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Modeling Warpage and Shrinkage in a Thermoplastic Blow Molded Part using BlowView

NRC: Zohir Benrabah and Anna Bardetti AIP: Geoff Ward

33rd Annual Blow Molding Conference October 2-4, 2017 Chicago, IL, USA







Overview

- > Who are we?
 - NRC
 - SIGBLOW consortium
 - BlowView Software
- > Objectives of warpage model development
- > Understanding shrinkage and warpage in blow molding applications
- Assessing the current cooling/warpage numerical tool available in BlowView based on a case study from Agri-Industrial Plastics (AIP)
- > Validation and comparison with experimental results
- Conclusion and future work



NRC SIGBLOW/SIGFORM/SIGSuBM: Industrial R&D Groups

- Established in 1992
- Blow molding simulation research consortium, led by NRC: Development of in-house engineering software (BlowView) dedicated to simulate Polymer Forming Processes
- Small membership base select group of OEMs, Automotive, resin manufacturers, packaging and suppliers, such as:
 - Ford Motor Company
 - Kautex Textron
 - Plastic Omnium
 - TI Automotive
 - ABC Group
 - The Coca-Cola Company
 - AMCOR
 - Graham Packaging
 - Agri-Industrial
- Meet semi-annually
- Members provide input to govern software development (New functionalities, capabilities)

Plastics

Plasticade

 \circ DSM

 \circ YAPP ○ Walbro

Silgan Plastics

Consolidated

• Conti-Tech

o Trinseo



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NRC BlowView software capabilities >>



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Objectives of Warpage Model Development

Background

- The shrinkage and warpage have been a big concern in the blow molding applications.
- For PFT in particular, poor dimensional stability due to warpage and shrinkage causes problems in:
 - > Assembling the fuel tank components (tolerance issue)
 - Improper location and/or fitting of components (i.e. fuel line inside tank groove)
 - Increase tank strap tension/stress
 - Increase strap bolt force
 - Increase tank shell stress
 - Decrease plastic welds quality/strength
 - > Erratic fuel volume level indication issues, due to
 - Changes in float location and/or orientation





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Objectives of Warpage Model Development

Background

KAUTEX-TEXTRON/FORD MOTOR/NRC (2013)

Usman M., Ahmad S., Benrabah Z., Atsbha H., A Plastic Fuel Tank Deformation in the Post Blow Molding Phase due to Material Shrinkage/ Warpage. SPE: Annual Blow Molding Conference, 8-9th October 2013, Atlanta. GA, USA

P.O/FORD MOTOR/NRC (2016)

Usman M., Ahmad S., Siddiqui S., Benrabah Z., Bardetti A., Mir H., Lempicki J., Kulevski J., Masse H, Plastic Fuel Tank Deformation in the Post Blow Molding Phase: Warpage and Shrinkage Tolerance Issue. SPE: Annual Blow Molding Conference, 3-5th October 2016, Atlanta. GA, USA





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Objectives of Warpage Model Development

ACTIONS

- Since tolerance issue due to warpage deformation is decisive quality criterion for part acceptance, an increasing attention is paid to part warpage in the early stages of product design.
- > Therefore, part warpage and tolerance issues need to be controlled and optimized using an accurate and suitable prediction tool using BLOWVIEW software

1. Benrabah Z., Mir H., Lempicki J., Bardetti A., Ahmad S., Siddiqui S., Usman M., **Contribution to Warpage Analysis Using BlowView Software**, 74th Annual technical conference of the Society of Plastics Engineers (ANTEC 2016); the plastics conference, 23rd-25th May 2016, Indianapolis, IN, USA

2. Benrabah, Z., MIR, H., Zhang, Y., 2013: "Thermo-Viscoelastic Model for Shrinkage and Warpage Prediction during Cooling and Solidification of Automotive Blow Molded Parts". SAE International Journal of Materials and Manufacturing, Volume 6, Issue 2, pp. 349-364.

3. Z. Benrabah Z., P. Debergue, R. DiRaddo, " Deflashing of Automotive Formed Parts: Warpage and Tolerance Issues". SAE 2006 Transactions Journal of Materials and manufacturing, Mechanical System: 493--501p

4.P. Debergue, H. Massé, Thibault F., Diraddo, " Modelling of Solidification Deformation in Automotive Formed Part ", SAE 2004 . Transactions Journal of Materials and manufacturing, Mechanical System: 112(5), 2004



Understanding Shrinkage and Warpage in Blow Molding

Warpage Causes ? Why does it occur

Process-induced Residual Stresses are the main cause of part warpage

- > Thermal-Induced Residual Stresses:
 - Differential shrinkage
 - Inhomogeneous cooling conditions
 - Uneven Part Temperature (across the thickness and over the part)
 - Uneven Part Thickness (~ 3 10 mm)
 - Inhomogeneous materials across the part thickness (up to 6-7 layers with varying properties)
- > Flow-Induced Residual Stresses :
 - Extrusion rate
 - Shear rate
 - Material viscosity
 - Shear & normal stresses
 - Melt temperature, Head pressure



Process prediction in BlowView : From Extrusion to Warpage Prediction

Process prediction in BlowView:

Extrusion
Pre-Blow
Inflation
Cooling in the Mold
Cooling after Ejection:

Air
In Shell Cooling
Underwater
<lu>Others.



Warpage Prediction Model in BlowView

Warpage analysis performed on the Part CAD vs the inflated parison



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Part CAD Mesh

AIP Validation Case General Information

Material:	Marlex HXM 50100
Total Mass Flow:	3733 Kg/hr
Extrusion Time:	7.0 sec
Cooling In-Mold:	180 sec
Total Shot Weight:	6.9 Kg
Tank Weight :	3.6 Kg
Flash Weight:	3.3 Kg





AIP Validation Case Material Data

Warpage Model

nogy o	well Th	ermal	Physical	Warpage	Slip	Mechanical	Absorptivity	Crystallinity	Molecular C 1
ner Const	ants							View Gra	iph
lumber of re	elaxation tim	nes	5	•					
		1 22	323 - 93						
g((MPa)	1	(sec)	No	ormalized Y	'oung's modulus			
1 0.06232	926	1		4	37.579	MPa			
2 0.40221	775	3.6594							
3 0 26434	448	304 310	06	Po	iisson's Ra	tio			
5 0.20434		504,513		0.	47				
4 0.18343	917	24458.9	976						
5 0.08766	935	146601	96						
Reference C1	e temperatu	ire	24.04 50000	'n					
C2			-211790	°C					
Solidificati	ion tempera	ture	109.95	°C					
Properties fr	om another	material.	. Prop	erties from	HDPE L	upolen 4261/	A are being us	ed.	

Linear Expansion Coefficients

	Physical V	/arpage Slip Med	chanical Absorp	tivity C	rystallinity	Molecula
onstant Linear/exponential	1					
Density constant						
Density (forming temp)	746	Kg/m³				
Density (Solid state)	945	Kg/m³				
Linear expansion co	efficients					
Liquid phase	0.0007969					
Solid phase	0.0005872					
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Properties from another ma Transition temperature (Tg) Conductivity forming temp	0 0.23	erties from HDPE Lu	polen 4261A are	being us	ed.	



AIP Validation Case Results - Parison Extrusion and Pre-Blow

End of Extrusion



End of Pre-Blow



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AIP Validation Case Results - End of Inflation

Lower Shell



Upper Shell

File Edit Simulation Display	Tools Help	Y 17 2 Y			.	100	99
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15 - Extrusion 15/30 (4.12 s)							
16 - Extrusion 16/30 (4.26 s)				-			
17 - Extrusion 17/30 (4.39 s)							
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20 - Extrusion 20/30 (4.99 s)						inic	:к(тт)
21 - Extrusion 21/30 (5.19 s)				n l	Ser.		150
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24 - Extrusion 24/30 (5.72 s)			1				
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20 - Extrusion 20/30 (3.92 s)							13.3
28 - Extrusion 28/30 (6.32 c)					and and		
29 - Extrusion 29/30 (6.45 s)							
30 - Extrusion 30/30 (6.65 s)				100			120
Parison Recoiled (6.85 s)				and the second	Long L		12.0
1 - Pre-Blow 1/7 (7.05 s)							
2 - Pre-Blow 2/7 (7.25 s)							
3 - Pre-Blow 3/7 (7.45 s)							10.5
4 - Pre-Blow 4/7 (7.65 s)							10.0
5 - Pre-Blow 5/7 (7.85 s)							
6 - Pre-Blow 6/7 (8.35 s)			112				00
7 - Pre-Blow 7/7 (8.85 s)							9.0
8 - Mould Group - Closing 1/5				-			1 C C T C
10 - Mould Group - Closing 2/5				A.			
11 - Mould Group - Closing 3/5							76
12 - Mould Group - Closing 5/5							1.0
13 - Pressure 1/5 (13.85 s)							
14 - Pressure 2/5 (15.85 s)				-			1000 000
15 - Pressure 3/5 (17.85 s)			T	C _ 1 / 1	-		60
16 - Pressure 4/5 (19.85 s)				S. 5 A.	100		0.0
17 - Pressure 5/5 (21.85 s)					Contraction of the local distance of the loc		
18 - Cooling In-Mould 1/1 (20:				~			
19 - Cooling Out-of-Mould (2h)			- Van Mar				4.5
20 - Cooling Out-of-Mould (2hi				-	A PR		
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23 - Cooling Out-of-Mould (2h							20
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AIP Validation Case Thickness Comparison with Measured Data



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AIP Validation Case Warpage Simulation

- Two warpage simulations were considered:
- > Warpage on Inflated Parison
- > Warpage on Part CAD



Warpage on Inflated Parison

Warpage on CAD Part



AIP Validation Case Warpage Results

Warpage Prediction on Inflated Parison (with flash)



Warpage Prediction on Part CAD



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Note: NormU is the total magnitude of the displacement in mm

AIP Validation Case Warpage on part CAD Results

Average Temperature at end of Cooling-in-Mold





Warpage Prediction





AIP Validation Case Warpage on part CAD Results vs Experimental





Note: Distance is the normal magnitude of the displacement between meshes

AIP Validation Case Thickness Comparison with Measured Data





AIP Validation Case Error between Warpage Simulation and Actual Part Scan



Average Error: 2.05 mm and STD : 1.76 mm

Note: Error Distance is the normal magnitude of the displacement between meshes RC-CNRC

AIP Validation Case Error between Warpage Simulation and Actual Part Scan



Y Position (mm)

AIP Validation Case Error between Warpage Simulation (on inflated parison) and Actual Part Scan



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Conclusion and Future Work

- This work was intended to validate the warpage prediction using BlowView for an industrial part provided by Agri-Industrial Plastics
- The predicted thickness are in good agreement with the measured data provided by AIP
- > Two warpage simulations were considered:
 - The results show that the Warpage on CAD Part improves the warpage prediction, due to better mesh quality
 - The predicted warpage results are in relatively good agreement with the measured data provided by AIP
- > Take into account a cooling channel in the mold
- > Sensitive analysis on material properties (i.e., L.E.C, HTC, etc...)

