Plastic Flow Analysis of Bicycle Chain Guard Using Mold Flow

[1]S.Kovalan, [2]G.Venkatachalam, [3]R.Vicknesh, [4]K.Elumalai
[1,2,3,4]School of Mechanical Engineering, VIT University, Vellore, Tamilnadu, India

Abstract
The intense global competition has been putting immense pressure on Mold Makers to avoid guess work and go scientific so they can be "First time right". This paper investigates the possibility of one such venture with the aid of a virtual manufacturing tool called Mold Flow from Autodesk. The Chain cover plastic part is analyzed for best gating location. It is optimized for best molding cycle, reducing the cycle time, improving part quality and avoiding rejections. The unnecessary rework to fine tune the mold after first try out has been eliminated.

Keywords
Mold Flow, Virtual Manufacturing, Plastic Flow Simulation, Mold Flow Synergy, Mold Flow Insight

I. Introduction

Global competition the need to be the first in the market, competitive pricing, quality of product, customer satisfaction and loyalty. These are the buzz words in the industry. How to get the product to the market within the budgeted cost, quality and time, these have been the murmurs of the marketing gurus. Well the answer is Virtual manufacturing. Here we are going to present a typical scenario of a bicycle component the chain guard cover. This plastic component is injection molded using Polypropylene Homo-Polymer. The component is large and is thin walled so the tendency to warp and not fill properly is a major issue.
The challenge was to get this product in the market in 4 week time. In order to accomplish this task we choose to use Autodesk Mold flow analysis software. The following are the benefits of doing a Mold flow analysis. The suitability of the product for molding can be analyzed. Best gating location can be determined [1, 4].
The flow for the given gate location or locations if multiple can be verified and if found satisfactory can be adopted or modified to suit the need. Various analyses can be conducted such as, fill, pack, cool and warp. The molding material can be chosen from a vast built in library, also custom material can be added to the library. A huge collection of popular branded injection molding machines with machine data is also readily available for use in the analysis. DOE (Design of experiments) can be done by specifying the required parameters.
Several parameters can be specified depending on the part and customer requirement for specific studies which can be analyzed using DOE.

II. Literature Survey

Several works have been done on mold flow analysis. Guilong Wang et al 2011, [5] investigated molding cycle time optimization using heating / cooling channels. He used mathematical models to optimize the layout of the cooling channels to minimize the required heating time within reasonable temperature distribution and structural strength of the mold. Babur Ozcelik et al 2009, [6] investigated the warpage and structural analysis of thin shell plastic injection molded parts. He used the Taguchi method to evaluate the influence of injection parameters on the warpage at different thickness levels.
D.Mathivanan et al 2009, [7] studied minimization of sink mark depths in injection molding plastic parts. He found that melt temperature, mold temperature, packing pressure and rib to wall thickness ratio were the most influential factors. YuchuaGaoet al 2009, [8] in his work used adaptive optimization method based on Kriging surrogate model to minimize the warpage of injection molded parts. He used mold temperature, melt temperature, injection time, packing time and packing pressure as design variables.
Ko-Tu Chiang et al 2007, [9] in his paper used Response surface methodology to design the experiment and adopted the Central Composite design. The mold temperature, packing time, packing pressure and cooling time were taken as the variables and the responces were shrinkage and warpage. . Fei Yin et al 2011, [10] in his paper investigated warpage of plastic products. He used Back propagation neural network model for warpage prediction and optimization of injection molded plastic parts. He used mold temperature, melt temperature, packing pressure, packing time and cooling time as key process variables.
M.C.Song et al 2007, [11] in his paper studied thin walled injection molding of plastic parts. He studied the effects of process parameters such as injection rate, injection pressure, melt temperature, metering size and part thickness on the molding process for ultra-thin wall plastic parts. He concluded that part thickness was a decisive parameter and metering size and injection rate to be principal factors in the molding parameters. B.Ozcelik et al 2006, [12] in his paper investigated the effects of process parameters such as mold temperature, melt temperature, packing pressure, packing time, cooling time, runner type and gate location on the warpage of a thin shell plastic part. He used ANOVA, artificial neural network with an effective Genetic Algorithm to find the minimum warpage value.

III. Analysis Using Mold Flow

There are a few things we need to know about the part to be molded before starting the analysis. The part material, the machines available with the molding shop to mold the component. The mold construction type, the runner system to be adopted, the positioning of the gate, the quantity to be produced, some bench mark data from similar mold to compare output data with. The part to be molded is shown in Figure 1.All data about the part was collected. The first analysis was to see the molding feasibility of the part which can be done also inside of the 3D modeling software such as Solidworks, Unigraphics, Creo, catia, etc. This basically does a draft analysis, undercut analysis and molding feasibility check. A more advanced analysis is a DFM analysis for checking the part with over 60 preset conditions, such as wall thickness, rib size, boss size, etc, which was also done to check for non-uniform wall thickness areas and draft. The gating location suitability study was carried out and the result is displayed in fig. 2.
The preliminary study using Mold Flow Advisor was able to detect the molding suitability with respect to the draft angles, wall thickness, and wall thickness variations, side core areas, and negative draft sections. The gating suitability diagram was used to position the gate at the customer preferred weld line location.

After determining the gate location the gate was positioned and using material manufacturer recommended settings the analysis was run to get the first set of results without the cooling circuits. Two different cooling circuits were used to determine which one yielded the best results.

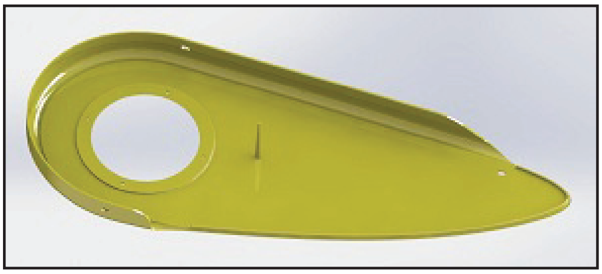


Fig. 1: Component Model Rendered View With Sprue Attached

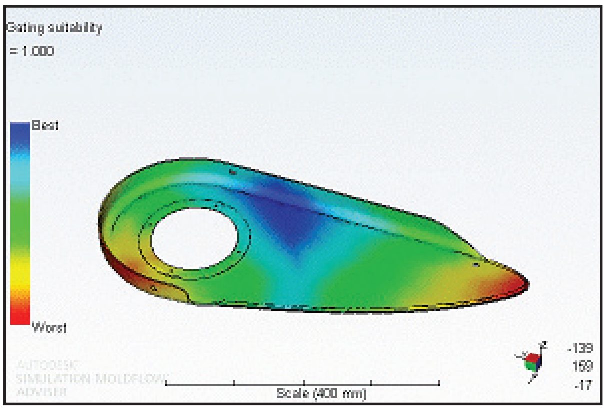
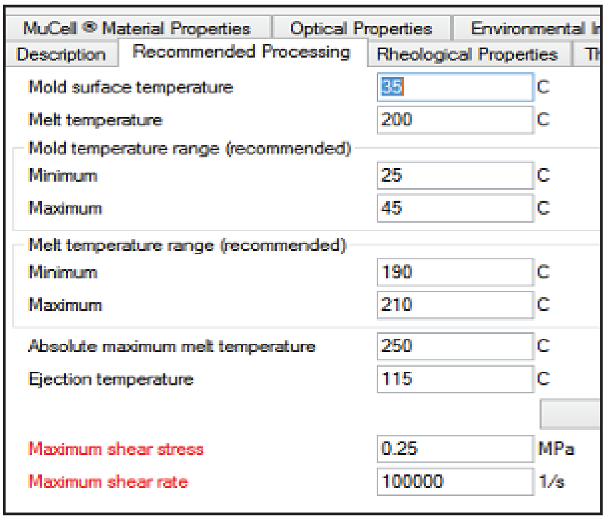


Fig. 2: Gating Suitability Analysis.

The required clamping tonnage (C_t) was calculated using the equation 1 below.

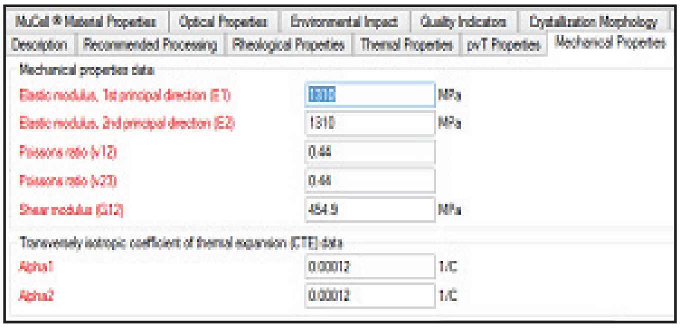
$$C_t = A_p \times P_i \div 10000 \quad (1)$$

Where A_p is projected area of part in cm^2, P_i is the injection pressure which is 35000KPa for thin walled parts. This works out to 190 tons. Mold flow synergy was used to do the rest of the analysis. A fill + pack + warp analysis was done to determine the basic molding conditions and see the possibility of optimizing the cooling system to solve the warpage issues and to reduce the cycle time. The plastic material properties of (Repol-H110-MA) are listed out in figs. 3 & 4.



Mold surface temperature	35	C
Melt temperature	200	C
Mold temperature range (recommended)		
Minimum	25	C
Maximum	45	C
Melt temperature range (recommended)		
Minimum	190	C
Maximum	210	C
Absolute maximum melt temperature	250	C
Ejection temperature	115	C
Maximum shear stress	0.25	MPa
Maximum shear rate	100000	1/s

Fig. 3: Mold Process Parameters.



Mechanical properties data		
Elastic modulus, 1st principal direction (E1)	1310	MPa
Elastic modulus, 2nd principal direction (E2)	1310	MPa
Poissons ratio (v12)	0.44	
Poissons ratio (v23)	0.44	
Shear modulus (G12)	454.9	MPa
Transversely isotropic coefficient of thermal expansion (CTE) data		
Alpha1	0.00012	1/C
Alpha2	0.00012	1/C

Fig. 4: Mechanical Properties of Plastic material

IV. Results and Discussions

The following are the results of the preliminary analysis. Figs. 5, 6 and 7 show the fill time estimate, the clamping tonnage required and the warpage values. The cavity fills in 3.1 seconds on a 200 ton machine with an injection pressure of 36MPa. The clamping force required is 200 ton to keep the mold shut during the filling process. The part deflects 3.5mm due to the stress developed during the molding process. This was minimized further in later analysis to 2.1mm for the 490mm length of the part.

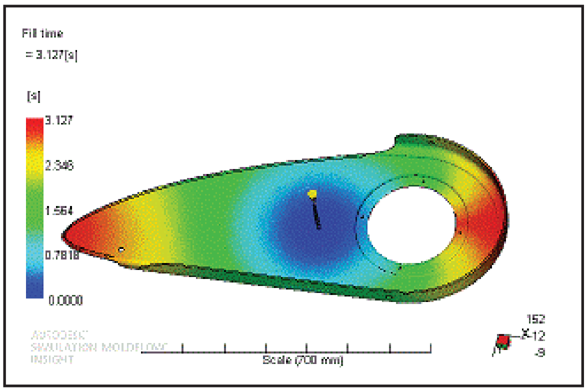


Fig. 5: Estimated Cavity Filling Time

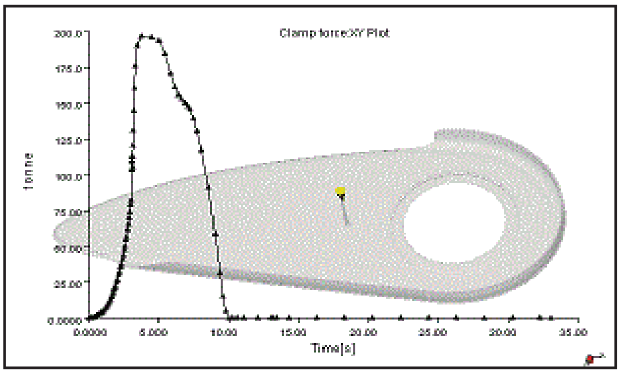


Fig. 6: Clamping Force Plot

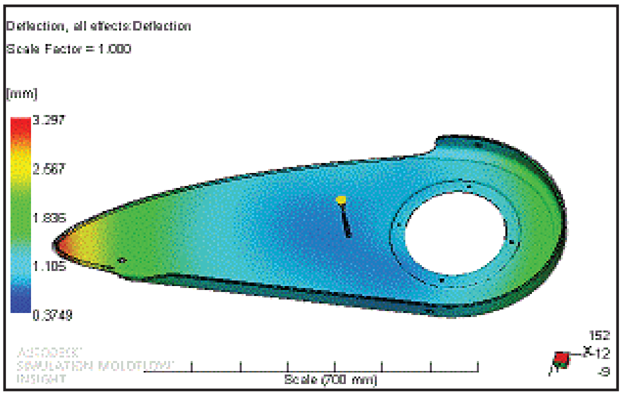


Fig. 7: Warpage Analysis, Deflection all Effects

Fig. 8 shows the weld lines image, these are the meeting points of the flow fronts from the different directions and these can be adjusted by moving the gate location around so that a more acceptable location is obtained. Figure 9 shows the air trap locations, these help us to provide air vents in the mold to release the entrapped air in the mold, which can cause serious molding defects.

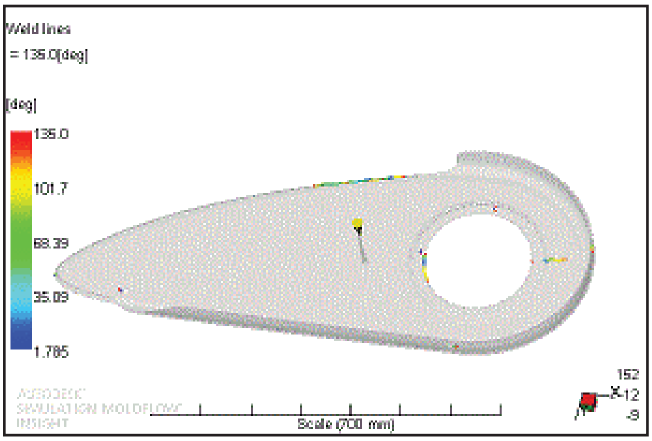


Fig. 8: Weld Lines Location Plot

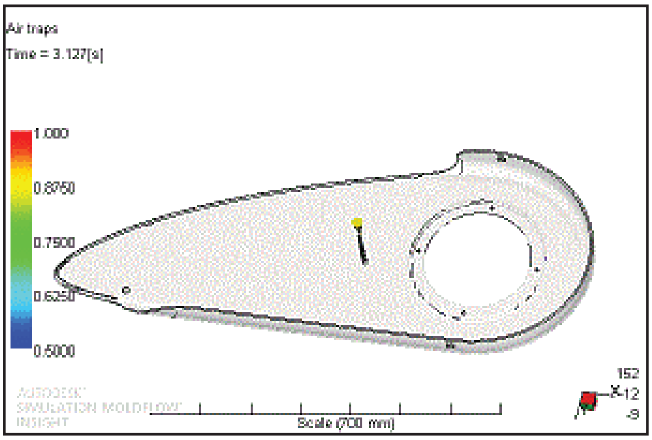


Fig. 9: Air Traps Location

A Vertical gradient cooling system with a single inlet and outlet was used and the temperature distribution in the mold across the length is shown in Figure 10. There is a steep drop in temperature across the mold surface which is about 25°C which is not desirable.

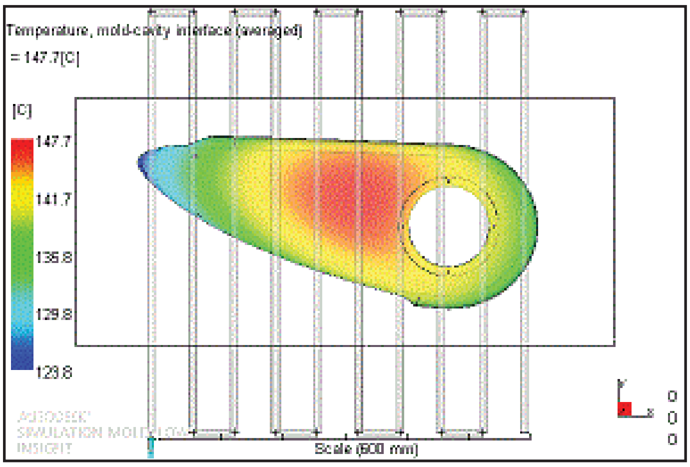


Fig. 10: Temperature of Mold Cavity Interface (Averaged)

The cooling system was modified and parameters adjusted. Fig. 11 shows the temperature distribution on the mold surface with this new setup. This is a very big improvement from the previous setup.

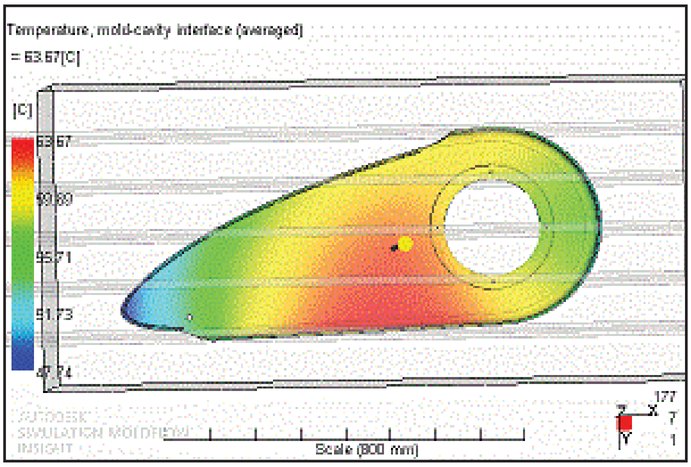


Fig. 11: Temperature of Mold Cavity Interface Improved.

Fig. 12: The Component Produced From the Injection Mold.

V. Conclusion

Mold flow analysis of the part has greatly helped in reducing the cycle time to mold the part. The issues with excessive warpage have been dealt with to a great extent. The molding cycle was optimized so that a part with the best quality can be produced without having to do any guess work. The analysis has saved several man hours of trouble shooting and rework associated with this process, saving considerable time, money and resources.Fig. 12 shows the Injection molded part.

The mold was manufactured utilizing CNC machines such as CNC Milling, CNC Wire EDM, CNC EDM, CNC Lathe. These machine tools were simulated virtually to check for any probable errors in programming and verified to avoid costly rework. Virtual manufacturing is the way to go in order to be on time, within cost and to be profitable.

Several CAE vendors have developed solutions for Mold Flow analysis. This software has proven to be a effective scientific method to analyze the plastic part before committing to any manufacturing activities. These software are finding their way slowly into the Indian Tool rooms and are really a boon to the mold makers.

References

[1] Joe Shoemaker,"Mold Flow Design Guide, Hanser Publishers, Munich Germany, 2006.

[2] Dominick V.Rosato, Injection Molding Handbook, Kluwer Academic Publishers, Boston, USA, 2000.

[3] Herbert Rees, Bruce Catoen, Selecting Injection Molds, Hanser Publishers, Munich Germany, 2006.

[4] John P.Beaumont, Runner and Gating design Handbook. Munich, Germany. Hanser Publishers, 2004.

[5] G. Wang, G. Zhao, H. Li, Y. Guan,"Research on optimization design of the heating/cooling channels for rapid heat cycle molding based on response surface methodology and

constrained particle swarm optimization", Expert Syst. Appl., Vol. 38, No. 6, pp. 6705–6719, 2011.
[6] B. Ozcelik, I. Sonat,"Warpage and structural analysis of thin shell plastic in the plastic injection molding," Mater. Des., Vol. 30, No. 2, pp. 367–375, 2009.
[7] D. Mathivanan, N. S. Parthasarathy,"Sink-mark minimization in injection molding through response surface regression modeling and genetic algorithm," Int. J. Adv. Manuf. Technol., Vol. 45, No. 9–10, pp. 867–874, 2009.
[8] Y. Gao, X. Wang,"Surrogate-based process optimization for reducing warpage in injection molding," J. Mater. Process. Technol., Vol. 209, No. 3, pp. 1302–1309, 2009.
[9] K. T. Chiang, F. P. 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., Vol. 35, No. 5–6, pp. 468–479, 2007.
[10] F. Yin, H. Mao, L. Hua, W. Guo, 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.
[11] M. C. Song, Z. Liu, M. J. Wang, T. M. Yu, D. Y. Zhao, "Research on effects of injection process parameters on the molding process for ultra-thin wall plastic parts," J. Mater. Process. Technol., Vol. 187–188, pp. 668–671, 2007.
[12] B. Ozcelik, T. Erzurumlu,"Comparison of the warpage optimization in the plastic injection molding using ANOVA, neural network model and genetic algorithm," J. Mater. Process. Technol., Vol. 171, No. 3, pp. 437–445, 2006.
[13] X. P. Liao, H. M. Xie, Y. J. Zhou, W. Xia,"Adaptive adjustment of plastic injection processes based on neural network," J. Mater. Process. Technol., Vol. 187–188, pp. 676–679, 2007.
[14] W.-C. Chen, P.-H. Tai, M.-W. Wang, W.-J. Deng, C.-T. Chen,"A neural network-based approach for dynamic quality prediction in a plastic injection molding process," Expert Syst. Appl., Vol. 35, No. 3, pp. 843–849, 2008.
[15] M. Altan,"Reducing shrinkage in injection moldings via the Taguchi, ANOVA and neural network methods," Mater. Des., Vol. 31, No. 1, pp. 599–604, 2010.
[16] P. Krishna, M. P. G. C,"A Review on Application of Artificial Neural Networks for Injection Moulding and Casting processes," Int. J. Adv. Eng. Sci., Vol. 3, No. 1, pp. 1–12, 2013.
[17] H. Kurtaran, T. Erzurumlu,"Efficient warpage optimization of thin shell plastic parts using response surface methodology and genetic algorithm," Int. J. Adv. Manuf. Technol., Vol. 27, No. 5–6, pp. 468–472, 2006.