Optimization of the Injection Molding Process Simulation Using Taguchi Method

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This work aims to present the optimization of the design of a plastic part manufactured at Accurate Machine and Tool Ltd. Canada, by using Moldflow [1] combined with the optimization method developed by Dr. Genichi Taguchi. The method uses statistical principles and involves reducing the variation in a process through robust design of experiments. The experimental design proposed by Taguchi uses orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Moldflow allows part designers and mold makers to predict the manufacturability and quality of their design during preliminary product development stages. It helps to select the best injection gates configuration, as well as the values of mold temperature (Tw), melt temperature (Tm) and an optimized body shape for a part in order to minimize variability in a key performance measure. This presentation discusses the application of these tools on a real life production of the parts. Using this method, with a modest number of simulations runs, the resultant savings are significant. The part has the weight reduced from 0.03lb for the initial part to 0.022lb. On this one design alone it is saved 27% of the material for each part.

Keywords: polymers, injection molding, design, optimization, Taguchi Method

In the last years the application of CAE analysis in injection-molded plastic part has become popular, especially for part design and molding process optimization [8, 21].

In this work *Moldflow* design analysis solutions are identified as tools that could aid in process improvement initiative. *Moldflow* is advanced computer simulation software that associates the capabilities of the rapid, accurate analysis with the function of computer-aided drawing for the establishment of the theoretical model.

On the other hand, the aim of a simulation optimization method is to provide a structure to determine the values of the controllable variables that optimize an objective function defined as a combination of the simulation model's outputs [7, 19]. An optimization routine uses the calculated values of the objective function and previous evaluations, to select a new set of input values; this is continued until a pre-selected convergence criterion is satisfied [12].

Governing Equations and Assumptions

The mathematical models for solid flow (*3D* flow) are governed by conservation of mass, the conservation of momentum, and the conservation of energy. Classic Galerkin technique provides nonlinear equations that are solved by the Newton-Raphson method. At each step a linear system must be solved [9, 11]. To avoid the temperature oscillations resulted by standard Galerkin methods [5, 13, 14], an implicit method is used to discrete the energy equation. The fluid is assumed to behave as non-Newtonian no isothermal fluid. Temperature *T*, pressure *p* and the velocity vector *u* are the unknown factors:

$$\varepsilon(u)=\frac{1}{2}\left(\nabla u+\nabla u^{t}\right); \tag{1}$$

$$\sigma=2\eta\varepsilon(u)-pI; \tag{2}$$

$$q=-k_{th}\nabla T, \tag{3}$$

where:
ε(u) - strain rate tensor;
σ - Cauchy stress tensor;
Q - heat flux;
H - viscosity;
k_{th} - thermal conductivity.

Considering the incompressibility of the material and the filled subdomains Ω_f, we can get the following equations:

$$\frac{\partial u}{\partial t}+(u\cdot\nabla)u=\nabla\sigma; \tag{4}$$

$$\nabla\cdot u=0; \tag{5}$$

$$\rho C_p\left(\frac{\partial T}{\partial t}+u\cdot\nabla T\right)=-div\,q+2\eta\varepsilon(u):\varepsilon(u), \tag{6}$$

where:
ρ - density;
C_p - specific heat.

Initial Conditions

The boundary ∂Ω (fig. 1) is composed of the inlet boundary Γ_i the wall of the mold Γ_w, and the interface Γ_m between melt and air in the empty mold [6, 18].

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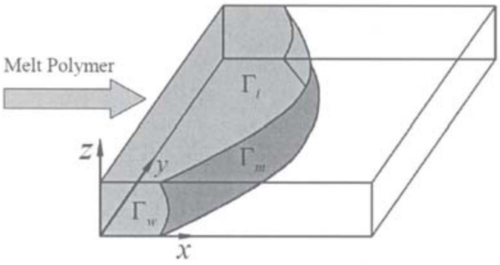

Fig. 1. ∂Ω Domain

(i). Velocity on the inlet boundary Γ_i is

$$u = u_i. \tag{7}$$

(ii) On each wall, Γ_i of the mold:

$$u = 0, \text{ (no-slip condition);} \tag{8}$$

$$q \cdot n = h(T - T_w) \text{ (wall heat flux),} \tag{9}$$

where h is heat exchange coefficient between melted polymer and mold wall.

(iii). On the front of the melted polymer:

$$\sigma_n = 0 \text{ (stress tensors),} \tag{10}$$

$$q \cdot n = 0 \text{ (heat exchange).} \tag{11}$$

(iv). The initial state of the fluid is melt staying with the velocity and temperature assumed to be constant:

$$u(x,0) = u_0; \tag{12}$$

$$T(x,0) = T_0. \tag{13}$$

Fluid Domain Evolution

A finite volume element method is employed to track the evolution of the free surface. A fill factor F associated with the element is tracked and solved using a transport equation of the form [4, 9]:

$$\frac{\partial}{\partial t} F_{\Omega f}(x,t) + u \cdot \nabla F_{\Omega f}(x,t) = 0, \quad \forall\, x \in \Omega, \forall t \in R^+. \tag{14}$$

Numerical Solution for Stokes Problem

If inertia is neglected in the momentum equation and the fluid is assumed to be isothermal the problem will become Stokes problem. Let take $v \in H_\Gamma^1(\Omega)^3$ the test functions, to multiply the momentum equation and integrate on the domain Ω_f [12]. The variational equation can be written as:

$$\int_{\Omega f} 2\eta\varepsilon(u) : \varepsilon(v) d\Omega - \int_{\Omega f} p \nabla \cdot v d\Omega = 0, \quad v \in H_\Gamma^1(\Omega)^3. \tag{15}$$

and the variational equation for continuous equation:

$$\int_{\Omega f} q \nabla \cdot u d\Omega = 0, \quad \forall q \in L^2(\Omega). \tag{16}$$

For flow simulation by finite element method, using velocity and pressure both as unknown variables, it is used an iterative technique that at any given point of time solves the components independently [12]. As element, it is used a tetrahedral first-order constituent with a linear continuous interpolation of pressure and velocity (fig. 2).

First, the pressure gradient is assumed to be constant at each element. The variational formulation [9] becomes:

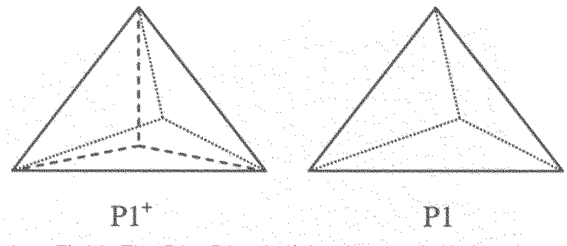

Fig. 2. The P1⁺, P1 velocity-pressure element

$$\int_{\Omega f} 2\eta\varepsilon(u) : \varepsilon(v) d\Omega + \int_{\Omega f} \nabla p \cdot v d\Omega = \int_{\Gamma_m} n \cdot \varepsilon(u) \cdot v d\Gamma, \quad v \in H_\Gamma^1(\Omega)^3. \tag{17}$$

Let ψ_j be the interpolated polynomial corresponding to the vertex j of element l. Then the velocity u on the element l can be expressed as:

$$u = \sum{}_j \Psi_j u_j. \tag{18}$$

By substituting this velocity into the variational equation (17) we get the following expression

$$a_{ij} u_i = -\sum_{j \neq i} a_{ij} \tilde{u}_i - \sum_l b_{il} \nabla_{pl}. \tag{19}$$

where:

j, n - are node and element order around node i,

u - velocity of last iteration.

The coefficients of the equation are:

$$b_{il} = \int \Psi_i d\Omega; \tag{20}$$

$$a_{ii} = \sum_l \int \varepsilon(\Psi_i) : \varepsilon(\Psi_i) d\Omega; \tag{21}$$

$$a_{ij} = \sum_l \int \varepsilon(\Psi_i) : \varepsilon(\Psi_j) d\Omega, \tag{22}$$

where:

$$\Psi_i = (\Psi_i, \Psi_i, \Psi_i)^T;$$

$$\Psi_j = (\Psi_j, \Psi_j, \Psi_j)^T.$$

By substituting the velocity derived from the equation (22) into (19) and by integrating by step, we get the pressure equations:

$$\int_{\Omega f} \nabla q \cdot (M \nabla p) d\Omega = -\int_{\Omega f} \nabla q \cdot \hat{u} d\Omega - \int_{\Gamma_i + \Gamma_m} q \tilde{u} \cdot n d\Gamma, \tag{23}$$

where at element l, $M^{(l)} = b_{il} / a_{ii}$ and $\hat{u}$ is defined as:

$$\hat{u}_i = \sum{}_{j \neq i} a_{ij} \hat{u}_j / a_{ii}. \tag{24}$$

Numerical Solution for Navier-Stokes Problem

We can derive the variational formulation for Navier-Stokes problem as [18]:

$$\int_{\Omega f} \frac{\partial u}{\partial t} \cdot v d\Omega + \int_{\Omega f} (u \cdot \nabla u) \cdot v d\Omega = -\int_{\Omega f} 2\eta\varepsilon(u) : \varepsilon(v) d\Omega - \int_{\Omega f} \nabla p \cdot v d\Omega + \\ + \int_{\Gamma_m} 2\eta n \cdot \varepsilon(u) \cdot v d\Gamma, \quad \forall v \in H_\Gamma^1(\Omega)^3. \tag{25}$$

The discrete equation for time can be expressed as [18]:

$$\int_{\Omega f} \frac{u^{n+1} - u^n}{\Delta t} \cdot v d\Omega + \int_{\Omega f} (u^n \cdot \nabla u^{n+1}) \cdot v d\Omega = -\int_{\Omega f} 2\eta\varepsilon(u^{n+1}) : \varepsilon(v) d\Omega - \\ \int_{\Omega f} \nabla p^{n+1} \cdot v d\Omega + \int_{\Gamma_m} 2\eta n \cdot \varepsilon(u^n) \cdot v d\Gamma, \quad \forall v \in H_\Gamma^1(\Omega)^3 \quad . \tag{26}$$

Discrete Scheme for Energy Equation

The evolution of the temperature inside a viscous flow is a function of heat conduction, heat dissipation and boundary condition. Applying the standard Galerkin method can generate solutions containing spatial variations [13], due mainly to the important temperature gradients. To overcome this phenomenon, different techniques have been tried such as mesh refinement [15], and "mass-limping"[16]. Sometimes, these different methods can be used alternatively or in complementarily [17]. Let's define the function spaces:

$$H_{\Gamma}^{1}(\Omega)=\left\{\phi\in H^{1}(\Omega):\phi=0,\ pe\ \Gamma_{i}\cup\Gamma_{m}\right\}. \tag{27}$$

and then take a test function $v\in H_{\Gamma}^{1}(\Omega)$ to multiply the energy equation (9) and integrate it in the filled region. We get the varitional formulation about temperature:

$$\rho C_v\int_{\Omega f}\frac{\partial T}{\partial t}wd\Omega+k_{th}\int_{\Omega f}\nabla T\cdot\nabla wd\Omega+h\int_{\Gamma_w}T_w d\Gamma=\rho C_v\int_{\Omega f}Tu\cdot\nabla wd\Omega+$$
$$+\int_{\Gamma_w}hT_w wd\Gamma+\int_{\Omega f}2\eta\varepsilon(u):\varepsilon(u)wd\Omega,\qquad\forall w\in H_{\Gamma}^{1}(\Omega). \tag{28}$$

In this condition the discrete form about time-dependent temperature becomes

$$\rho C_v\int_{\Omega f}\frac{T^{n+1}-T^{n}}{\Delta t}wd\Omega+k_{th}\int_{\Omega f}\nabla T^{n+1}\cdot\nabla wd\Omega+h\int_{\Gamma_w}T^{n+1}w\cdot d\Gamma=$$
$$\rho C_v\int_{\Omega f}T^{n}u\cdot\nabla wd\Omega+\int_{\Gamma_w}hT_w wd\Gamma+\int_{\Omega f}2\eta\varepsilon(u):\varepsilon(u)wd\Omega,\quad\forall w\in H_{\Gamma}^{1}(\Omega). \tag{29}$$

When all the filled elements are discredited and assembled, we get the linear equations for temperature and use an over-relax iteration to solve this problem [1, 18].

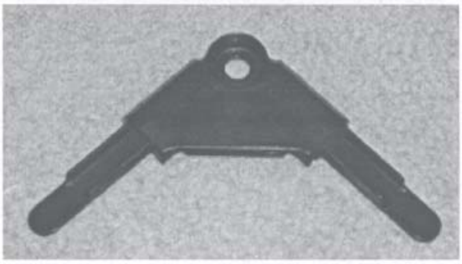

Fig. 3. Ionic Air Filter Reinforcement

CAD Transference

Moldflow Adviser analyzes solid models of thin-walled parts using patented Dual Domain technology which allows users to work directly from 3D solid CAD models without the need to create a finite element mesh analysis model. For complex parts the software perform true 3D simulations using a technique based on a solid, tetrahedral finite element volume mesh, ideal for thick structural components, and geometries with extreme thickness variations. During the model import process, Moldflow Adviser automatically evaluates geometry to determine which analysis technology—3D or Dual Domain—is best for a given part.

A corner reinforcement plastic part for ionic air filter (Fig. 3), produced at Accurate Machine and Tool Ltd. Canada is simulated and optimized.

The part is fabricated in a multi-cavity mold. The data are adopted from a CAD system-Inventor (fig. 4), and simply imported into the pre-processor. The transferring of 3D model into Moldflow Adviser is fully automatic.

After the geometry is being entered, next task is to determine a suitable gate location for a specific material. Autodesk Moldflow Adviser features the world's largest plastic materials database of its kind. With access to more than 8000 grades of commercial plastics and the most up-to date and accurate material data, it has the ability to evaluate different materials, to predict molded part properties and to make the right choice.

The following table and graphs describe the numerical values of functional parameters used in this paper, considering injection molding of CYCOLAC GHT4400 Resin by SABIC Innovative Plastics (GE Plastics), an ABS (Acrylonitrile Butadiene Styrene) plastic material (table 1, fig. 5).

Once the Gate Locator calculation is being finished, the display would show in a spectrum of colours, the potential location of the gate for a balanced flow of the material. Red indicates the worst location to inject the material and blue indicates the best location to inject the material (fig. 6).

The software does not take into account how difficult it is to access a location to inject the material, or if a location is visually sensitive. The advisers allow us to work with single or multiple polymer injection locations. After we

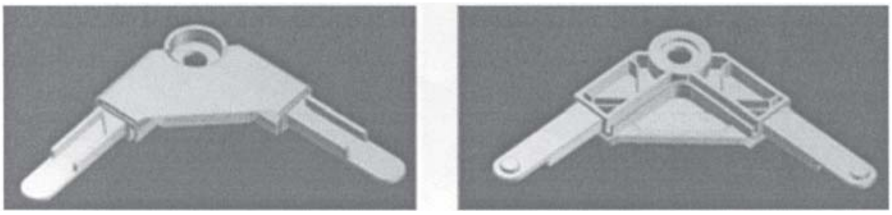

Fig. 4. 3D Model

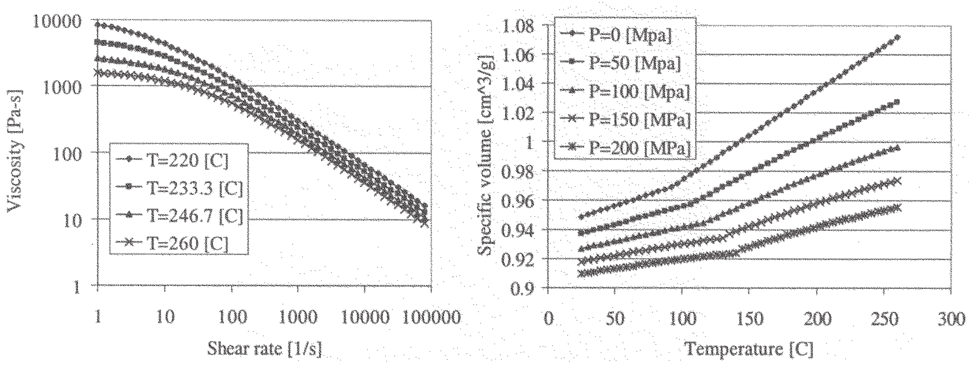

Fig. 5. CYCOLAC GHT 4400 Rheological and PVT Properties (*Moldflow*)

Table 1
CYCOLAC GHT 4400 PROPERTIES

Recommended Processing	Mold Surface Temperature	60 °C	Mechanic Properties	Elastic Modul	2240 MPa
	Melt Temperature	240 °C		Poissons Ratio	0.392
	Mold Temperature Range	(40-80) °C		Shear Modul	805 MPa
	Melt Temperature Range	(220-260) °C		Thermal Exp.	8e-005 1/°C
	Ejection Temperature	15 °C	Proces Cond.	Mold Temperature	60 °C
	Max. Shear Stress	0.3 MPa		Melt Temperature	240 °C
	Max. Shear Rate	50000 1/s		Injection Pressure	180 MPa

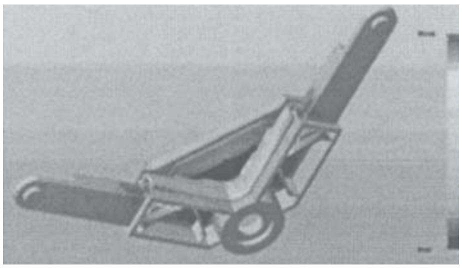
Fig. 6. Gate Locator Calculator

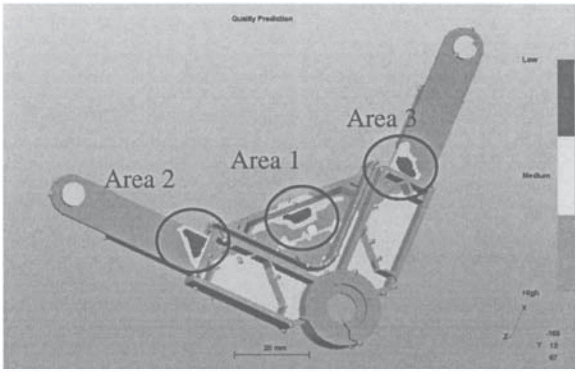

Fig. 7. Quality Prediction

choose the gate location, we run the analysis and save the results. When filling is being completed, a *Results Summary* would be displayed. This gives us a guide to the suitability of our model for injection molding. It also gives temperatures, pressures, weld lines and air trap summaries.

Moldflow Simulation

An optimized design for the part and the mold can thus be developed prior to start of mold construction. Figure 7 shows the quality prediction distribution at the conclusion of mold filling.

As we can see, we have 3 red areas with low quality prediction and 3 yellow areas with medium prediction that involve redesign. On *Area 1* the shear stress caused by friction between the moving melted polymer and the mold wall is too high.

The shear stress should be less than the critical maximum value for that material. (This can be obtained from the Material Database of the *Moldflow*). High shear stress can cause cracks in the plastic, which can make the part degrade and fail. We should try to reduce the friction between the moving plastic and the mold wall, by thickening the part, by reducing the plastic viscosity, or by

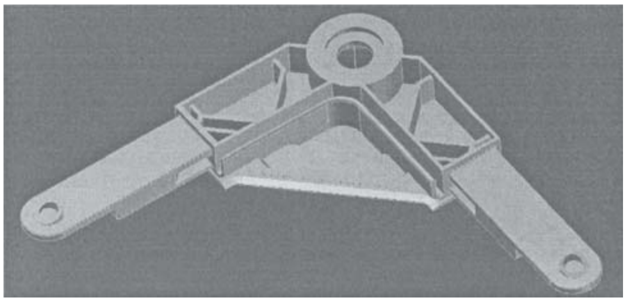
Fig. 8. Redesigned plastic part

slowing the plastic flow. Some ways of achieving these changes are:

- increase the mold or melt temperature;
- thicken the part;
- decrease the maximum injection time. This would make the plastic inject more quickly that would increase the frictional heating;
- select a less viscous material (higher melt flow rate).

On *Area 2* and *Area 3* the cooling time is too high (48.52s) compared to the other parts of the model (aprox. 4.2s). Warping would occur if the cooling time in one area of the model is greater than in other areas. It is usually the best if the elements requiring the longest cooling time are at or near the gate.

To reduce excessive cycle time we have a few different options:

- decrease the melt temperature;
- decrease the mold temperature;
- make the problem area thinner.

Each option requires individual consideration with reference to all relevant aspects of the mold design specification. There are also extensive yellow areas where the cooling time is too high. This could generate packing problems. Therefore the part needs to be redesigned. Filling problems are typically solved using an iterative process involving several analyses. At each step the results are reviewed, problems are identified and fixed. The iterative process could be time consuming.

Figure 8 show the redesigned plastic part, ready for a new and complete simulation.

Summary of Taguchi Method

The method is based on statistical principles and was developed by Dr. Genichi Taguchi to improve the quality of his company's product. Two important tools used by this method are orthogonal arrays and signal-to-noise (S/N) ratios [2, 3]. Orthogonal arrays have a balanced property in which every factor setting occur the same number of times for every setting of all other factors in the experiment.

Factors		Level		
		1	2	3
A	Melt Temperature (°C)	220	240	260
B	Mold Temperature (°C)	40	60	80
C	Injection Pressure (MPa)	40	50	60
D	Cycle Time (Inj.+Pack.+Cool.) (s)	9	11	13
E	Filling Time (s)	0.4	0.55	0.7
F	Gate Injection Position	1	2	3

Table 2
FACTORS AND LEVELS

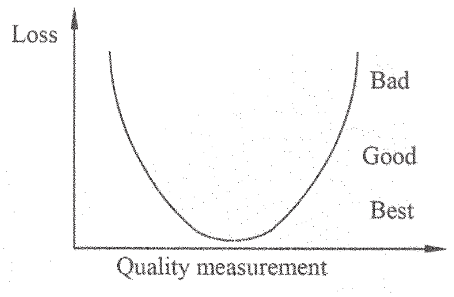

Fig. 9. Quality loss function

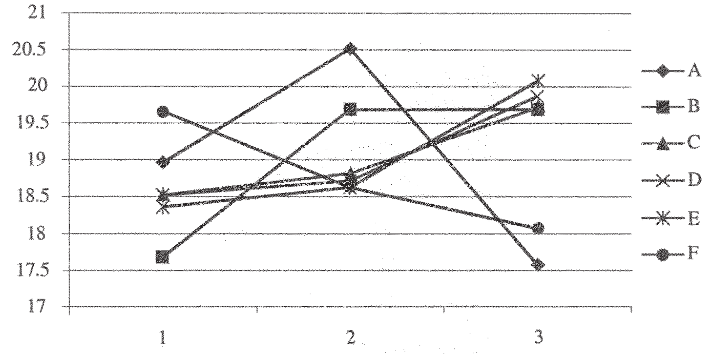

Fig. 10. Signal of noise response graph

Orthogonal arrays allow designers to study many design parameters simultaneously and can be used to estimate the effects of each factor independently [20].

The signal-to-noise ratio, a key idea in Taguchi method, it is a quality indicator that quantifies the effect of a specific design factor over the performance of the process or product.

The general steps involved in the application of the Taguchi method are [5]:

-identify the process objective, as a target value for the performance of the process or product;

- identify the design parameters affecting the process;
- select appropriate orthogonal arrays for the parameter design indicating the number of and conditions for each experiment;
- conduct the experiments;
- analyze the data to determine the effect of the different parameters on the performance of the process;
- conduct the confirmation experiment.

Instead of using factorial DOE and test all possible combinations, the Taguchi method tests pairs of combinations which could give the full necessary data of all the factors that affect the product quality with a minimal number of experiments.

The main idea of Taguchi method is to assume that *m* is the target value of the performance characteristic of a process, and *y* is the measured value of quality, a loss function is defined as [2]

$$l(y) = k_c(y-r)^2 \qquad (30)$$

where k_c can be determined by considering the specification limits or the acceptable interval, delta

$$k_c = C/\Delta^2. \qquad (31)$$

If the goal is to minimize the performance characteristic value, the loss function is defined as follows

$$l(y) = k_c\,(y-m)^2 \qquad (32)$$

where $m=0$.

If the goal is to maximize the performance characteristic value, the loss function is defined as follows

$$l(y) = k_c \frac{1}{y^2} \qquad (33)$$

Taguchi technique adopted *consistency of performance* as the generalized definition of quality. To measure the performance of population's test sample in terms of its consistency, a quantity called *mean-squared deviation* (MSD) has been defined as

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - m)^2, \qquad (34)$$

and

$$L = l\frac{1}{n}\sum_{i=1}^{n}(y_i - m)^2 = k(MSD). \qquad (35)$$

MSD of three quality characteristics is calculated as below (fig. 9):

Nominal the best:

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - m)^2; \qquad (36)$$

Smaller the better:

$$MSD = \frac{1}{n}\sum_{i=1}^{n} y_i^2; \qquad (37)$$

Bigger the better:

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}; \qquad (38)$$

where:

$$MSD = (W)^2, \qquad (39)$$

and

$$S/N = -10\log(MSD). \qquad (40)$$

In this study, the warpage (W) can be regarded as a loss. When there is a uniform volumetric shrinkage across the part, warpage is reduced. Warpage occurs when there are variations of internal stresses caused by a variation in shrinkage, therefore, when the shrinkage is reduced so is the warpage. For specific character of warpage problems in Taguchi method, it's belonging to "Bigger the better".

Based on the initial simulations results, and referring to recommended parameters given by the producer for Cyclonac 4400, and considering also other factors that could affect the quality of the product [10, 21], an orthogonal array L18 of Taguchi method is used. The table of factors and level is shown in table 5 where:

	A	B	C	D	E	F	W	MSD	S/N
1	220	40	40	9	0.4	1	0.169	0.028561	15.44226591
2	220	40	50	11	0.6	2	0.123	0.015129	18.20189777
3	220	40	60	13	0.7	3	0.117	0.013689	18.63628277
4	220	60	40	9	0.6	2	0.112	0.012544	19.01563955
5	220	60	50	11	0.7	3	0.111	0.012321	19.09354042
6	220	60	60	13	0.4	1	0.068	0.004624	23.34982175
7	240	80	40	11	0.4	3	0.087	0.007569	21.20961495
8	240	80	50	13	0.6	1	0.069	0.004761	23.22301819
9	240	80	60	9	0.7	2	0.057	0.003249	24.88250289
10	240	40	40	13	0.7	2	0.102	0.010404	19.82799656
11	240	40	50	9	0.4	3	0.158	0.024964	16.02685826
12	240	40	60	11	0.6	1	0.127	0.016129	17.92392558
13	260	60	40	11	0.7	1	0.098	0.009604	20.17547849
14	260	60	50	13	0.4	2	0.1175	0.013806	18.59924267
15	260	60	60	9	0.6	3	0.127	0.016129	17.92392558
16	260	80	40	13	0.6	3	0.168	0.028224	15.49381437
17	260	80	50	9	0.7	1	0.129	0.016641	17.78820579
18	260	80	60	11	0.4	2	0.168	0.028224	15.49381437

Table 3
ORTHOGONAL ARRAY OF TAGUCHI METHOD

Level	A	B	C	D	E	F
1	18.95657	17.67654	18.52747	18.51323	18.3536	19.65045
2	20.51565	19.69294	18.82213	18.68305	18.63037	18.63037
3	17.57908	19.68183	19.70171	19.85503	20.06733	18.06401
Delta	2.936573	2.016404	1.174244	1.341796	1.713732	1.586447

Table 4
SIGNAL OF NOISE RESPONSE TABLE

Factors		
A	Melt Temperature (ºC)	240
B	Mold Temperature (ºC)	60
C	Injection Pressure (MPa)	60
D	Cycle Time (Inj.+Pack.+Cool.) (s)	13
E	Filling Time (s)	0.7
F	Gate Injection Position	1

Table 5
THE RECOMMENDED FACTORS
FOR A QUALITY

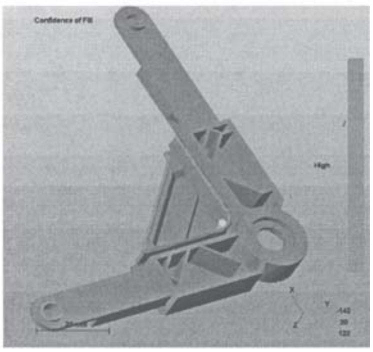

Fig. 11. Confidence to Fill

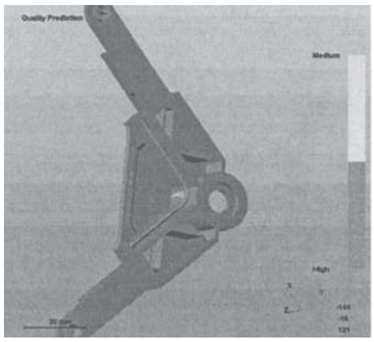

Fig. 12. Quality Prediction

- Gate Injection Position 1 = one gate up side of the part;
- Gate Injection Position 2 = one gate down side of the part;
- Gate Injection Position 3 = two lateral gates up side of the part.

After simulation in Moldflow, and adding a column for signal of noise, the orthogonal arrays are shown in table 3.

Table 4 and figure 10 show the average signal of noise for each factor and interaction level.

Based on analysis "bigger the better", the recommended factors for a quality of the surface – high gloss and minimum warpage are shown in table 5.

Applying the results of optimization on *Molflow*, we get the quantitative filling analysis and quality prediction presented on figure 11 and 12.

In addition, the software judges the appearance and mechanical properties of the part by consideration of temperatures, pressures, shear stresses, molecular chain orientation, residual stresses, etc. and presents a quality assessment. This result is presented in figure 13.

It is clear that, with minimal input and a clear understanding of mold filling and the effects of processing variables, we are able in a minimum amount of time to perform a relatively sophisticated analysis of a plastics injection molding process including issues such as weld lines, air traps, and sink marks.

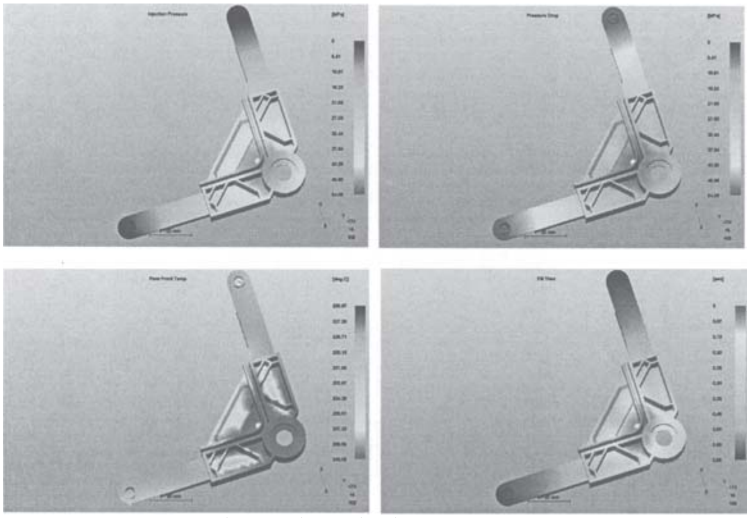

Fig. 13. Final Injection Parameters

Table 6
SUMMARY RESULTS OF FINAL PART

Mold Parameters	
Mold Temp	60 °C
Melt Temp	240 °C
Max Injection Pressure	180 MPa
Filling Analysis	
Actual Injection Time:	0.65s
Actual Injection Pressure	54.06 MPa
Shot Volume	10.01 cm^3
Max Clamp Force	14.62 Tone
Estimated Cycle Time	9.13 s

Conclusions

In this work, the application of a simulation optimization method in a real life production is presented. The method found an attractive solution with a modest number of simulations. The summary of the results of our final test is presented in table 6.

By redesigning it, the mass of the final part is reduced form 0.03lb to 0.022lb that represents 73% of the initial weight and an optimization for the position of the gates is presented. The method can be applied to either discrete or continuous simulations.

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References

1.ARAMPHONGPHUN, C. In-mold Coating of Thermoplastic and Composite Parts: Microfludics and Rheology, PhD Thesis, The Ohio State University. 2006

2. ROY, R.K., Design of experiments using the Taguchi approach: 16 step to product and process improvement, John Wiley Sons, Inc., 2001

3. TAGUCHI, G., Quality engineering (Taguchi Methods) for the development of electronic circuit technology, IEEE Transactions on Reliability, 44, 2, 1995

4. LAMB, H. Hydrodynamics. Cambridge University Press. (1993)

5. PANTON, R.L. Incompressible Flow. John Wiley & Sons, Inc. (2005)

6. TADMOR, Z., GOGOS, C.G., Principles of Polymer Processing, Wiley Intersicence, 2006

7. APRIL, J, GLOVER F, KELLY J, MANUEL L, Simulation-based optimization: practical introduction to simulation optimization, Proceedings of the 35th conference on Winter simulation: driving innovation, 2003

8. JANKO HODOLIC, IVAN MARTIN, MIODRAG STEVIC, DJORDJE VUKELIC, Mat. Plast., **46**, 3, 2009, p 245

9. COUPEZ, T.; MARIE, S. From a direct solver to a parallel iterative solver in 3D forming simulation. International. Journal of High. Performance Computing Applications, 11, 1997, p. 277

10. MARIES, R., E., MANOVICIU, I., BANDUR, G., RUSU, PODE, G., V., Mat. Plast., **46**, no. 1, 2009, p. 58

11. WATHEN, A.; SILVESTER, D., Fast iterative solution of stabilized Stokes systems. Part I: Using simple diagonal preconditioners. SIAM Journal on Numerical Analysis, 30, p.1993, 630

12. RAJAPALEM, V., TALWAR, K.; FRIEDL, C. ANTEC'97. Society of Plastics Engineers. Technical Conference,1997, p. 670

13. PICHELIN, E.; COUPEZ, T. A Taylor discontinuous Galerkin method for the thermal solution in 3D mold filling. Computer Methods in Applied Mechanics and Engineering, 178, 1999, p. 153

14. ARNOLD, D.N., BREZZI, F., FORTIN, M. A stable finite element for Stokes equations. Calcolo, 21, 1984, p. 337

15. PITTMAN, J.F.T., MAHMOUDZADEH, H. Permance of melt thermocouples. Part 2. The upstream-pointing parallel-to-flow type. Polymer Engeering and Science, 3 (1), 1983, p.75

16. GHONEIM, H., Simulation of balancing multi-cavity molds. International Polymer Processing, 1, p. 161987,

17. MAL, O., DHEUR, L., VAN RUTTEN, N. A realistic wall thermal boundary condition for simulating the injection molding of thermoplastics. Simulation of materials processing. Theory methods and applications, 4, 1996, p. 1165

18. WEI C., CHANGYU S., RUI W. 3D Flow Simulation for Viscous Non-isothermal Incompressible Fluid in Injection Molding. Polymer-Plastics Technology and Engineering, 44, 2005, p 901

19. ILIESCU N, HADAR, A, PASTRAMA, S.D. 2009, Mat. Plast., **46**, no. 1, 2009, p 91

20. PEACE, G.S.,Taguchi methods: a hands-on approach. Addison-Wesley Publishing Company. (1993)

21. STAN, D., TULCAN, A., TULCAN, L., ICLĂNZAN, T., Mat. Plast. **45**, no. 1, 2008, p. 119

22. *** Autodesk Inventor 2010. Plastic Part Design

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