Deniz Ufuk Erbulut

AN INTELLIGENT PROCESS DESIGN FOR STRETCH BLOW MOULDING

Microwave Processing of Plastics

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By

Deniz Ufuk Erbulut

BEng, M.I.T., GDip (AMT)

Submitted in total fulfilment of the requirements of the degree of Doctor of Philosophy

October 2008

The University of Melbourne

ABSTRACT

The growing worldwide demand for single-serve PET containers has led to research into improving the stretch blow moulding process and developing high performance intelligent design tools. Economical and fast manufacturing of PET containers with high functional performance (low permeability and high strength) properties through the injection stretch blow moulding process are the main goals of the research. In the stretch blow moulding process, the strength, accuracy and the performance of the PET bottle depends greatly on the proper design of the PET preform and precise determination of blowing temperature.

The aim of this research work is to develop a highly efficient process environment for the production of PET bottles. The ingenious process design carried out includes optimization of both the preheating stage of the process and PET preform shape.

Optimization of the preform design is carried out to produce PET bottles with a more uniform thickness distribution and better properties using the B-SIM blow moulding simulation software. The main objective is to re-design an existing preform and come up with a new design that will give a uniform wall thickness distribution and better barrier properties for the blown bottle. B-SIM is then used to simulate the blow moulding of the various perform models to come up with the optimized preform geometry. The newly designed preform is evaluated based on its thickness distribution and barrier properties of bottle. The simulation and mathematical calculations indicate that the new preform design responds better than the existing preform design in terms of barrier properties and uniform thickness distribution. Another remarkable outcome is that material usage is reduced in the new design.

A novel methodology is developed to measure the dielectric properties of polymeric materials for microwave heating. This method can be applied to any form of material without needing to consider the shape or dielectric property of the dielectric sample. All other existing measurement methods have limitations in regards to the geometry of the sample. Dielectric properties of the PET preform are successfully determined using the developed novel method. Measurement is carried out on the PET preform as it is used in the industry without any change to its shape.

The novel method is applied to other known polymers and the results are compared with published data. The results verify that the novel technique is in good agreement. Three important outcomes are drawn from the developed measurement method:

- the dielectric sample can be used in the "as is" form,
- any liquid and solid material can be measured and
- no complex mathematical calculations are required.

The heating of the PET preform is conducted using microwave. Several microwave heating applicators are investigated to achieve efficient energy usage and desirable temperature profile. Dielectric properties of the PET preform, measured in this thesis, are used for designing microwave applicators. The investigations show that a cylindrical resonant cavity is the best option over other heating applicators.

Studies into heat transfer were conducted by measuring temperature rise and temperature distribution during heating. Direct temperature measurement indicates that temperature rise is higher on the inside rather than the outside wall of the preform. In fact, the desirable temperature profile needed on the preform for the stretch blow moulding process cannot be achieved using current technology i.e. infrared heating. A remarkable achievement is presented showing that PET preforms can be heated at least 5 times faster and more efficiently by microwave power.

Free blowing of the PET preforms is carried out after microwave heating to validate the technology based on two objectives i.e. uniform temperature profile along the preform and efficient heating. The results indicate that the designed cylindrical cavity works perfectly and validates the microwave heating for uniform and efficient heating.

Microwave heating and conventional heating are then compared based on mechanical strength and thickness distribution of the end product (bottle). ANSYS Finite Element Analysis (FEA) software and B-Sim blow moulding simulation software are used for structural analysis and thickness distribution analysis respectively. The comparative study concludes that microwave heating is an appropriate replacement for infrared heating.

DECLARATION

This is to certify that

i. The thesis comprises only my original work.

ii. Due acknowledgement has been made in the text to all other material used.

iii. The thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Deniz Ufuk Erbulut

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NOMENCLATURE

PP	polypropylene
PVC	polyvinyl chloride
AN	acrylnitrile
PS	polystyrene
PC	polycarbonate
PA	polyamide
PET	polyethylene terephthalate
PAN	polyacrylonltrile
PETP	terephthalate Polyester
PA-6	nylon 6
PTFE	teflon
T_g	glass transition temperature
D_1	bottle diameter
D_2	preform diameter
L1	bottle length
L2	preform length
BUR	blow up ratio
DLC	diamond like carbon
A	axial stretch ratio,
H	hoop ratio
S	second
IR	infrared
^0C	degree celsius
FEM	finite element method

CAD	computer aided design
FE	finite element
CO_2	carbon-dioxide
O_2	oxygen
T1	position and timing of the stretch rod
T2	the pre- blow and final blow pressures
FDTD	finite-different time-domain
BEM	boundary-element-method
FDM	finite-difference-methods
FDFD	finite-difference-frequency-domain
2D	two dimensional
3D	three dimensional
S/C	short circuit
ISBM	injection stretch blow moulding
SBM	stretch blow moulding
700W-bottle	bottle created using PET preform heated with 700Watts power output of microwave
800W-bottle	bottle created using PET preform heated with 800Watts power output of microwave
900W-bottle	bottle created using PET preform heated with 900Watts power output of microwave
infrared-bottle	bottle created using PET preform heated with infrared
actual-bottle	physical bottle created by ISBM
temp	temperature
MPa	mega pascal
KPa	kilo pascal
ms	millisecond

ml	millilitre
mm	millimetre
gr	gram
W	watt
N	Newton
Nmm	Newton millimetre
EM	electromagnetic
E-field	electromagnetic field
E_x	electric field in x direction
H_y	magnetic field in y direction
TEM	electric magnetic mode
TE	transverse electric
TM	transverse magnetic
Z	direction of wave propagation
GHz	Gigahertz
ε_0	free space permittivity (8.854×10^{-12} F/m)
μ_0	free space permeability (1.256×10^{-6} H/m)
f	frequency
Δf	frequency separation at the half power points.
λ	wavelength
c	viscosity
P	incident power
α	attenuation content
D_p	penetration depth
ε'	dielectric constant

ε''	dielectric loss factor
j	current density
ω	angular frequency
ε_0	permittivity of free space (8.85×10^{-11} farads/meter)
σ_e	electronic conductivity
σ_i	ionic conductivity
$\tan\delta$	loss tangent
Q	quality factor
U	average total energy stored over a cycle
VSWR	voltage standing wave ratio
S-parameters	scattering parameters
S_{11}	reflection coefficient from port 1 to port 2
NA	network analyzer

LIST OF PUBLICATIONS

From this research, the following publications have been generated.

Journal Papers:

D.U. Erbulut, S.H. Masood, H. Senko, K. Davies, (2008) *Preheating of Poly(Ethylene Terephthalate) Preform for Stretch Blow Moulding Using Microwave.* Journal of Applied Polymer Science, 112(3):1670-1679

D.U. Erbulut, S.H. Masood, V.N. Tran and I. Sbarski, (2008) *A Novel Approach of Measuring the Dielectric Properties of PET Preforms of Stretch Blow Moulding.* Journal of Applied Polymer Science, 109(5):3196-3203

Conference Papers:

D.U. Erbulut, S.H. Masood, S. Vasa, (2009), *Structural Strength of Blow Moulded PET Bottle Using Microwave Pre-heated Preforms,* International Annual Technical Conference, Society of Plastic Engineers, Chicago, USA to be held on 22-24 June. (Accepted).

D.U. Erbulut, S.H. Masood, (2008) Dielectric Properties of Polyethylene Terephthalate (PET) Preforms. 16th Polychar World Forum on Advanced Materials, Lucknow, India.

D. U. Erbulut, S. H. Masood, I. Sbarski, (2007) *Comparative Study of Simulation Software for Stretch Blow Molding.* International Annual Technical Conference, Society of Plastic Engineers, Ohio, USA, 2165-2168. (**Winner of the scholarship award**)

D.U. Erbulut, S.H. Masood, I. Sbarski, (2007) *A Simulation study of stretch blow moulding of PET bottle using B-Sim.* World Conference on Integrated Design & Process Technology, SDPS, Antalya, Turkey, 488-491.

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