Product Design Optimization through Seamless Integration of CAD and CAE

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ABSTRACT

With the increasing diverse and complex product design in recent years, the application of CAD and CAE tools in product development and trouble shooting of injection molding processes becomes common. No matter in product design or process optimization, in a short time, CAD and CAE tools can complete multiple design changes, which can be verified with experimental data for further reliability and accuracy. Based on these verified design results, design guideline and optimal process condition can be gained before mass production, the time and cost by the empirical method or trial and error method in conventional process can be saved, and product development cycle and product quality can be improved definitely. However, due to the different development teams of CAD and CAE, it commonly makes different user interfaces and data structures. This results in weak connection between CAD and CAE user, decreasing integration benefit. Beside, the lack of material properties induced in processing, usually we overlook the effects of process during product design or structure analysis stage. It makes the difference between the analysis results and actual product on the deformation behavior. After identifying problems found in the CAE analysis, the design correction must be returned to model designer and then the CAE analysis of changed design will be run again, which takes time and effort.

Keywords: seamless integration, PLM, injection molding, structure analysis.
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1. INTRODUCTION

Due to its economy, easy processing, and better material properties, recently, plastics are widely used for product production in industries, instead of mental material. Not only for appearance but also strength demand, plastic can meet those requests. With the trend of small profit and diversification in market, product life cycle become shorter, which means product and mold designer have to decrease cost and time in developing stage. However, conventional empirical method or trial and error method cannot satisfy the demands in more and more real cases. To efficiently control product development, nowadays using CAD and CAE technology become popular. CAD software is already well-developed worldwide and has advantage of high flexibility to modify the geometry model. In Product Lifecycle Management (referred to as PLM), only relying on CAD software and technology is not enough for product development (see Fig. 1). For injection molding process, PLM is usually considered to cover both CAD and CAE technologies as shown in Fig. 2.

However, platform difference between of both CAD and CAE tools is very crucial to solve. The key problems commonly are not only for CAD and CAE software interfaces, but also file format and conversion tolerance error. This decreased the efficiency the convenient of integration. Therefore, nowadays people expect the technology of seamless integration of CAD and CAE.

This paper is going to interpret seamless integration of CAD and CAE technology demands and concept. Then explain how process condition affects result by using CAE technology, especially focus on CAE injection molding analysis. A case study of using seamless integration of CAD and CAE technology is showing product quality affected by process condition. Finally are the conclusions of the entire paper.

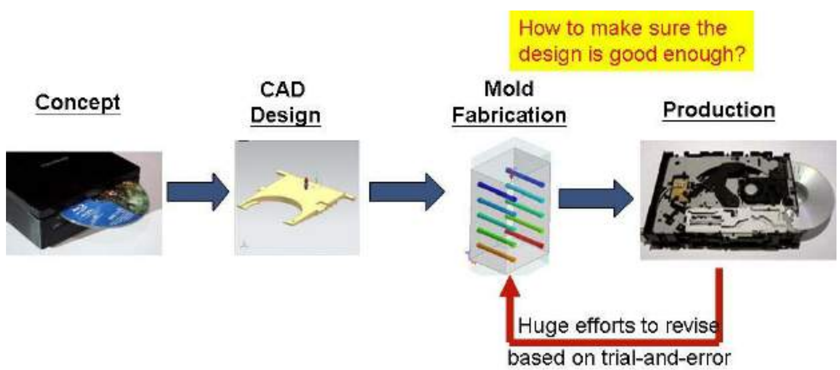

Fig. 1: Early product development process of plastic injection molding.

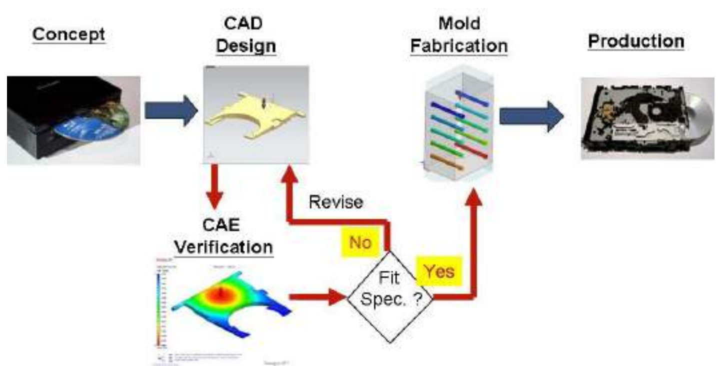

Fig. 2: Product development process of plastic injection molding.

2. THE DEMANDS AND CONCEPT OF SEAMLESS INTEGRATION OF CAD AND CAE

In early injection molding products development, mold was manufactured directly after CAD stage. If it is not going well, trial-and-error usually has been used for solving the problem (in Fig. 1). With the evolution of the times, people know how to use CAE technology to simulate molding process before mold manufacturing and trial as shown in Fig. 2. To eliminate potential problems pass down to next stage. This method increases production rate and yield. Even so, due to the different development teams of CAD and CAE, it commonly makes different user interfaces and data structures. This results in weak connection between CAD and CAE user, decreasing integration benefit. According to this situation, in Fig. 3, people anticipate new generation seamless integration of CAD and CAE [1-2].

However, this kind of integration has many internal processes details need to be solved. In Fig. 4, generally, the first step is pre-processing of geometry model and mesh generation. This step includes importing CAD file, checking geometry topology, defining components of gate and cavity, generating solid mesh. It then executes injection molding process simulation. After injection molding simulation, using the analysis results, people can predict the production can meet the specifications or requirements virtually. If it doesn't fit the requirement, in this seamless integration, it can be iterated through injection molding parameter modification or via part and design modification effectively.

In this integration, one of the key issues is that it is very hard to image injection molding process due to complexity and varied internal process (see Fig. 5). If we make closer study, it has been recognized that the thermo-mechanical history experienced during processing, fountain flow in the vicinity of the melt front, viscoelastic behavior and crystallization kinetics of the polymer melt, as well as the compressible flow during packing stage influence the microstructure development, stress

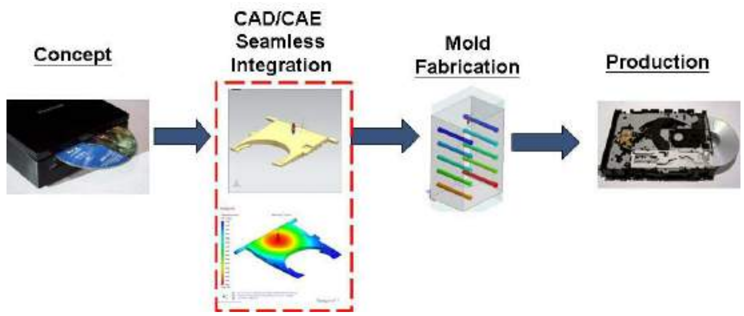

Fig. 3: New generation product development process of plastic injection molding.

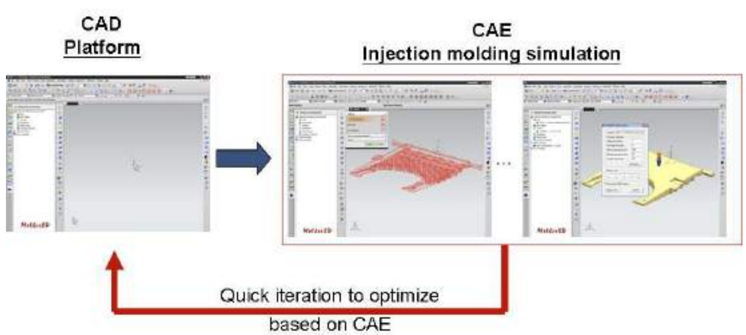

Fig. 4: The concept of new generation CAD/CAE seamless integration.

relaxation, and ultimately, the quality of the molded article. Indeed, factors that influence the thermal-mechanical history of polymer chains and hence the properties of end products include part design, mold design, material selection, process condition and machine setting.

All these factors contribute to the process dynamics of an injection-molding process. For instance, the processing property of a plastic material influences its flow behavior, internal pressure distribution and ultimate properties and applications. A process condition such as melt temperature or injection pressure will directly contribute to the thermal-mechanical history of a molding. Part design and mold design determine the path of melt flows and their temperature distribution. The dimensional accuracy of the part depends on the pvT behavior of the plastic material and the design of the cooling lines [1-2].

One should evaluate the effects of various factors on the properties and behavior of molded parts in order to control quality.

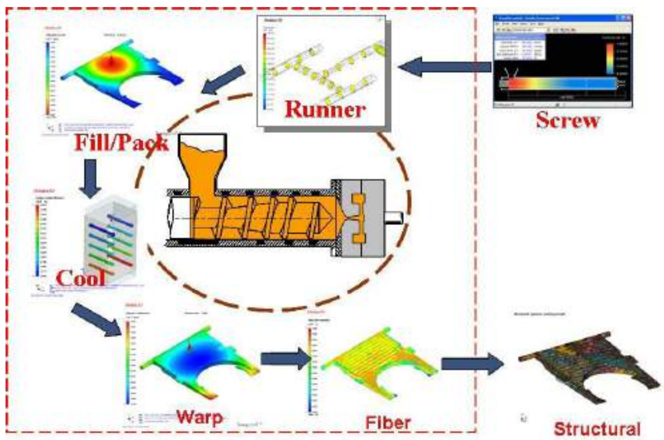

Fig. 5: The concept of injection molding and structure analysis seamless integration.

3. THEORETICAL BACKGROUND

Flow Behavior:

The model used for filling and packing stage during polymer material molding process is Generalized Newtonian Fluid (GNF). The anisotropic 3D flow behavior governing equations are as following:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho u = 0 \tag{3.1}$$

$$\frac{\partial}{\partial t}(\rho u) + \nabla \cdot (\rho u u - \sigma) = \rho g \tag{3.2}$$

$$\sigma = -PI + \eta(\nabla u + \nabla u^T) \tag{3.3}$$

$$\rho C_p\left(\frac{\partial T}{\partial t} + u \cdot \nabla T\right) = \nabla(K\nabla T) + \eta \dot{\gamma}^2 \tag{3.4}$$

where u is the velocity vector. T is the temperature, t is the time. P is the pressure, σ is the total stress tensor. ρ is the fluid density. η is the viscosity. K is the thermal conductivity, C_p is the specific heat, and $\dot{\gamma}$ is the magnitude of the rate of deformation tensor. In this work, the Modified-Cross model with Arrhenius temperature dependence is employed to describe the viscosity of polymer melt:

$$\eta(T,\dot{\gamma}) = \frac{\eta_o(T)}{1+\left(\eta_o\dot{\gamma}/\tau^*\right)^{1-n}} \tag{3.5}$$

with

$$\eta_o(T) = BExp\left(\frac{T_b}{T}\right) \tag{3.6}$$

where η is the viscosity, η_o is the zero shear viscosity, n is the power law index, B is called the consistency index, and τ^* is the parameter that describes the transition region between zero shear rate and the power law region of the viscosity curve. A volume fraction function f is introduced to track the evolution of the melt front. Here, f=0 is defined as the air phase, f=1 as the polymer melt phase, and then the melt front is located within cells with 0<f<1. The advancement of f over time is governed by the following transport equation:

$$\frac{\partial f}{\partial t} + \nabla \cdot (\mathbf{u}f) = 0 \tag{3.7}$$

Regarding to stabilization and efficiency of calculation, Finite Volume Method (FVM) has been used to solve 3D transient state flow behavior.

Fiber Orientation:

The fiber orientation state at each point in the part is represented by a 2nd-order orientation vector A, where

$$A_{ij} = \int (p_i p_j)\varphi(p)dp \tag{3.8}$$

The equation of orientation change for the orientation tensor proposed by Advani and Tucker is employed for the analysis:

$$\frac{\partial A_{ij}}{\partial t} + u_k \frac{\partial A_{ij}}{\partial x_k} = A_{ik}\Omega_{kj} - \Omega_{ik}A_{kj} + \lambda\left(A_{ik}E_{kj} + E_{ik}A_{kj} - 2A_{ijkl}E_{kl}\right) + 2C_I\dot{\gamma}\left(\delta_{ij} - 3A_{ij}\right) \tag{3.9}$$

Where C_I is the interaction coefficient with the value ranged from 10^{-2} to 10^{-3}. In this study, we take C_I as 10^{-2} for default value. For the fourth-order tensor A_{ijkl}, a closure approximation is needed in order to calculate the distribution of 2nd order A on the basis of a velocity field. Here, the hybrid closure approximation will be primarily adopted [3-4].

4. CASE STUDY

To understand seamless integration of CAD and CAE, we use NX as CAD and Moldex3D eDesignSYNC for NX as interface CAE system. The study case is a slot-in CD-ROM bearing as shown in Fig. 6. This part is using for stabilizing motor bearing.

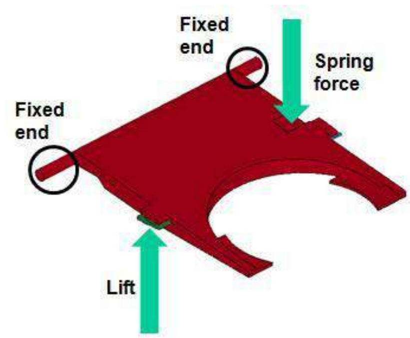

Fig. 6: Slot-in CD-ROM bearing.

After design has been completed in NX, execute Moldex3D eDesignSYNC for NX to run injection molding analysis. Then it can be further through Moldex3D-I2 exported to LS-Dyna for structure analysis. Material in this study is PA66 Ultramid A3W. The system has filling time with 0.2 sec. The specification for this product includes:

- To decrease warpage value to be less than 0.1 mm
- In motion, height difference around the bearing should be less than 1 mm.

5. RESULT AND DISCUSSION

Fig. 7 shows the melt flow behavior. It can easily understand the flow balance in this geometry model. Using this flow behavior, we can predict the weld line, air trap, and other filling defects. To further predict product quality, it can perform packing, cooling and warpage deformation to examine in Fig. 8.

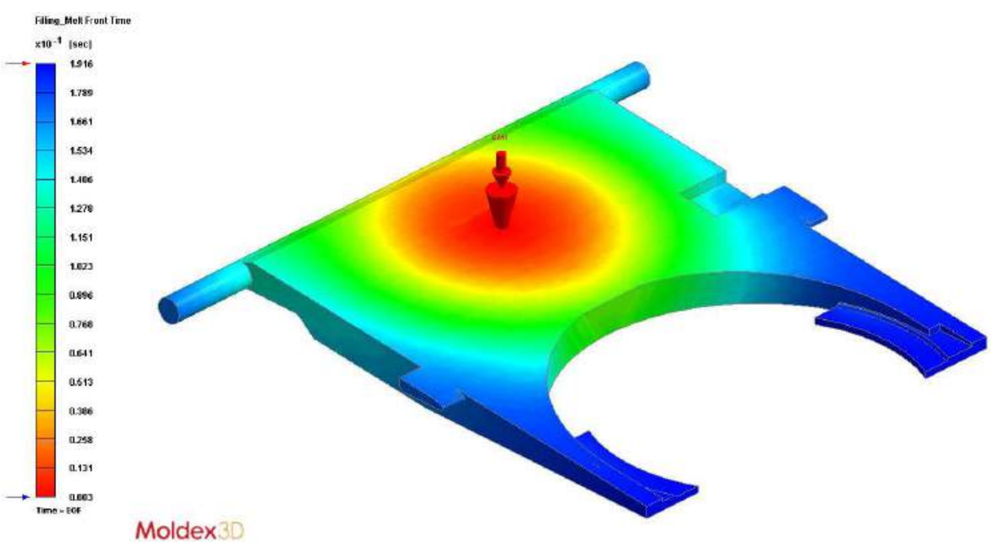

Fig. 7: Slot-in CD-ROM bearing melt front time.

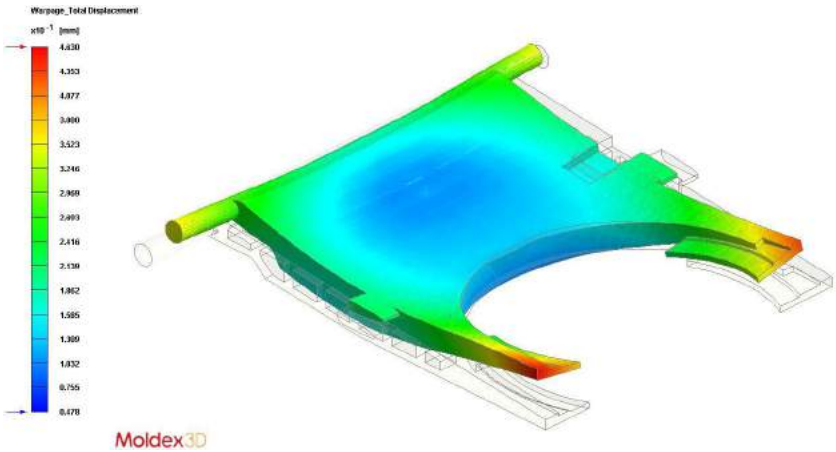

Fig. 8: 10X Warpage trend of product.

Through this result we can clearly found the product is not perfect after injection molding process. The appearance might have warpage deformation or other defects. Besides, if the plastic has fiber added, it should consider fiber-reinforced content. This component will result in flow induced fiber orientation. To visualize this property, we can use CAE in injection molding analysis to get filling, packing and warpage results. Then fiber orientation can be estimated as shown in Fig. 9. The anisotropic behavior and residual stress due to processing of this plastic with fiber orientation can be delivered to structure analysis software via Moldex3D-I2 exporting.

Moreover, when an engineer finishes one CAD design, he might expect to obtain one unique product. Unfortunately, to injection molding parts, the final product can be coming out with various possibility. For example, in Fig. 10, when we apply the same part and mold designs with different injection molding time from 0.05 sec to 0.2 seconds. The warpage value increases from 0.11 mm to 0.27 mm. When the injection time increases from 0.2 to 1.0 second, the warpage value decreases from 0.27 mm to 0.15 mm. Obviously, even to the same design, the final product can exists in various possible quality.

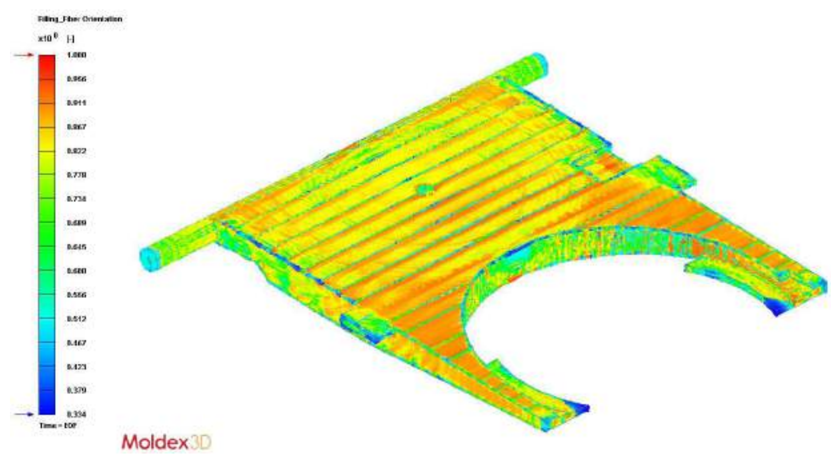

Fig. 9: Fiber orientation.

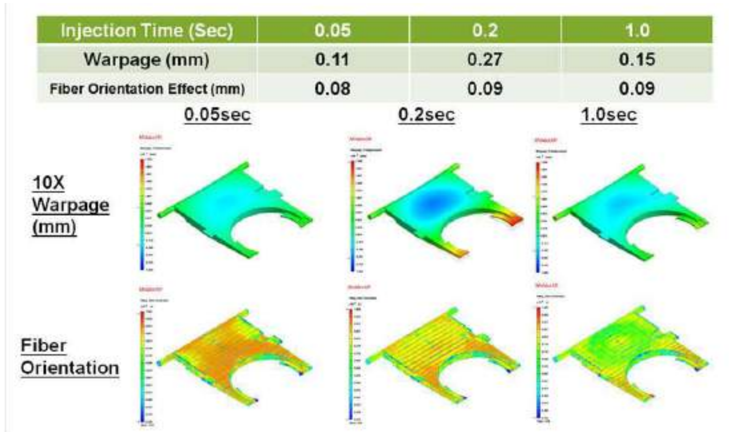

Fig. 10: The effect of injection time.

Furthermore, when the plastic has fiber content, the fiber will affect the product significantly. For example, in Table 1, we apply the other material PA66 Ultramid A3WG10 with 50% fiber content. For the same product and mold design, after went through the injection molding process simulation with filling, packing, cooling, and warpage analyses, the warpage of the final product is down to 0.27 mm. The height difference around the bearing also decreases from 1.8 mm to 0.6 mm. which means mechanical property is affected strongly by different materials.

Moreover, during the product design development and process optimization, sometimes it is very hard to obtain the good quality based on the original design. In this situation, we probably can move back to CAD to modify geometry using the same working interface. For example, Fig. 11 shows two geometry modify testing. Firstly, the bottom thickness is extended to 1.0 mm, and the warpage value increases from 0.49 mm to 0.72 mm. Secondly, the bottom grid area can be filled to 1 mm, and the warpage value decreases from 0.49 mm to 0.46 mm.

Tab. 1: Different material with fiber content and its fiber effect.

Material	*Ultramid A3W*	*PA66 Ultramid A3WG10*
Fiber Content(%)	*0*	*50*
Elastic Modulus(dyne/cm2)	*3.1e+010*	*1.96e+011 / 5.76e+010*
Poisson Ratio	*0.4*	*0.37(v12) / 0.56(v23)*
CLTE(1/K)	*8.5e-005*	*1.2e-005 / 5.5e-005*
Warpage(mm)	*0.49*	*0.27*
Height difference around the bearing (mm)	*1.81*	*~0.60*

Revised Design	Extend the Bottom	Original Design	Fill the Bottom
Warpage (mm)	0.72	0.49	0.43

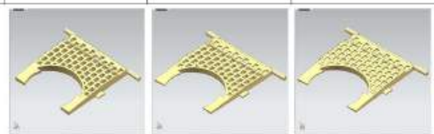

Fig. 11 The effect of geometry modify.

6. CONCLUSIONS

In order to fulfill product diversity and versatility, the design complexity and precision is in greater demand nowadays. CAD and CAE utilization in plastic injection molding design and process condition verification has been widely accepted and applied in the industry by conducting PLM. However, in recent years, how to seamlessly integrate CAD and CAE technique has become one of the important issues constituting to successful product development. This paper demonstrates seamless integration of CAD and CAE technique by using slot-in CD-ROM bearing as an example. It offers process optimization by accurately performing product behavior and quality check before manufacture production. Regardless of product development stages or process condition optimization, seamless CAD and CAE integration technique can be utilized to verify and validate design parameters efficiently and cost-effectively comparing to traditional trial-and-error method. Ultimately, it can shorten overall product development cycles, increase product quality, and provide higher return on investment.

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