermoforming experiments showed that radiation cross linked PA12 films offer very good thermoformability. The lower temperature limit rises with areal draw ratio while the upper limit is falling. The forming temperature window of irradiated PA12 film is, depending on the areal

draw ratio, 40 °C to 100 °C broad which shows the high process stability when using cross linked sheets.

In contrast non irradiated films could not be sufficiently thermoformed. It was not possible to heat non cross linked sheets above their crystalline melting temperature. Due to insufficient stiffness of the polymer excessive sagging occurs during heating and the film gets destroyed.
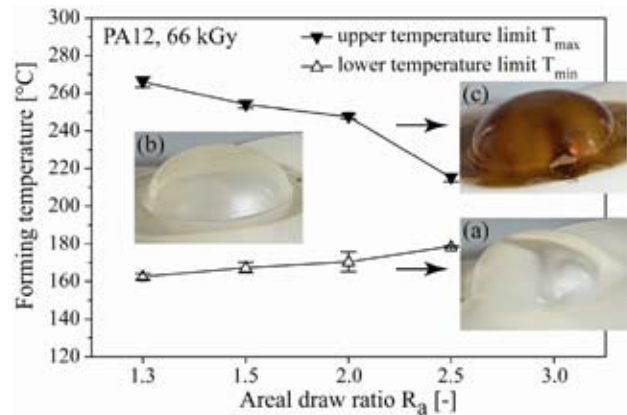
Figure 3. Forming temperature window of radiation cross linked PA12 for different areal draw ratios and examples of formed parts: (a) insufficiently formed part, (b) well formed part, (c) sheet rupture.

Figure 4 points out the influence of forming temperature on the resulting strains within the forming window for an areal draw ratio of 1.5. As the measurements show, there is no significant influence of forming temperature on the strain distribution.
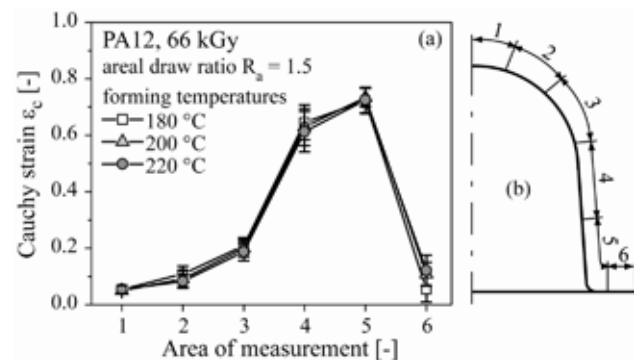
Figure 4. Influence of forming temperature on the strain distribution in thermoformed parts: (a) Cauchy strains of thermoformed cross linked PA12 sheet, (b) areas of strain measurement.

For the different mold inserts Figure 5 shows the yielded strains in thermoformed parts. As it is to be expected, the mean as well as maximum strains are higher for inserts with larger areal draw ratios. This leads to the explanation for the form of the lower temperature limit of

the forming window. In order to reach higher draw ratios with the constant atmospheric pressure in vacuum thermoforming, sheet temperature has to be elevated to increase deformability.
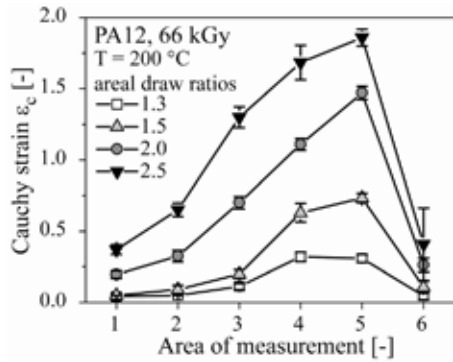
Figure 5. Cauchy strains in thermoformed sheets for molds with different areal draw ratios.

Figure 6 exemplifies the distribution and direction of maximum principal strain $\varepsilon_{1,c}$ and minimum principal strain $\varepsilon_{2,c}$ of thermoformed parts measured by digital image correlation.
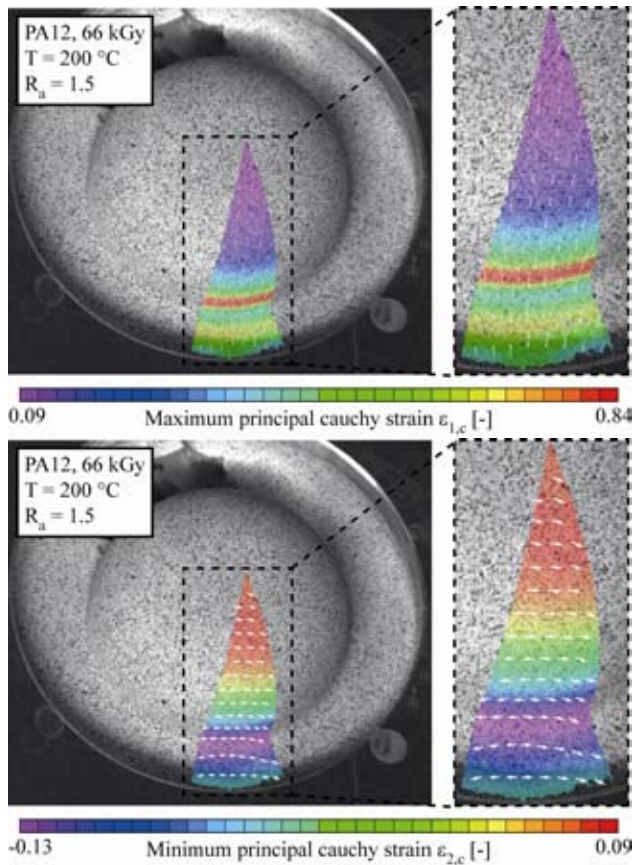
Figure 6. Distribution and orientation of maximum and minimum principal cauchy strains in a thermoformed part as results of digital image correlation measurements.

As usual for thermoforming with a male mold $\varepsilon_{1,c}$ is relatively low at the tip of the specimen and highest near its bottom. $\varepsilon_{1,c}$ is oriented in radial direction. Furthermore the values of $\varepsilon_{2,c}$ at the part bottom are negative.

Figure 7 shows the distribution of $\varepsilon_{1,c}$ and $\varepsilon_{2,c}$ in radial direction of thermoformed parts for different irradiation doses. For all doses areas of equibiaxial stretching (around measurement point 0) and planar stretching (around measurement point 60) can be found, but the corresponding strains $\varepsilon_{1,c}$ are low compared to those at the specimen bottom. The major deformation mode lies between uniaxial and planar elongation. Thus characterization of the extensional material behavior using uniaxial elongational rheometry seems appropriate. Moreover the peak value of $\varepsilon_{1,c}$ is smaller for an irradiation dose of 66 kGy than for lower doses.
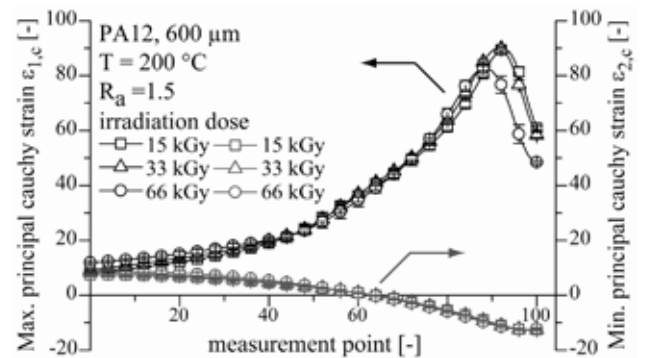
Figure 7. Radial distribution of maximum and minimum principal strains in thermoformed sheets with different irradiation doses.

Effect of Cross Linking on Shear Modulus

The storage and loss moduli of non irradiated and irradiated PA12 were measured over a wide temperature range, Figure 8.
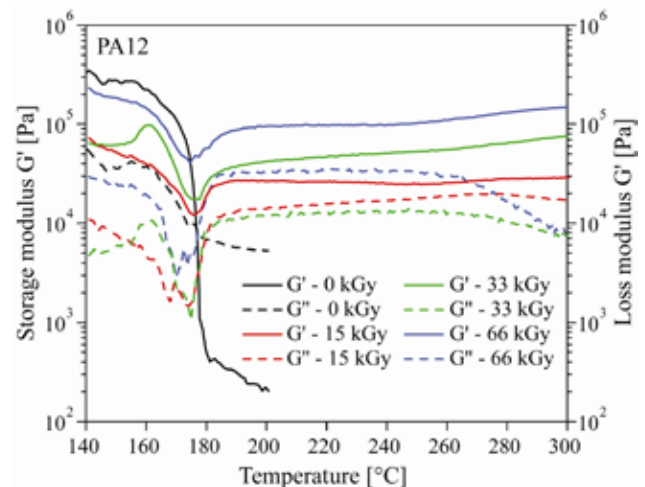
Figure 8. Temperature dependant storage and loss moduli of non cross linked and cross linked PA12.

Due to covalent bonds between macromolecules, irradiated PA12 shows much higher storage modulus above crystalline melting temperature than the non cross linked one. Higher irradiation doses lead to higher storage moduli. This indicates a higher degree of cross linking with rising dose and contradicts the gel values.

The cross linked melts behave rubber-elastic and show a nearly constant modulus up to about 250 °C. Even the storage modulus for a dose of only 15 kGy is sufficient to avoid excessive sagging during the thermoforming heating step. The reason for the excessive sagging of non cross linked PA12 sheet can be seen in the low modulus of less than 10^3 Pa.

Effect of Temperature on Elongational Viscosity

The elongational viscosity of polymer melts generally depends on temperature. For PA12 cross linked with 66 kGy there is only a minor influence of measurement temperature on the elongational viscosity, Figure 9. As can be seen from the constant grow in viscosity with testing time and the lack of a stationary level, strain hardening occurs. Viscosity slightly falls with rising temperature. The small influence of temperature on elongational viscosity gives the explanation for the independence of strain distribution in thermoformed parts from forming temperature, Figure 4. This indicates that the elongation behavior is dominated by stretching of the polymeric network and not by chain entanglements or sliding of the macromolecules.
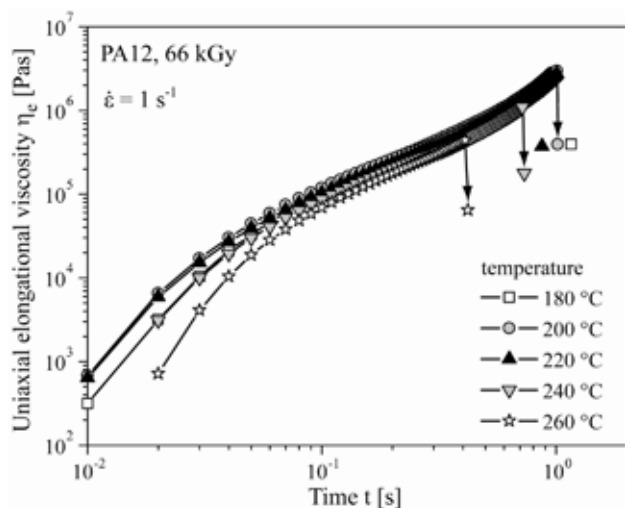
Figure 9. Transient uniaxial elongational viscosity of cross linked PA12 at different measurement temperatures; arrows indicating fracture of specimens.

Moreover a reduction of elongation at break with rising temperature can be observed. Whereas measurements in the temperature range from 180 °C to 220 °C show no effect of temperature on the resulting elongation at break, specimens fracture at lower strains for temperatures above 220 °C. This can be explained by thermal and thermo oxidative degradation effects at measurement temperature.

Effect of Irradiation Dose on Elongation Behavior

The elongational viscosities of PA12 without irradiation and irradiated with different doses is shown in Figure 10. Non irradiated PA12 has a low elongational viscosity of 10^3 Pas to 10^4 Pas. For the purpose of thermoforming this level of viscosity has to be seen as very low. As an effect of cross linking, irradiated samples show a 2 to 3 decades higher viscosity as a result of the deformation restraint by cross links.

With rising dose elongation at break falls. Specimens irradiated with 66 kGy have lower elongation at break than those treated with 33 kGy, although gel values of 58 % for 33 kGy and 53 % for 66 kGy, which is a measure of the amount of macromolecules cross linked, were detected. The elongational viscosity data as well as the storage moduli, Figure 8, indicate that a higher dose might affect the number of cross linked chains or the network density. This might lead to stronger strain hardening and a reduced ultimate elongation. The stronger strain hardening effect may explain the more homogenous deformation of sheets irradiated with 66 kGy compared to those with lower doses, Figure 7.
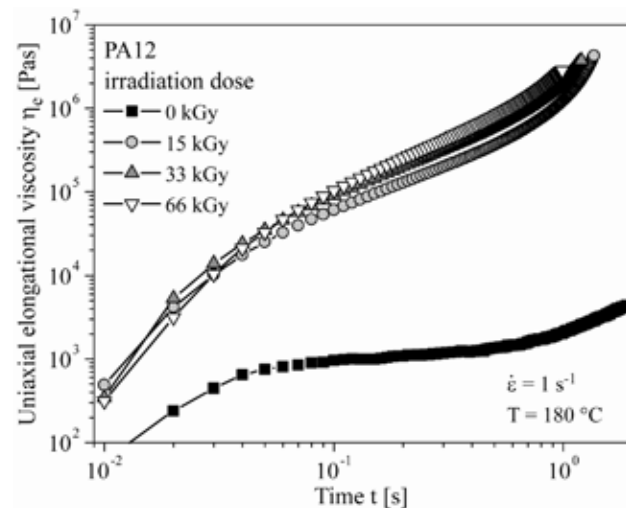
Figure 10. Transient uniaxial elongational viscosity of non cross linked and cross linked PA12 irradiated with different doses.

Conclusions

The results presented in this article show that thermoforming of radiation cross linked PA12 is generally possible. Irradiation enhances the processability of the polymer and grants an extraordinary robust vacuum

thermoforming process. This possibility to modify semi crystalline technical thermoplastics like PA12 offers the potential to make new materials available for vacuum thermoforming technical products like engine covers or components for noise protection.

The excellent thermoformability of the irradiated polymer is due to its modulus during heating and its elongational viscosity during sheet stretching. Cross linking greatly increases the modulus above melting temperature and allows the polymer to be heated without excessive sagging.

The elongational viscosity of PA12 cross linked with 66 kGy is only slightly influenced by temperature, but at higher temperatures lower elongations at break are reached due to degradation. Thus higher forming temperatures lead to smaller realizable draw ratios. The small influence of temperature clarifies the potential of cross linked thermoplastics for an extremely robust thermoforming process.

Lower doses lead to lower initial transient viscosities but similar ultimate viscosities are reached for a test temperature of 180 °C. Furthermore higher elongations at break result from smaller radiation doses which allow higher draw ratios. The use of low doses is particularly interesting for commercial applications, where lower doses are more efficient and might even allow recycling of the material if they are low enough.

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Control Your Destiny

Freetech Plastics Student Thermoformed Parts Competition – More Challenging in 2011

The Freetech Plastics Student Thermoformed Part Competition is designed to stimulate use of the thermoforming process in design and engineering schools. Finalists from 5 different schools submitted entries at the 2011 Industrial Designers Society of America Conference in New Orleans, LA.

1st place ($2,500): *Grayson Byrd* from Georgia Tech for the **Casper Chair**. This chair combines a plywood frame which is then over-molded with styrene sheet which holds the entire structure together. The judges admired the clever combination of materials and the use of a feature of thermoforming which is usually avoided but which in this case provides the means to hold the supporting structure in place without the need for fasteners or adhesives.

2nd Place ($1,500): *Jerrold Anchetta* from San Jose State. As part of a class project, he produced a bud vase that the judges found quite appealing. The vase required 2 different molds plus some fabrication and assembly.

3rd place ($1,000): *Zheyan Hong* from Auburn University. She spent time at construction sites looking for ways to make finishing concrete easier and came up with a rotatable kneeboard. It was formed in 2 parts: a base to lay on the concrete and the kneeboard which then rotates giving the finisher additional range of motion.

The purpose of the Freetech Plastics Student parts competition is to encourage college and university industrial design and engineering students to design and manufacture a product using the thermoforming process. The contest is judged by both senior industrial designers and thermoforming experts. The prizes are awarded on both design creativity and best use of process. The awards are announced in the design gallery during the IDSA National Conference. In 2012, they will become a regular feature of the IDSA conference in the materials and processes section program.

For further information about next year's competition and entry forms, go to www.freetechplastics.com.

Grayson Byrd from Georgia Tech for the Casper Chair - 1st Place

Zheyan Hong from Auburn University for the Rotatable Kneeboard - 3rd Place

From the Editor

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

- New materials development
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- Industry partnerships
- New or expanding laboratory facilities
- Endowments

We are also interested in hearing from our members and colleagues around the world. If your school or institution has an international partner, please invite them to submit relevant content. We publish press releases, student essays, photos and technical papers. If you would like to arrange an interview, please contact Ken Griep, Academic Programs, at:

ken@pcmwi.com or 608.742.7137

This year's Parts Competition saw a broad range of technically diverse heavy-gauge parts as well as some uniquely developed thin gauge pieces. We received parts from all around the United States, from a variety of industries. The judges for the competition were looking for unique design characteristics as well as how challenging the parts were to create in a production environment. There seemed to be more of a focus this year on heavy-gauge parts which was a change from last year where thin-gauge submissions seemed to dominate. The pressure forming category was probably the most contested. There were some very large pressure formed parts as well as some parts highlighting very challenging draws and undercuts. Secondary operations highlighting decorating and painting really helped to showcase some very attractive and eye-catching pieces. It was a privilege to be involved with all participants in this year's competition and I look forward to seeing what might be submitted at next year's conference. – Bret Joslyn, Chair, Parts Competition

Roll Fed – Industrial – Silver Award
Toyota Avalon Energy Absorber
Oakwood Energy Management

Roll Fed – Medical – Silver Award
HeartMate Package
TEQ

Roll Fed – Industrial – Gold Award
Bath Tub Protector
Amros Industries, Inc.

Roll Fed – Medical – Gold Award
Surgical Device Package
Perfecseal, a Bemis Company

Heavy Gauge – Vacuum Form – Silver Award
Exterior Fender
Minimizer

Heavy Gauge – Vacuum Form – Gold Award
ValuStair
LRM Industries Intl., Inc.

Heavy Gauge – Twin Sheet – Silver Award
Resistall Restroom Partitions
Spencer Industries

Heavy Gauge – Pressure Form - Silver
Pet Tag Engraver
Specialty Manufacturing Inc.

Heavy Gauge – Twin Sheet – Gold Award
Bariatric Headboard
Associated Thermoforming Inc.

Heavy Gauge – Pressure Form - Gold
DNA Imaging Machine
Freetech Plastics

Judges Award
CT Scanner Gantry
Productive Plastics, Inc.

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Roger Kipp
Councilor

Change + Innovation = A Bright Future

The big news since the ANTEC Council meeting is the announcement by SPE that Executive Director, Susan Oderwald, will be stepping down at the end of the year. The Society is extremely grateful for the leadership and expertise Susan has provided over the last 11 years. We are fortunate to have had the professional integrity and dedication to fiscal stability as embodied by Susan during a most difficult period in the history of SPE. We wish her the very best both professionally and personally.

SPE is actively seeking Executive Director candidates and has secured the services of Kellen Company to coordinate that effort. The new Executive Director will be charged with growing our organization, continuing to support global growth, expanding meaningful member benefits, and sustaining the fiscal stability Susan and her team have directed.

Our SPE President, Russell Broome, presided over an on-line leadership presentation on October 12th. The foundation of his message was to embrace change as an opportunity to grow. Continuous improvement inspired by change will help us to further expand our reach to plastics professionals in North America and around the globe. The key strategic objectives that President Broome will continue to focus on are:

- Membership
- Revenue
- Member groups

It all starts with membership. Revenues to support member value resources are created through member involvement and membership growth. The organization and functions of member groups should correlate with member needs. Council and Committees are re-thinking the member group structure. As we all know, membership growth provides the sustainability foundation on which Society activity is based.

In order to coordinate Council support for membership growth activities, President Broome re-established the Membership Committee that had been eliminated a number of years ago. This new committee is being chaired by Rich Bradley. In addition, the Executive Committee now has a VP focused on membership.

Sustainability of the Society further hinges on the continuing growth of student members and, perhaps more importantly, retention of those members after they enter the workforce. The Next Generation Advisory Committee and the Academic Outreach Committee are two new committees that will focus on value for the next generation of plastics professionals and to communicate the SPE value proposition to the academic community. In turn, the value of an academic alliance will be communicated to industry with SPE as the delivery conduit.

New programs are already surfacing from these committees with a new "University News" section featuring an academic institution that will premier in the November / December issue of *Plastics Engineering.* In addition, a Student Jobs Fair is being planned for the 2012 ANTEC in Orlando, as well as formation of "discussion groups" at student chapters. Free student SPE membership and a free student link to an AutoDesk Design and Simulation Software will provide further student value.

At last report, membership continues to grow and at the end of September 2011, SPE membership stands at 14,600 globally.

Financially, SPE is tracking ahead of last year's positive results with 2011 providing one of the most successful ANTEC events ever, as evidenced by attendance, technical content, and financial results. The budget work for 2012 is complete and will be voted on by Council in Barcelona. The budget forecasts a positive net balance while being somewhat conservative due to the ANTEC / NPE Orlando format (first ever Orlando NPE). This co-event will be a great opportunity to find the latest in plastics technology and commercially available materials, processes and equipment at one venue. I hope you will attend.

SPE is evolving. Innovation, creation, communication and commercialization of meaningful ideas outline the path to our future success. That is the approach to change that Council is focused on in the governance of SPE.

If you have any comments or ideas relating to the continuous improvement of SPE, please email me at rkipp@mcclarinplastics.com.

Executive Committee
2010 - 2012

CHAIR

Ken Griep
Portage Casting & Mold
2901 Portage Road
Portage, WI 53901
(608) 742-7137
Fax (608) 742-2199
ken@pcmwi.com

CHAIR ELECT

Phil Barhouse
Spartech Packaging Technologies
100 Creative Way, PO Box 128
Ripon, WI 54971
(920) 748-1119
Fax (920) 748-9466
phil.barhouse@spartech.com

TREASURER

James Alongi
MAAC Machinery
590 Tower Blvd.
Carol Stream, IL 60188
(630) 665-1700
Fax (630) 665-7799
jalongi@maacmachinery.com

SECRETARY

Mike Sirotnak
Solar Products
228 Wanaque Avenue
Pompton Lakes, NJ 07442
(973) 248-9370
Fax (973) 835-7856
msirotnak@solarproducts.com

COUNCILOR WITH TERM ENDING ANTEC 2010

Roger Kipp
McClarin Plastics
P. O. Box 486, 15 Industrial Drive
Hanover, PA 17331
(717) 637-2241 x4003
Fax (717) 637-4811
rkipp@mcclarinplastics.com

PRIOR CHAIR

Brian Ray
Ray Products
1700 Chablis Avenue
Ontario, CA 91761
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