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Original Article

A novel simulation of bottle blow molding to determine suitable parison thicknesses for die shaping

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Abstract

This study proposes the use of an artificial intelligence (AI) method to determine suitable parison thicknesses at the horizontal cross-section of a bottle in die shaping. The cross-section of the bottle was subjected to blow molding simulation by the finite element method (FEM) in order to achieve more accurate results than by simulating the full bottle shape. The absolute average error in cross-section simulation was 17.02% relative to experimental data. Subsequently, an artificial neural network (ANN) was trained using the FEM data on cross-section blow molding. The ANN was in good agreement with the experimental data for more complex shapes of two implementable bottles, and this model had an absolute average error of 15.66%. Eventually, a genetic algorithm (GA) was developed to determine the uniform perimeter thickness of a bottle so that it passes the top load testing. The predicted parison thickness by the AI model had an absolute average error of 4.18% from the desired thickness.

Keywords: simulation, bottle, blow molding, parison, die shaping

1. Introduction

Lubricant oil bottles are attractively colored and shaped. There are many complex shapes of lubricant oil bottles launched in the automotive market. These bottles are produced with extrusion blow molding. There are two extrusion methods, namely the die-gap programming and the die shaping, that have been used to prepare plastic tubes or parisons for blowing lubricant oil bottles. A suitable parison thickness is important for forming the lubricant oil bottles by inflation to completely contact the surface of the bottle mold cavity. Parison thickness is regulated by the die extrusion to obtain bottle thickness matching the design. However, blow molding theory is employed to calculate the initial thickness of parison (Lee, 1998), and trial and error method is often used to adjust the die gap for complex shaped bottles. The thickness of parison is difficult to control properly on forming lubricant oil bottles, which principally have a reflective symmetry in shape. This often relies on the experience of die makers, to shape the extrusion die. Consequently, significant amounts of plastic, cost and time are lost in making parison settings.

Currently, computer aided engineering (CAE), which involves the finite element method (FEM) to simulate the extrusion blow molding process, is used in engineering design to reduce the need for trial and error runs to set up the parison thickness (Marcmann, Verron, & Peseux, 2001). Nevertheless, the FEM modeling is started by preparing an extrusion blow molding model, which is difficult with complex shaped bottles. Particularly, there are limitations to optimizing the parison thickness for the desired design thickness of bottle. Also simulation time is consumed in trial and error testing to

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prepare the blow molding model, and to determine the suitable thickness of parison.

Optimization techniques have been applied with finite element analysis (FEA) to find an appropriate parison thickness for hollow products (Biglione, Bereaux, Charmeau, Balcaen, & Chhay, 2016). Gradient-based optimization has been proposed to determine the optimal bottle thickness with required resistance to two types of loading, top loading and internal pressure (Gauvin, Thibault, & Laroche, 2003). The parison thickness has been controlled by parison programming or by die gap opening. The variable thickness of parison has forced researchers to run FEA multiple times for the optimization of each shape of a bottle. The optimal die gap programming of an extrusion blow molding process could use a neural network to suggest the uniform part thickness after the parison inflation. Taguchi's method was applied to reduce the number of die gap runs with FEA used to train an artificial neural network (ANN). The parison thickness relation to cross section area was predicted by the neural network. A genetic algorithm (GA) was then applied to search for the optimal parison thickness (Jyh-Cheng, Xiang-Xian, Tsung-Ren, & Thibault, 2004). The fuzzy neural-Taguchi network with GA (FUNTGA) was established to help the parison programming of bottles with axisymmetric shape. Huang and Huang (2007) used POLYFLOW 3.10 software to prepare the blow molding data of bottles for the ANN, which was combined with GA to find the optimal parison thickness. Yu and Juang (2010) proposed fuzzy reasoning of the prediction reliability to evolve the ANN training to guide the GA searching. A small number of training runs was performed using Taguchi's orthogonal array. This methodology balances reliability and optimality for the FEA of extrusion blow molding process. Even though AI methods (ANN, fuzzy logic and GA) were used to optimize the parison thickness for extrusion blow molding process, the scope was limited to axisymmetric bottle shapes. Otherwise, the previous AI method did not perform in choosing a suitable parison from die shaping (Lee, 1990) in the blow molding process. Unfortunately, the AI could not be trained when the FEA could not prepare the training samples for complex bottle shapes, such as rectangular shaped bottles, bottles with a single handle, or bottles with two handles.

This study proposes novel simulation techniques for the die shaping of complex shaped bottles in a blow molding process. The horizontal cross-section of bottle shape was reasonable to simulate using FEM, instead of simulating the full shape of bottle in blow molding with a shaping die. The ANN and GA were applied to optimize parison thickness an obtain a uniform cross-section thickness of the bottle, such that satisfies the top load specifications (Suvanjumrat & Chaichanasiri, 2014). The flow chart of the novel approach used to determine suitable parison thickness for die shaping is shown in Figure 1.

2. Experiment

The lubricant oil bottle is shown in Figure 2a. This lubricant oil bottle has a reflection symmetric shape. It was produced with high density polyethylene (HDPE) grade 6140B from SCG Plastic Company Ltd. Extrusion blow molding was employed to produce the lubricant oil bottles and the production conditions were set for the parison outer diameter of 52 mm, initial temperature of 180 °C, die gap opening of 150 mm, die closing speed of 2.2 mm/sec, blow-up pressure of 1 bar, and blow-up time of 0.3 sec. The blow molding machine had three shaping dies without the parison programming. The five parisons that were extruded through the shaping dies had been selected by thickness (Figure 2b). The twelve columns (A to F) around parison perimeter were assigned as the reference line for measuring parison thickness. These were started from A at 15 degrees from the front parting line of bottle in the counterclockwise (CCW) rotation direction, and started from A at -15 degrees from the front parting line of bottle in the clockwise (CW) direction. The thickness of parison at every 20 mm along its height were assigned points for thickness measurement. The thickness gauge model MiniTest 7200 FH of ElektroPhysik (±3 µm resolution) was used to measure the parison thickness at the reference points. Figure 3a shows the average thickness profile of parisons to make lubricant oil bottles. The parison was a circular hollow cylinder with outer diameter 52.00 mm and did not have uniform thickness around its perimeter. The thickness of parison increased from top to bottom due to gravity. The relation of parison height and thickness was approximated as

$$t_p = ah + b_{A-F} \tag{1}$$

where t_p is the parison thickness, h is the parison height, a is 2.492×10^{-3}, and b_{A-F} is a constant dependent on the initial thickness of parison forced through the die gap.

The label area on bottle surface at the bottle height of 115.00 mm had the maximum blow ratio of parison along the bottle height, and caused an unsuitable die shape that did not give uniform thickness around the bottle perimeter. Fifteen bottles were sampled and measured for wall thickness. The bottles were also assigned column positions according to the parison columns. Figure 3b shows the average thicknesses of the lubricant oil bottles along the bottle height. The die shaping had been performed to control the parison thickness to form the complete shape of bottle; therefore the parison thickness at bottle corner was more than at other columns in the parison tube. The column of parison which was formed to bottle wall was thicker than other parison columns. The parison thickness obtained by die shaping depended on the experience of die maker. The shaping needed to obtain the final shape of die gap affected time and cost of setting up the extrusion blow molding process of lubricant oil bottles.

3. The Bottle Blow Molding Models

The 3D model of a 1.0 liter lubricant oil bottle shown in Figure 4 was used to create a finite element model of the blow molding process. The full shape of bottle would be created by starting at the mold clamping on parison until the parison was blown to the bottle shape. The cross-section shape of bottle would be investigated in a horizontal section at 115. 00 mm height from the bottom. The bottle mold did not clamp on parison to blow the bottle wall at the height of 115.00 mm; therefore, the clamping process was not considered in the finite element model. The bottle blow molding simulation was performed using a personal computer with Core-i5 CPU (3.3 MHz) and 4 GB DDR III SDRAM memory.

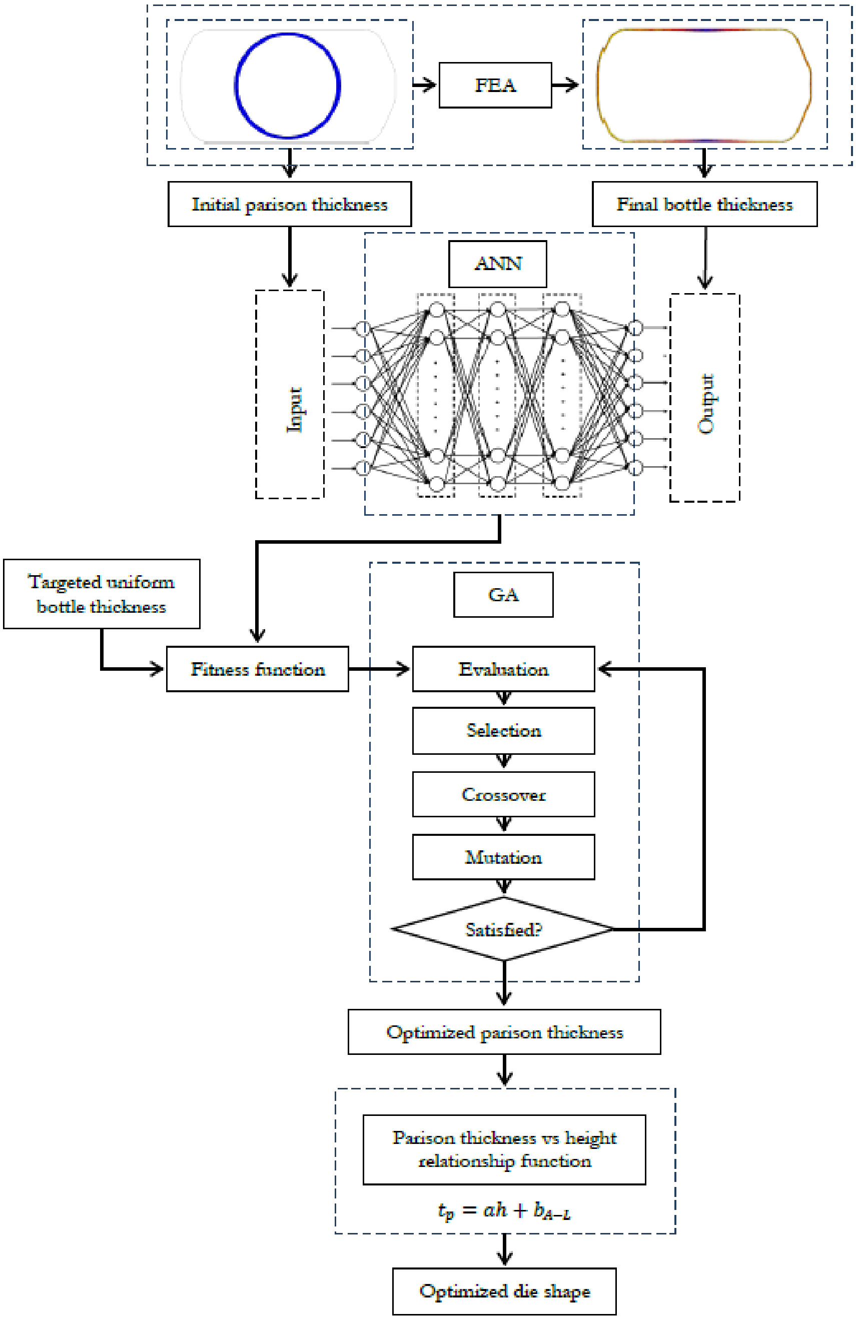
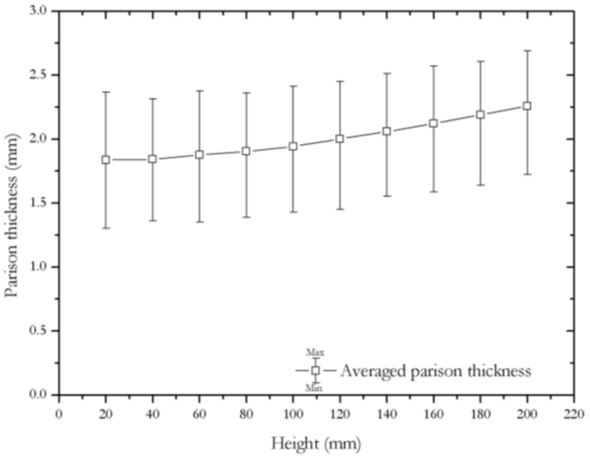


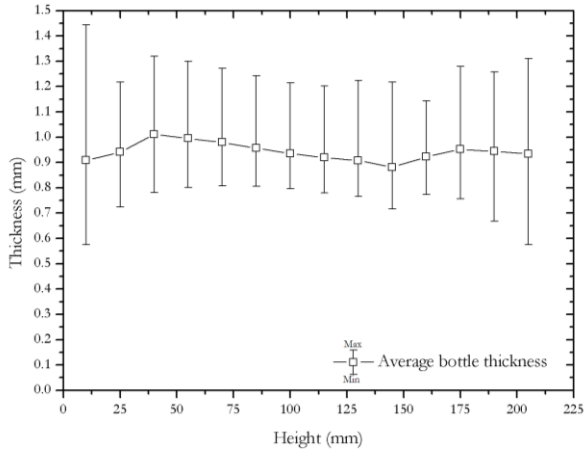
Figure 1. The parison thickness optimization flow chart.

(a) (b)

Figure 2. (a) The 1.0 liter lubricant oil bottle, (b) samples of parison for blowing the 1.0 liter lubricant oil bottle.

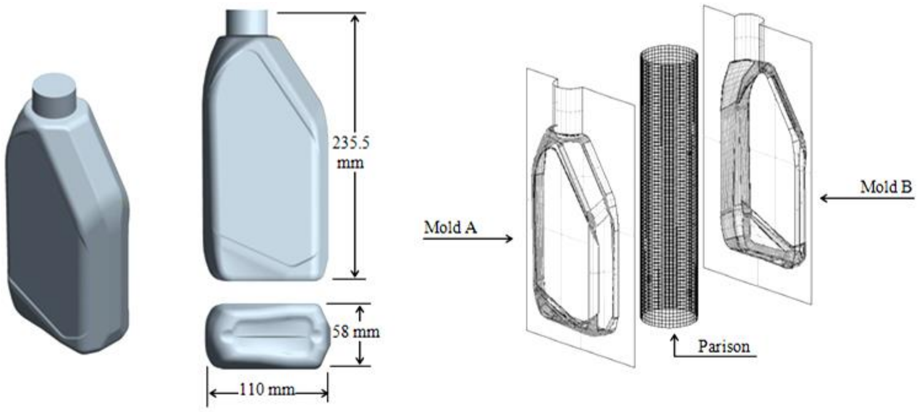


(a)



(b)

Figure 3. The height vs. the average wall thickness of: (a) parison and (b) lubricant oil bottles.



(a) (b) (c)

Figure 4. The 3D model of 1.0 liter lubricant oil bottles in: (a) an isometric view, (b) with detailed dimensions, and (c) the finite element model for extrusion blow molding.

3.1 Full shape bottle

The blow molding model was prepared using three parts of finite element model, two mold parts and one parison part. Figure 4c shows the finite element model of full shape bottle blow molding process. The parison part was represented by 2,880 rectangular elements. The plate elements had width and length of 3.75 and 4.53 mm, respectively. The mold parts were placed on two sides of parison for clamping and blowing, respectively. The surface model was assigned to be the bottle mold because the parison was clamped and blown to contact only with the inner surface of mold. The material model assigned for parison was as in Thusneyapan and Rugsaj (2014). The thickness of parison used was the average of measured thicknesses around the perimeter.

The fixed boundary condition was defined on nodes at the top edge of parison model. The surface molds were assigned to clamp parison and to hold until the parison was blown to the final shape of a bottle. The blowing pressure was set at 607.95 kPa at the inner surface of parison. The temperature of parison was 180 °C, while the ambient temperature was 35 °C.

The simulation results are illustrated by a sequence of images of blow molding process, in Figure 5a. The color contours represent the thickness of the bottle from start to finish. The final simulated thickness of bottle was compared with experimental data. Figure 5b shows graphs of bottle thickness from experiments and simulations, with similar trends. The finite element analysis (FEA) results had an absolute average error of 32.35%.

3.2 Cross-section shape of bottle

The finite element model of cross-section shape of bottle in blow molding process was more advanced than the full shape bottle blow molding simulation. The interesting horizontal section, which was at 115.00 mm height from the bottom, was simulated using FEM. This bottle section was unaffected by the clamping step in the extrusion blow molding process. The initial section of parison was in the clamped mold at the initial step of simulation; therefore, the parison was represented with a 2D finite element model. The hollow circular shape of parison was divided into rectangular plate elements. The parison thicknesses were defined to match the

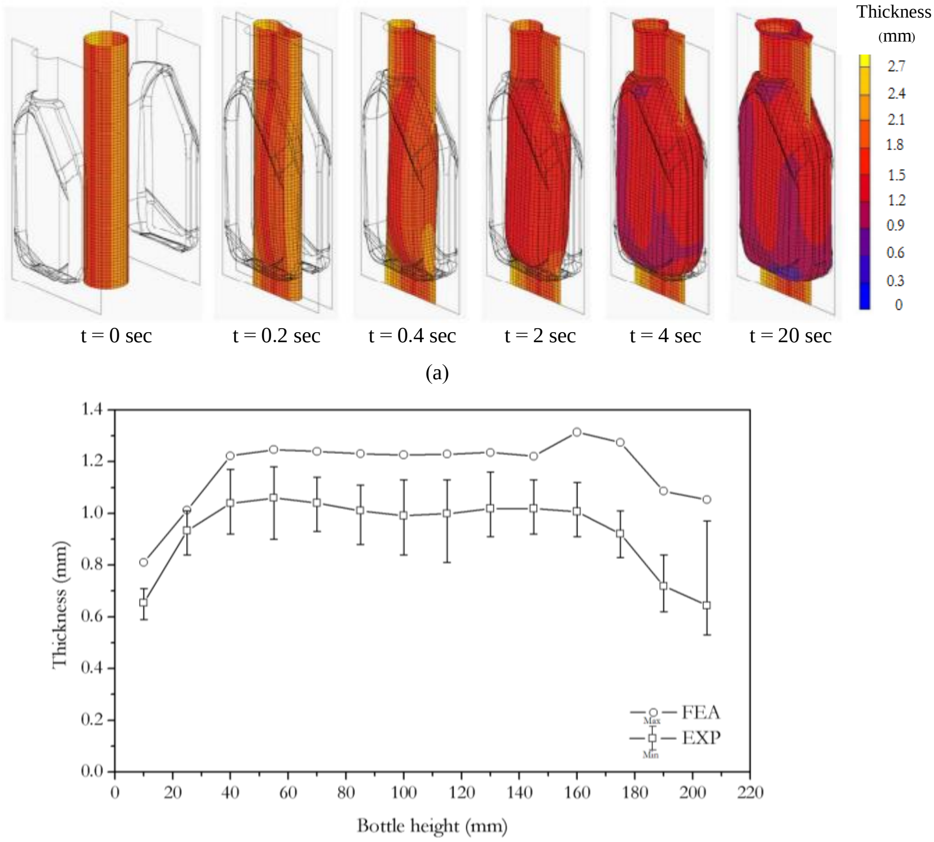


Figure 5. (a) Sequence of images from simulation of extrusion blow molding process, (b) height vs. average wall thickness of lubricant oil bottles from experiments and simulations.

experimental data at the bottle height of 115.00 mm. Totally 120 elements were used in the parison model. The material properties of parison were the same as in the parison model in the full shape bottle blow molding simulations. Also the internal pressure and environment temperature were the same as earlier.

Figure 6a shows the simulation results of the cross-section shape in bottle blow molding process. The cross-section of parison was inflated to the shape of a bottle at 115.00 mm height. The deformation of parison could be represented by color contours. A thinner area is shown as yellow and thickener area as blue. The bottle thickness could be determined from the distance between inner and outer perimeter in the finite element model at the final step of simulation. Figure 6b shows a comparison of bottle thickness between experiment and simulation. The FEA results of the cross-section shape of bottle were in better agreement with experiments than the full shape bottle blow molding simulation. The absolute average error of the cross-section shape relative to experiment was 17.02%.

The blow molding simulation using the cross-section shape of bottle can be improved for better accuracy by use of other material models, such as K-BKZ, following works by (Rasmussen & Yu, 2008). However, the cross-section shape of bottle in blow molding has the final thickness of bottle well approximated, and can the cross-section parison thickness at level of interest can be used to determine the initial parison thickness around the die gap, using Equation 1. Particularly, this FEM can be used to guide the mold makers for die shaping of the extrusion blow molding in the future**.**

4. Artificial Neural Network

The cross-section bottle blow molding simulation was further modeled using an ANN. The back propagation learning with Levenberg-Marquardt algorithm was used to fit the model parameters. The ANN architecture had three hidden layers. The multiple input neurons and three hidden layers were trained to learn the blow molding simulation of the cross-section of bottle. The ANN gave the final thickness of cross-section of bottle at desired height, when the parison thicknesses were entered as inputs. The thicknesses of parison and bottle at 15°, 45°, 75°, 105°, 135° and 165° were the input and output data, respectively. The Log-Sigmoid transfer function (Rajasekaran & Vijayalakshmi Pai, 2008) in Equation 2 was used in the first and the second hidden layers, while linear transfer functions were used in the third hidden layer of network. The first, second and third hidden layers had 25, 15 and 10 neurons, respectively.

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}} \quad (2)$$

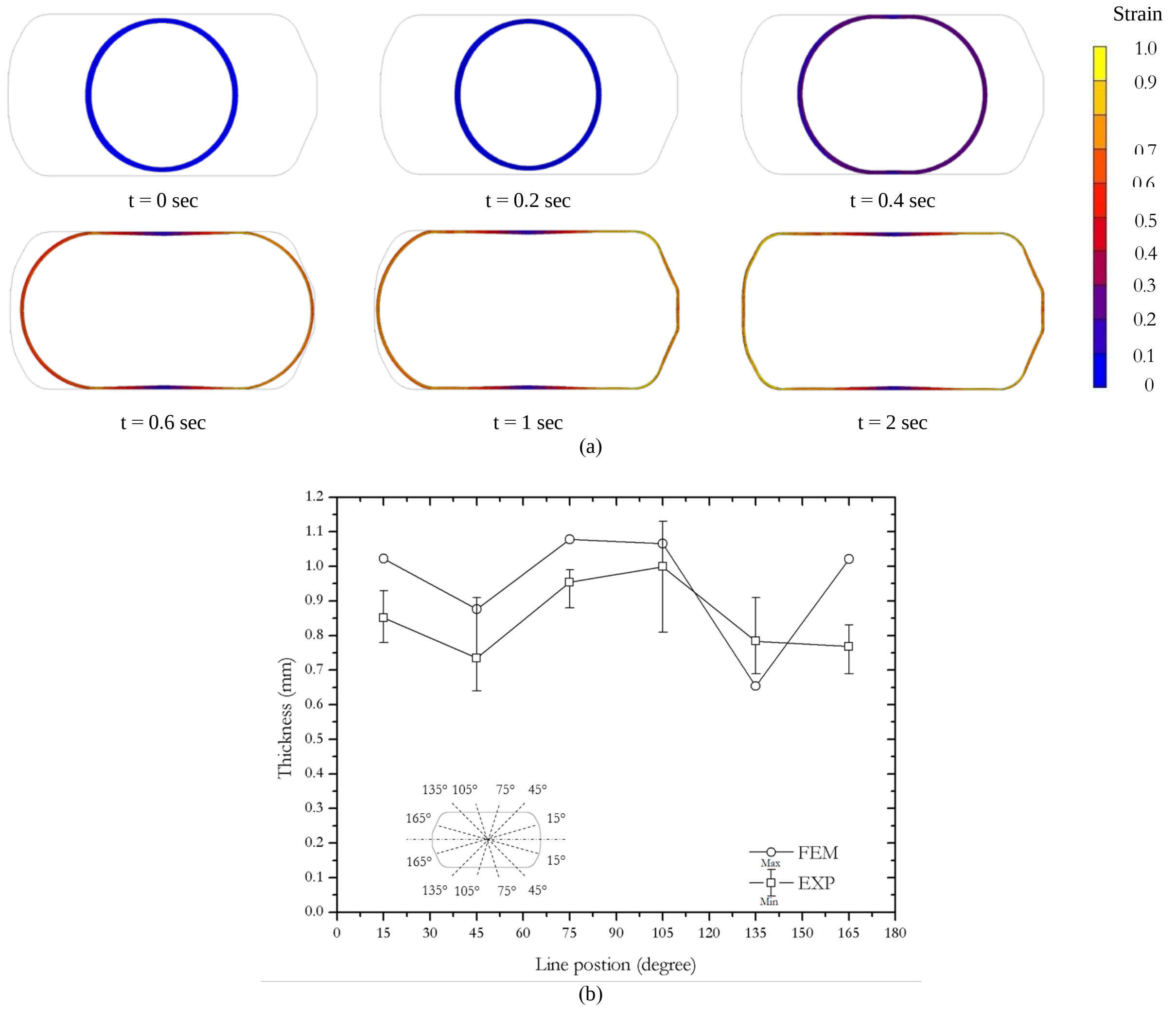


Figure 6. (a) Sequence images from simulation blow molding of cross-section shape of bottle, (b) column line position vs. average wall thickness of lubricant oil bottles from experiments and simulations.

where x_0 is the x-value of the sigmoid's midpoint, L is the curve's maximum value, and $k$determines steepness of the curve**.**

A novel orthogonal array was created to reduce input data preparation from the FEA. The orthogonal array had a simple concept to arrange thickness of parison in the input data. The three level thicknesses around parison perimeter were defined, for high, middle and low thickness. The parison thickness at two consecutive columns was random for the three level thicknesses, while the residual columns were for the middle thickness. The level of thickness was arranged for each set of the input data; therefore, the input data of 54 training samples to the ANN were prepared for predicting the cross-section thickness of bottle wall at the bottle height of interest.

The ANN trained using an orthogonal array could be used to predict thickness of the cross-section shape in bottle blow molding simulation. The thicknesses around cross-section perimeter in ANN prediction are compared with the FEA in Figure 7. The absolute average error of ANN, when compared with the FEA using five unseen initial parison thicknesses, was less than 8.88%. The ANN showed good agreement with the FEA and could be used to predict the bottle thickness rapidly.

The parison tubes of two different shapes for one-liter bottle extrusion blow molding were collected for ANN testing. The A-shape and B-shape bottle had specified positions for measuring parison thickness, shown in Figure 8 (right). These parisons are blown to A-and B-shaped bottles, shown in Figure 8 (left). The interesting cross-sections of A-and B-shaped bottles were at bottle heights of 112.5 and 118.0 mm, respectively. The ANN was tested by inputting the average thickness of parisons, five parison tubes for each bottle shape. The output from ANN was the bottle thickness at the interesting horizontal cross-section, and was compared with experimental data. Figures 9a and 9b show comparisons between the ANN and experiment for A-and B-shaped bottles, respectively. The ANN could predict the bottle thickness in good agreement with experiments. The absolute average error of ANN was 12.28% and 19.05% when comparing cross-section thicknesses of A-and B-shaped bottles, respectively.

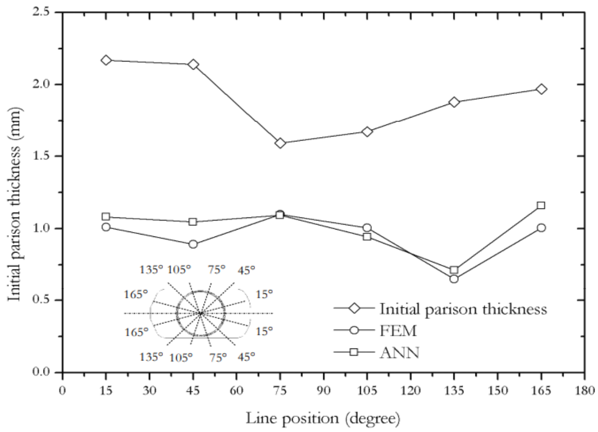


Figure 7. Column line positionvs. wall thickness of lubricant oil bottles from ANN and from simulation, at bottle height of 115.00 mm.

5. Genetic Algorithm

The top load simulation was performed on the one-liter bottle model to determine the target thickness. The one-liter bottle thickness of 1.164 mm was required to support a 25 kg top load. The bottle thickness around perimeter of the interesting cross-section, which was equal to the desired thickness, was the optimal solution for the GA. The objective function as fitness function in GA was designed for determining the initial parison column thicknesses, which would give the final bottle, the desired thickness. This study used the trained ANN prediction model for the fitness function. The goal output of ANN prediction can be represented by the following fitness function.

$$F(t) = \sum_{i=1}^{n} \left(\frac{(t_i - t_0)^2}{\sum_{i=1}^{n} t_i} \right) \quad (3)$$

where t_0 is the desired bottle thickness, t_i is the bottle column thickness, and n is the number of bottle columns.

The GA was applied to search for the parison thickness that would give uniform cross-section of blown bottle thickness. The parison thicknesses at A to F column of the one-liter bottle are described in Table 1. The suitable parison thicknesses were specified for the finite element model of the cross-section shape bottle blow molding. The results of blow molding simulation are shown in Figure 10. The final thicknesses of parison which were blown to one-liter bottleshad uniform thickness. The bottle thickness could be predicted using the ANN. The final thicknesses of bottle at the bottle height of 115.00 mm by the FEA and ANN by specifying the suitable parison thicknesses using GA are described in Table 2. The thickness of bottle from ANN had an absolute average difference from the FEA of 0.199 mm, and deviated from the target (1.164 mm) by the absolute error 4.18%**.**

The suitable parison thicknesses that were blown to bottles with uniform thickness at specified bottle height, can be used to calculate the initial parison thicknesses at the die gap using Equation 1. The parison thicknesses at the die gap will be used for die shaping of the blow molding process in further work. This provides useful guidance to the die maker in lubricant oil bottle manufacturing.

6. Conclusions

This study developed a novel approach to optimize the parison thickness using a hybrid method combining FEM, ANN, and GA. The horizontal cross-section of a bottle was simulated in blow molding process using FEM. It was demonstrated that this FEM was advantageous over a finite element model of the full bottle shape. Otherwise, the cross-section simulation of bottle blow molding was validated against physical experiments. The thicknesses of cross-section bottle at a height of interest were simulated with results in good agreement with experimental data; the absolute average error was less than 17.02%. The horizontal cross-section simulation of bottle blow molding was used to prepare initial parison and final bottle thickness data to train an ANN. A novel orthogonal array was developed based on logical connectivity of parison at each zone to optimize the amount of data required to train the ANN. The ANN was compared with FEA simulations of the cross-section of bottle in blow molding process, using five unseen sets of initial parison thicknesses. It was found that the absolute average error of ANN was 8.88%. Particularly, it was validated with two complex shaped bottles and had an absolute average error less than 15.66% when compared with physical experiments. Subsequently, the trained ANN was used as the fitness function for parison thickness optimization by GA. The objective of the GA was suitable initial parison thickness that could give uniform thickness around the horizontal cross-section perimeter at height of interest on the reflection symmetric bottleshape. The optimized parison thickness obtained from GA was validated using FEM. The cross-section bottle blow molding was simulated using the initial parison thickness by GA. The simulated results indicated that the optimized parison thicknesses were successful giving uniform targeted bottle thickness. The absolute deviation of thickness was 4.18% from the target. The optimization of parison thickness by the novel method, which was developed in this study, could guide shaping the extrusion die with simplified relationship equations between the parison height and thickness. This novel approach to determine initial thickness of parison that was extruded through a die will be useful as guide to die makers for shaping the die gap in further work.

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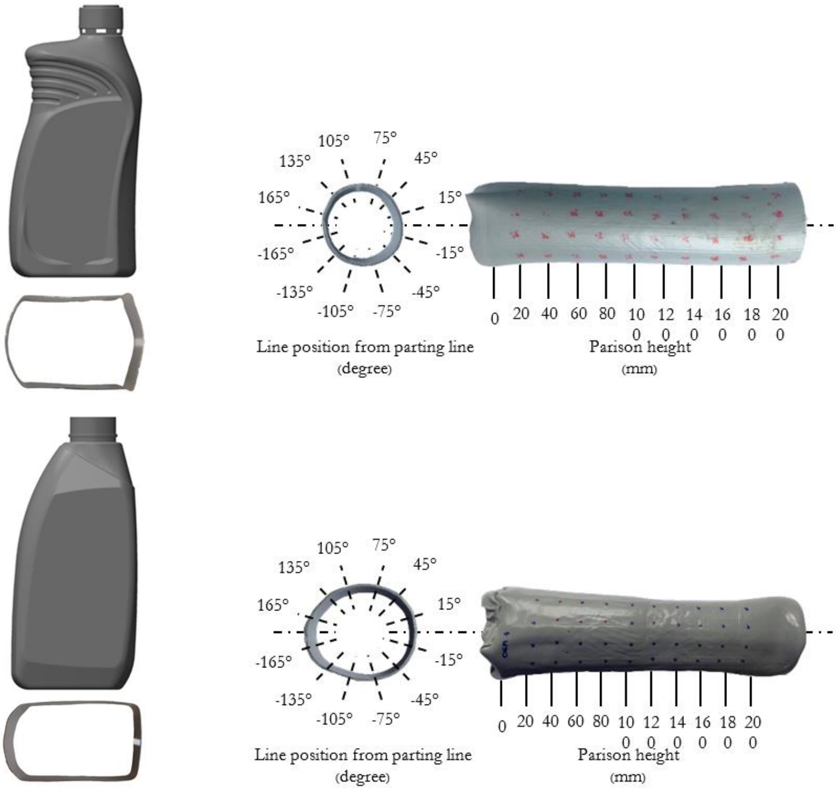
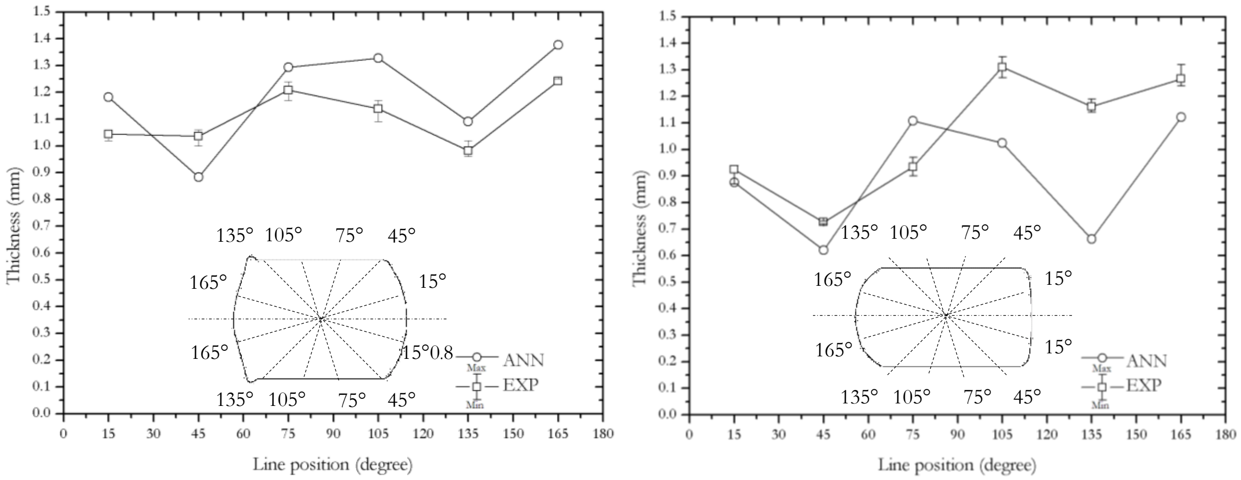


Figure 8. Samples of lubricant oil bottles with cross-sections (left) and parisons for blowing (right) of: (a) A-shaped and (b) B-shaped lubricant oil bottle.



(a) (b)

Figure 9. Column line position vs. wall thickness of: (a) A-shaped, and (b) B-shaped lubricant oil bottle from ANN and experiments, at bottle heights of 112.5 mm and 118.0 mm, respectively.

Table 1. The suitable parison thicknesses for achieving uniform thickness of cross-section of bottle.

Column	A (15 deg)	B (45 deg)	C (75 deg)	D (105 deg)	E (135 deg)	F (165 deg)
Thickness (mm)	2.86	2.69	2.26	1.98	2.89	2.83

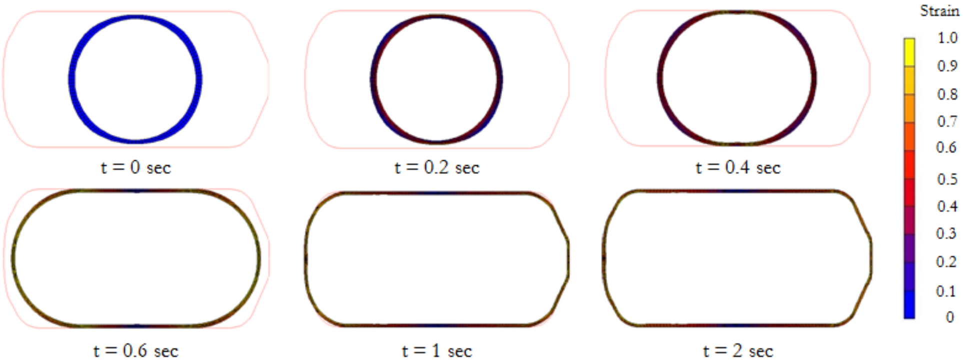


Figure 10. Sequence of images from simulation of cross-section shape of bottle in extrusion blow molding process,on using suitable parison thickness given by GA.

Table 2. The final thicknesses of bottle at height of 115.00 mm from FEA and ANN,when using suitable parison thickness provided by GA.

Method	Bottle Column Thickness (mm)						Average Thickness (mm)
	A (15 deg)	B (45 deg)	C (75 deg)	D (105 deg)	E (135 deg)	F (165 deg)	
FEM	1.365	1.362	1.298	1.315	1.319	1.475	1.356
ANN	1.200	1.085	1.181	1.197	1.075	1.202	1.157
Different Thickness (mm)	0.165	0.277	0.117	0.118	0.244	0.273	0.199

was developed in this study, could guide shaping the extrusion die with simplified relationship equations between the parison height and thickness. This novel approach to determine initial thickness of parison that was extruded through a die will be useful as guide to die makers for shaping the die gap in further work.

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References

Biglione, J., Bereaux, Y., Charmeau, J. Y., Balcaen, J., & Chhay, S. (2016). Numerical simulation and optimization of the injection blow molding of polypropylene bottles – a single stage process. *International Journal of Material Forming, 9*(4), 471-487.

Gauvin, C, Thibault, F., & Laroche, D. (2003). Optimization of blow molded part performance through process simulation. *Polymer Engineering and Science, 43* (7), 1407-1414.

Huang, G. Q., & Huang, H. X. (2007). Optimizing parison thickness for extrusion blow molding by hybrid method. *Journal of Materials Processing Technology, 182*(1-3), 512-518.

Jyh-Cheng, Y., Xiang-Xian, C., Tsung-Ren, H., & Thibault, F. (2004). Optimization of extrusion blow molding processes using soft computing and Taguchi's method. *Journal of Intelligent Manufacturing, 15*(5), 625-634.

Lee, N. C. (1990). *Plastic Blow Molding Handbook*. New York, NY: Van Nostrand Reinhold.

Lee, N. C. (1998). *Blow Molding Design Guide*. Munich, Germany: Hanser.

Marcmann, G., Verron, E., & Peseux, B. (2001). Finite element analysis of blow molding and thermoforming using a dynamic explicit procedure. *Polymer Engineering and Science, 41*(3), 426-439.

Rajasekaran, S., & Vijayalakshmi Pai, G.A. (2008). *Neural Networks, Fuzzy Logic, and Genetic Algorithms*. New Delhi, India: Prentice-Hall.

Rasmussen, H. K., & Yu, K. (2008). On the burst of branched polymer melts during inflation. *Rheologica Acta, 47*(2), 149-157.

Suvanjumrat, C., & Chaichanasiri, E. (2014). Finite element method for creep testing of high density polyethylene lubricant oil bottles. *Kasetsart Journal (Natural Science), 48*(3), 487-497.

Thusneyapan, S., & Rugsaj, R. (2016). Non-linear finite element analysis of time-varying thickness and temperature during the extrusion blow molding process. *Journal of Research and Applications in Mechanical Engineering, 4*(1), 12-24.

Yu, J. C., & Juang, J. Y. (2010). Design optimization of extrusion-blow-molded parts using prediction-reliability-guided search of evolving network modelling. *Journal of Applied Polymer Science, 117*, 222-234.