Optimization of Process Parameters in Injection-Molding by Recent Methods for Optimization – Literature Review

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Abstract - In plastic injection molding, process parameters play a major role in the product quality. The values of process parameters depend on varies thinks like, type of plastics, the dimension of the object, dimensional tolerance, etc., so there is no set values and formula of different process parameters. Injection molding has been a challenging process for many manufacturers and researchers to produce products meeting requirements at the lowest cost. Faced with global competition in injection molding industry, using the trialand- error approach to determine the process parameters for injection molding is no longer good enough. Factors that affect the quality of a molded part can be classified into four categories: part design, mold design, machine performance and processing conditions. The part and mold design are assumed as established and fixed. During production, quality characteristics may deviate due to drifting or shifting of processing conditions caused by machine wear, environmental change or operator fatigue. Determining optimal process parameter settings critically influences productivity, quality, and cost of production in the plastic injection molding (PIM) industry. Previously, production engineers used either trial-and-error method or Taguchi's parameter design method to determine optimal process parameter settings for PIM. However, these methods are unsuitable in present PIM because of the increasing complexity of product design and the requirement of multi-response quality characteristics.[1-6]

This article aims to review the recent research in designing and determining process parameters of injection molding. A number of research works based on various approaches have been performed in the domain of the parameter setting for injection molding. These approaches, including mathematical models, Taguchi method, Artificial Neural Networks (ANN), Fuzzy logic, Genetic Algorithms (GA), Finite Element Method(FEM),Non Linear Modeling, Response Surface Methodology, Linear Regression Analysis ,Grey Rational Analysis and Principle Component Analysis (PCA) are described in this article. The strength and the weakness of individual approaches are discussed..

Key words: Case Based Reasoning (CBR), Genetic Algorithms (GA), Finite Element Method(FEM),Non Linear Modeling, Response Surface Methodology, Linear Regression Analysis ,Grey Rational Analysis and Principle Component Analysis (PCA)

Introduction

Mainly in plastics injection molding there is a requirement of developing more efficient management system which can minimize the deficits in plastic manufacturing. This literature includes information about the injection molding of plastic and their parameters used in the previous studies. As a result, optimization of the parameters in PIM is important regarding minimizing shrinkage and warpage. Minimizing the parameters is not a new concept, but the parameters are different for different machines and products, so it is required to figure out optimality of them every time. Therefore, in this manner, some of the techniques like RSM, GA and combination of them are used to minimize failures in plastics.

Role and importance of process parameters in plastic injection molding

Injection molding is widely used to make plastic parts because this method is low cost, less time commuting, and excellent dimensional tolerance. Moreover, there are some more advantages are their like light weight of part and high finish of surface of optioned part, which make this process more superior than other. Beside this, plastic injection molding is a very complex process. One of the followings can increase defects in an object like improper mold design, inappropriate material selection and most important improper selection of process parameters [7-9].
The object design and mold design both are mainly done at initial stages of product development, which cannot easily and directly change. So the proper selection of process parameters is the only method to decrease defects and increase quality [10].
In today production system 30% of plastic parts are made by plastic injection molding. Proper selection of process parameters is called as "Black Art" because it depends on upon experience and previous knowledge of machine operator and includes a trial-and-error process. Many researchers are work on it to eliminate the costly trial-and-error method by various techniques [9, 11].
In injection molding process there are mainly three stages: filling phase (packing phase), cooling phase and ejection phase. Cooling phase influences productivity and quality of the product. In injection molding, there are many process parameters which depend on and controlled by the machine of plastic injection molding [12].
At time of manufacturing, quality terms of object such as shrinkages such as shrinkage, warpage, weld lines, mold lines, flow marks, flash marks, sink marks, and void depend on upon process parameters which include [13-14]:-

- Melt temperature
- Mold temperature
- Injection pressure
- Cooling duration
- Cooling temperature
- Screw speed
- Packing pressure or holding pressure
- Packing duration
- Cycle time
- Fill time or injection time
- Injection speed

DEFECTS IN PLASTIC INJECTION MOLDING

Plastic injection molding is one of the important net-shape-forming processes for plastic material like thermoplastics. During this process some defect may occur like:

- Warpage
- Sink marks
- Shrinkage
- Air traps or voids
- Weld lines
- Mold lines
- Flow marks
- Flash marks

However, all defects can avoid and removed by proper selection and optimization of process parameters which discuss in the previous article [15].

Table 0.1 Effect of Injection Molding Parameters on Product Quality

DEFECT	ADJUSTMENT FOR PARAMETER SETTINGS
Poor surface finish	Increase shot size Increase injection pressure and speed Increase melt temperature Increase mold temperature Increase cycle time
Flash	Decrease melt temperature Decrease injection pressure Decrease cycle time Improve mold venting Increased clamp pressure
Weld lines	Increase injection pressure Increase packing duration and pressure Increase melt temperature Increase mold temperature
Sinks or Voids	Increase injection pressure Increase packing duration and pressure Increase melt temperature Decrease mold temperature
Warpage	Increase mold temperature Increase injection pressure and velocity Increase packing duration and pressure

The value of shrinkage is different for different type of plastic materials, in some plastics, it may be zero and others it may little or in some, it may be higher in degrees. The value of tolerance in molded parts is mainly determined by the predicted value of shrinkage rightly. It's hard to control and predict shrinkage because it is not isotropic always [16]. The amount of shrinkage is depending upon following causes:

Uneven cooling

Non-uniform volumetric shrinkage

Anisotropic material behaviors

Differential thermal strain

From Figure 0.1, its show effect of varies process parameters on shrinkage. Shrinkage is increased with increasing in melt temperature, mold temperature, and part thickness but in the case of increasing packing pressure and packing duration it is decreasing. With increasing of injection rate the first shrinkage reduced, but slowly it is increasing.

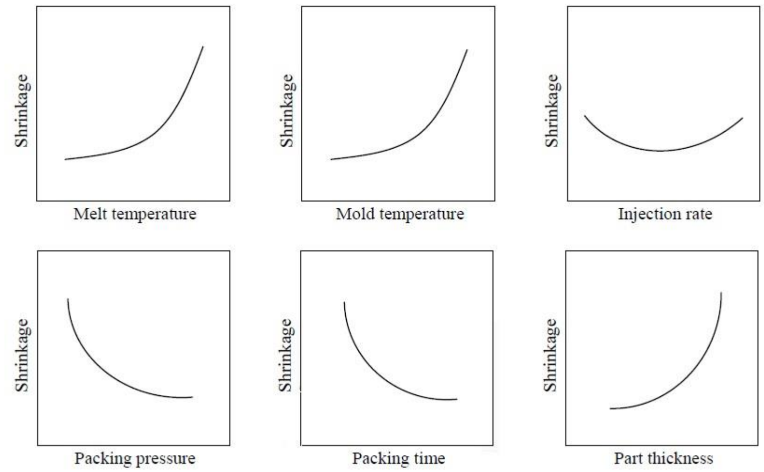

Figure 0.1 The Variation of Shrinkage Caused by Processing and Design Parameters [17]

Warping is due to differential shrinkage if two layers or part of the same object have a different amount of shrinkage than the object will warp. In other words, if there is variation in shrinkage, than warpage is there in plastic parts. Warpage is the part defect which originated by a non-homogenous change in internal stresses. It is due to imbalance following causes:
Imbalance in mold temperature
Imbalance in injection pressure due to this there is sudden changes in velocity
Imbalance in packing pressure due to this there is sudden changes in packing duration
Among all defect, warpage is considered to be one of the most difficult defects to control. There is one more reason for warping if one area over packed, and another one is less packed, due to which differential shrinkage occurs, and warpage is there [13, 15, 18-20].

OPTIMIZATION METHODS IN PLASTIC INJECTION MOLDING

Different researchers apply various methods for optimization. Reddy et al. [13] had applied mold flow simulation software and ANN for prediction of warpage in plastic injection molded part. This study proposed further extension by considering number process parameters and output characteristics. Kamaruddin et al. [14] focused only on Taguchi method and target on bending deflection of the plastic tray. The L_9 OA with three levels of four process parameters used. In this study melting temperature, injection speed, cooling duration, and holding pressure investigated. The result shows holding a pressure was the main contribution of all parameters.
Several studies expose that combination of different optimization techniques; will give improved results in injection molding. This combination of techniques called as hybrid optimization system; firstly it was used by Babur Ozcelik and Tuncay Erzurumlu [21] in 2005. They used a combination of response surface method and genetic algorithm to find the effect of dimensional parameters on warpage. Since each technique has own advantages and disadvantages, so a hybrid technique is a good way to conquer this difficulty by allowing the benefits of each technique and to discard their weaknesses. However, the best result can only be attained by picking the right process parameters. In previous studies, researchers combined many optimization techniques such as Taguchi, RSM, GA, PSO, SA, and others to improve the quality of the plastic product.
Following Table 2.2 shows a summary of different studies in the area of plastic injection molding. It contents optimization methods used, parameter setting, and the target of research**.**
Table 0.2 Summary of Optimization Methods in Plastic Injection Molding

Researcher	Method	Target	Parameter settings
Reddy et al. [13]	Mold flow ANN	Warpage	Mold temperature Melt temperature Packing pressure Packing time Cooling time
Kamaruddin et al. [14]	Taguchi	Bending deflection	Melting temperature Injection speed Cooling time Holding pressure
Chen et al. [7]	Taguchi ANOVA BPNN GA Hybrid PSO-GA	Length Warpage	Melt temperature Injection velocity Packing pressure Packing time Cooling duration
Tang et al. [9]	Taguchi	Warpage	Melt temperature Filling time Packing pressure Packing time
Taghizadeh et al. [22]	Mold Flow ANN	Warpage	Mold temperature Melt temperature Ejection Temperature Thermal Conductivity
Yin et al. [23]	BPNN Fe simulation	Warpage	Mold temperature Melt temperature Packing pressure Injection pressure Packing time Cooling time
Tzeng et al. [24]	Taguchi BPNN GA RSM	Ultimate strength Flexure strength Impact Resistance	Nozzle temperature Melt temperature Packing pressure Packing time Mold temperature
Mathivanan et al. [11]	FFD RSM-CCD	Sink depth	Melt temperature Mold temperature Injection time Volume-to-pressure Switch Over Packing time

			Packing pressure Rib-to-Wall ratio Rib distance from gate
Chiang et al. [25]	RSM	Shrinkage and warpage	Mold temperature Packing time Packing pressure Cooling time
Shi et al. [10]	ANN Mold flow	Warpage	Mold temperature Melt temperature Injection Time Packing time Packing pressure Cooling Time
Chen et al. [26]	Taguchi BPNN GA PSO	Product length Warpage	Melt temperature Injection velocity Injection pressure Packing pressure Packing time
Guo et al. [15]	FFD CCD	Warpage	Mold temperature Melt temperature Injection time V/P switch-over Packing pressure Packing time Coolant temperature Coolant Reynolds number
Ozcelik et al. [21]	Mold Flow GA RSM	Warpage	Dimensional parameters
Sun et al. [27]	RSM GA	warpage	Melt temperature Mold temperature Injection time Packing pressure Packing time
Shen et al. [28]	ANN GA	volumetric shrinkage	Melt temperature Mold temperature Injection time Packing time Holding pressure

Ehsan et al. [29]	RSM Simulated Annealing Algorithm	Warpage; Shrinkage	Melt temperature Mold temperature Injection pressure

Response Surface Methodology (RSM):-

In the field of mathematical statistics, response surface methodology (RSM) investigates the relationships between explanatory variables (an independent variable) and one or more than one dependent variable (also known as response variables). G. E. P. Box and K. B. Wilson in 1951 develop is a method. The main thought of RSM is to make use of predesigned sequence (runs) to conduct experiments to find the best response.

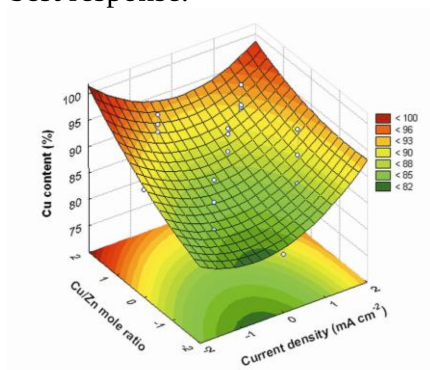

Figure 0.2 Response Surface and Contour Plot of Copper Content (%) as a Function of Current Density and Cu/Zn Mole Ratio. [30]

Example: The regression model for Cu content (f_1) is stated by the subsequent second-order polynomial equation:

f_1 *(% Cu content)* $= 66.32 + 4.21x_1 + 1.23x_2 + 0.62x_3 + 2.62x_4 + 1.15x_2^2 + 2.58x_3^2 + 3.13x_4^2 – 1.34x_1x_2 – 2.51x_1x_4 – 2.18x_2x_3$

Developers suggested the use of second-degree (the sum of the power of the variables) polynomial model to do this. They accept that this model is the only estimation, but applying RSM model is simple to approximate and use, even the knowledge of the process is less.

Response surface methodology (RSM) Steps

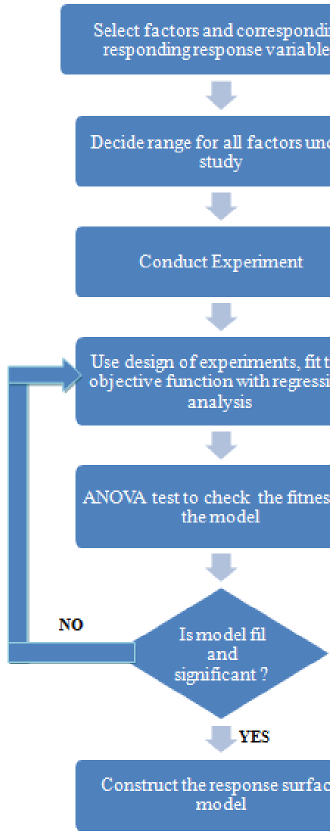

Figure 0.3 Steps in RSM

Central composite design

The second-order model can effectively and central composite design (CCD) (Montgomery, 1997) to build. CCD is a first order (2^N) designed to enhance tuning parameters by the additional central and axial points to let estimate of the second-order model. In the Figure 2.4, the factorial design involves 2^N points, 2^N axial points, and a center point. In CCD, 3^N presented to the second-order model construction design by reducing the number of experiments judge against to an FFD (15 experiments in the case of CCD, as compared to 27 for the full factorial design) instead. In the issue, a significant number of design variables under the circumstances, the experiment may be time-consuming, CCD even use.

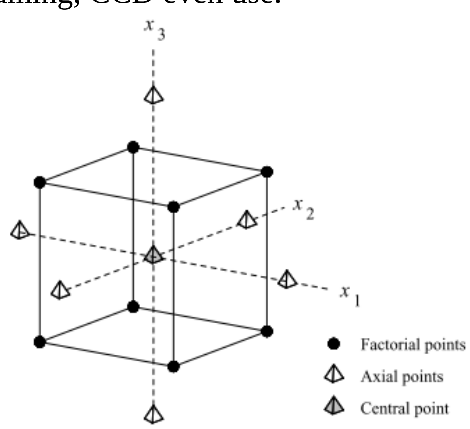

Figure 0.4 Modal Design of CCD for Three Design Variables at Second Level [31]

Genetic algorithm (GA):-

Introduction

A genetic algorithm is a mathematical technique which based on “Natural Selection” of nature. This technique uses in many fields like artificial intelligence, optimization, and research problems. A genetic algorithm is belong to the evolutionary algorithms (ES). This algorithm gives a solution of the problem by using the natural evolution of mankind. In this algorithm, there are some stages like,

Representation (inheritance or population)

Selection (reproduction)

Crossover

Mutation

GA can apply to resolve problems even they are not well suited for the standard optimization problem, even in which objective function discontinued or higher nonlinear.

Various Steps involved in GA Procedure

Representation (inheritance or population)

In GA each variable is first coded into a defined length of binary values (1 and 0) which called as a set. This set further divided into N small sets as shown:

$$\underbrace{11010}_{x_1}\ \underbrace{1001001}_{x_2}\ \underbrace{010}_{x_3}\ldots\underbrace{0010}_{x_N}$$

Selection (reproduction)

This is the first function which applied to the population. In this step, only good set out of population is selected and mark it as the mating pool. A good set is referring to a set which is capable of generating best results. The main idea is to take above average sets to next level in the form of mating pool. The respite of them gets rejected at this level.

Crossover

In this operation, two different sets are picked from the mating pool at random, and some part out of that one set exchanged from another set. In crossover both sets, which is called parent cut at the same place and the first half of sets exchanged and two new strings called as a child made. As shown in Figure 0.5:-

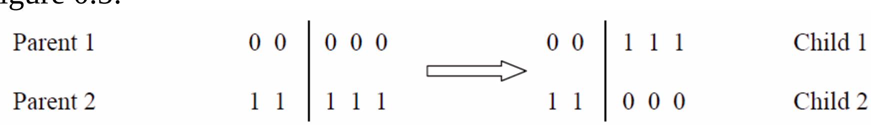

Figure 0.5 Crossover

Childs, which is newly constructed sets, are much better than their parent sets if the suitable side was taken. This process is random because it's hard to know proper side. Due to random side selection, the child sets some time may be not good than parent sets. In such cases, this type non-fit child created by crossover will not carry on in next reproduction.

Mutation

In this operation sets created by crossover are alters locally to make better sets. The mutation operation changes a1 to a 0 and vice-versa with small probability P_n for example:

0 0 0 0 0 0 0 0 1 0

The main need of mutation is there due to create some diversity.

After applying all steps on complete population, one generation of GA is completed. These steps are applied again and again depend on generations are decided [32].

Steps in Genetic Algorithm

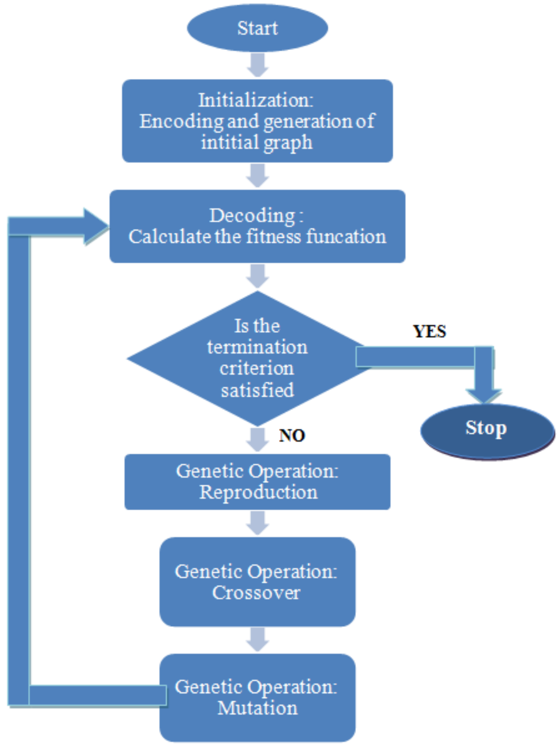

Figure 0.6 Flow Chart of Genetic Algorithm

REFERENCES

[1] "Plastics Manufacturing." [Online]. Available:http://www.the- warren.org/GCSE Revision/engineering/plastic forming.htm.

[2] "Injection Molding." [Online]. Available: http://www.rutlandplastics.co.uk/images/ Moulding Machine lg.jpg.

[3] "Rotational." [Online]. Available: http://www.roto-industry.com/wp-content/uploads/ 2014/04/PROCESS.jpg.

[4] J. Melorose, R. Perroy, and S. Careas, "Computer Aided Design of Side Actions for Injection Molding of Complex Parts Ashis," *Statew. Agric. L. Use Baseline 2015*, vol. 1, 2015.

[5] **Rosato**, D.V., **Rosato**, Marlene G. "Injection Molding Handbook, 2nd ed", ISBN 978-1-4615-4597-2, Springer Science & Business Media, 2012.

[6] P. K. Bharti, M. I. Khan, and H. Singh, "Recent Methods for Optimization of Plastic Injection Molding Process – A Retrospective and Literature Review," *Int. J. Eng. Sci. Technol.*, vol. 2, no. 9, pp. 4540–4554, 2010.

[7] W.-C. Chen and D. Kurniawan, "Process Parameters Optimization for Multiple Quality Characteristics in Plastic Injection Molding Using Taguchi Method, BPNN, GA, and Hybrid PSO-GA," *Int. J. Precis. Eng. Manuf.*, vol. 15, no. 8, pp. 1583–1593, Aug. 2014.

[8] X.-P. Dang and H.-S. Park, "Design of U-Shape Milled Groove Conformal Cooling Channels for Plastic Injection Mold," *Int. J. Precis. Eng. Manuf.*, vol. 12, no. 1, pp. 73–84, Feb. 2011.

[9] S. H. Tang, Y. J. Tan, S. M. Sapuan, S. Sulaiman, N. Ismail, and R. Samin, "The Use of Taguchi Method in The Design of Plastic Injection Mould for Reducing Warpage," *J. Mater. Process. Technol.*, vol. 182, no. 1–3, pp. 418–426, Feb. 2007.

[10] H. Shi, S. Xie, and X. Wang, “A Warpage Optimization Method for Injection Molding Using Artificial Neural Network With Parametric Sampling Evaluation Strategy,” *Int. J. Adv. Manuf. Technol.*, vol. 65, no. 1–4, pp. 343–353, May 2012.
[11] D. Mathivanan and N. S. Parthasarathy, “Prediction of Sink Depths Using Nonlinear Modeling of Injection Molding Variables,” *Int. J. Adv. Manuf. Technol.*, vol. 43, no. 7–8, pp. 654–663, Sep. 2008.
[12] H.-S. Park and X.-P. Dang, “Optimization of Conformal Cooling Channels With Array of Baffles for Plastic Injection Mold,” *Int. J. Precis. Eng. Manuf.*, vol. 11, no. 6, pp. 879–890, Dec. 2010.
[13] B. Reddy and J. Kumar, “Application of Soft Computing for The Prediction of Warpage of Plastic Injection Molded Parts,” *J. Eng. Sci. Technol. Rev*, vol. 2, no. 12, pp. 8071–8083, 2009.
[14] S. Kamaruddin, Z. A. Khan, K. S. Wan, and N. Tebal, “The Use of The Taguchi Method in Determining The Optimum Plastic Injection Moulding Parameters for The Production of a Consumer,” *J. Mek.*, pp. 98–110, 2004.
[15] W. Guo, L. Hua, H. Mao, and Z. Meng, “Prediction of Warpage in Plastic Injection Molding Based on Design of Experiments,” *J. Mech. Sci. Technol.*, vol. 26, no. 4, pp. 1133–1139, Apr. 2012.
[16] S. Nykänen, “Shrinkages– Injection Casting Design,” *CAE DS – Inject. Cast. Des.*, pp. 1–2, 2007.
[17] D. Kurniawan, “An Integrated Optimization System for Plastic Injection Molding Using Taguchi Method , BPNN , GA, and Hybrid PSO-GA,” *Thesis PSO*, 2014.
[18] D. Lee, “Factors Influencing the Warpage in In-Mold Decoration Injection Molded Composites,” *Intern. Polym. Process.*, vol. XXVIII (20, no. Imd, pp. 221–227, 2013.
[19] T. Jaruga, K. Lubczyñska, and A. Gnatowski, “Warpage of injection moulded parts as the result of mould temperature difference,” *Arch. Mater. Sci. Eng.*, vol. 44, no. 1, pp. 28–34, 2010.
[20] R. Spina, P. Walach, J. Schild, and C. Hopmann, “Analysis of Lens Manufacturing with Injection Molding,” *Int. J. Precis. Eng. Manuf.*, vol. 13, no. 11, pp. 2087–2095, Oct. 2012.
[21] B. Ozcelik and T. Erzurumlu, “Determination of Effecting Dimensional Parameters on Warpage of Thin Shell Plastic Parts Using Integrated Response Surface Method and Genetic Algorithm,” *Int. Commun. Heat Mass Transf.*, vol. 32, no. 8, pp. 1085–1094, Aug. 2005.
[22] A. Ö. A. O. U. S. Taghizadeh, “Warpage Prediction in Plastic Injection Molded Part Using Artificial Neural Network,” *IJST*, vol. 37, pp. 149–160, 2013.
[23] F. Yin, H. Mao, L. Hua, W. Guo, and M. Shu, “Back Propagation Neural Network Modeling for Warpage Prediction and Optimization of Plastic Products During Injection Molding,” *Mater. Des.*, vol. 32, no. 4, pp. 1844–1850, 2011.
[24] C.-J. Tzeng, Y.-K. Yang, Y.-H. Lin, and C.-H. Tsai, “A Study of Optimization of Injection Molding Process Parameters for SGF and PTFE Reinforced PC Composites Using Neural Network and Response Surface Methodology,” *Int. J. Adv. Manuf. Technol.*, vol. 63, no. 5–8, pp. 691–704, Jan. 2012.
[25] K. Chiang and F. Chang, “Analysis of Shrinkage and Warpage in an Injection-Molded Part with a Thin Shell Feature Using The Response Surface Methodology,” *Int J Adv Manuf Technol*, pp. 468–479, 2007.
[26] W.-C. Chen, P.-H. Liou, and S.-C. Chou, “An Integrated Parameter Optimization System for MIMO Plastic Injection Molding Using Soft Computing,” *Int. J. Adv. Manuf. Technol.*, vol. 73, no. 9–12, pp. 1465–1474, May 2014.

[27] B. Sun and Z. Wu, "Optimization of Injection Molding Process Parameters Based on Response Surface Methodology and Genetic Algorithm," *2010 2nd Int. Conf. Comput. Eng. Technol.*, pp. V5–397–V5–400, 2010.
[28] C. Shen, L. Wang, and Q. Li, "Optimization of Injection Molding Process Parameters Using Combination of Artificial Neural Network and Genetic Algorithm Method," *J. Mater. Process. Technol.*, vol. 183, no. 2–3, pp. 412–418, Mar. 2007.
[29] M. Ehsan and J. jelodar Mostafa, "A Hybrid Response Surface Methodology and Simulated Annealing Algorithm," *ipcsit.com*, vol. 5, pp. 570–576, 2011.
[30] G. Orhan, G. Hapçi, and Ö. Keleş, "Application of Response Surface Methodology (RSM) To Evaluate The Influence of Deposition Parameters on The Electrolytic Cu-Zn Alloy Powder," *Int. J. Electrochem. Sci.*, vol. 6, no. 9, pp. 3966–3981, 2011.
[31] A. I. Khuri and S. Mukhopadhyay, "Response Surface Methodology," *Wiley Interdiscip. Rev. Comput. Stat.*, vol. 2, no. 2, pp. 128–149, 2010.
[32] L. Avenue, "Genetic Algorithms and Their Applications : An Overview," *Thesis GA Appl. page 11*, no. 9068, 1986.
[33] "Adell AL-18 Nylon 66, 40% Glass Reinforced; Mineral Filled." [Online]. Available: http://www.matweb.com/search/datasheet.aspx?matguid=caf9958fd67f4d4381b9effd3bd2fd18&ckck=1. [Accessed: 08-Jun-2015].