SIMULATON AND VERIFICATION ON PART SURFACE QUALITY USING EXTERNAL GAS-ASSISTED INJECTION MOLDING PROCESS

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Abstract

In this research, both simulation and experiment are carried out to study the part surface sink index when molded by conventional injection (CIM) and external gas-assist injection molding (EGAIM). The part of 100 mm long, 50 mm wide and 1.5 mm thick was designed with ribs of different thickness varied from 0.9 mm to 1.8 mm. The results indicate that the rib would lead surface sink varying from 1.61 µm to 8.32 µm depending on different rib designs when molded by CIM. Using EGAIM process would reduce sink value to 0.74µm and 3.9µm respectively. Both results of experiment and simulation by Moldex3D and ANSYS show the similar variation tendency of surface sink for both CIM and EGAIM.

Introduction

The processing and application of thermal plastic play the indispensable and critical role in daily life and industrial manufacture of nowadays. Plastic material is with the characters of light-nature, easy-processing, good electronic and mechanical properties.

Accompanying with the I.T. industry develops vigorously, more and more people ask for stylish design, strength quality and good looking of products. Conventional Injection Molding Process (CIM) can't afford the desire of the market, and most high quality products need to be reprocessed. Therefore, External Gas-Assisted Injection Molding (EGAIM) can not only enhance part surface quality and strength but also make design flexible and variable [1-2].

The EGAIM is a micro-thin layer of gas injected between one surface of the plastic and the adjacent mold cavity surface after the end of filling. Use the gas to apply pressure to the plastic while cooling, forcing it against the opposite mold cavity surface to improve replication of that surface. It is applied to 3C products fittingly nowadays, but still short of related references of the process.

In the current study, the surface quality of products by processes of CIM and EGAIM is investigated. The true 3D numerical approach developed in recent years [3-4] is applied to simulate the processes. And the comparison of simulation and experimental results with sink mark index can also serve as the reference for the injection molding industry to evaluate the product quality.

Experiment

The molding part used in the current study is designed as a plate (100*mm* x 50*mm* x1.5 *mm* (Fig. 1)), with four ribs. And the thicknesses of the four ribs are 0.9 *mm*, 1.2 *mm*, 1.5 *mm* and 1.8 *mm* respectively.(Fig. 2) The detailed molding conditions applied in the experiment are shown in table 1.

The CLF-80T machine is applied in the injection molding process. The gas-assisted equipments (Polypro Technologies Corp. Taiwan) include the gas supply, pressure generator, gas pressure control module, and air injector.

In this study, we utilize an instrument with nano-scale accuracy to get the surface contour data around the ribs, and then put the data into post-processing software developed by Taylor Hobson to calculate the sink mark value. The location of measurement is shown as Fig. 3.

Numerical modeling

The polymer melt is assumed to behave as Generalized Newtonian Fluid (GNF). Hence the non-isothermal 3D flow motion can be mathematically described by the followings:

(1) Conservation of Mass

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

(2) Conservation of Momentum

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

$$\text{where} \quad \boldsymbol{\sigma} = -p\mathbf{I} + \eta\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right)$$

(3) Conservation of Energy

$$\rho C_P\left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \nabla(\mathrm{k}\nabla T) + \eta \dot{\gamma}^2$$

where $\mathbf{u}$ is the velocity vector, T the temperature, t the time, p the pressure, $\boldsymbol{\sigma}$ the total stress tensor, ρ the density, η the viscosity, k the thermal conductivity, C_p the specific heat and $\dot{\gamma}$ is the shear rate. In this work, the modified-Cross model with Arrhenius temperature dependence is employed to describe the viscosity of polymer melt:

(4) Modified-Cross model

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

with

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

where n is the power law index, η_o the zero shear viscosity, and τ^* is the parameter that describes the transition region between the shear rate of zero 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:

(5) Transport Equation

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

The flow rate or injection pressure is prescribed at mold inlet. No slip is assumed at mold wall. Note that only inlet boundary condition is necessary for the hyperbolic transport equation of volume fraction function.

Simulation

The hexa mesh is applied in the model (Fig. 4), and the element number is 600000. The material used in this study is ABS-CHIMEI PA757. Fig. 5(a) and (b) are the viscosity and pVT curves for the material. The process condition of simulation is the same as that of the experiment.

Regarding the EGAIM, Moldex3D-I2 is utilized to export results to other structure analysis package software to carry out the EGAIM simulation.

The loading condition used in the structure analysis software regarding EGAIM simulation is shown as Fig. 6.

Results and discussions

The experimental results are shown in Fig. 7. With the results one can see that with the application of EGAIM, products have a significant improvement in the surface quality.

By comparing the simulation result of melt front to the actual short shot product, the flow pattern is identical (Fig. 8). Based on the distribution of temperature on ribs (Fig. 9), the intensity of high temperature distribution tends to be higher as the thickness of the rib increases. Hence, the thicker the rib is, the more difficult the heat elimination will be. Therefore, warpage will occur more easily in some areas due to uneven temperature distribution. From figure 10, uneven temperature distribution also results in the difference in volume shrinkage.

The product deformation in CIM simulated by injection molding analysis software is similar to that of structure analysis software (Fig. 11). Fig. 11 shows that sink mark tends to get deeper as the thickness of the rib increases, and it is corresponded to the experimental results. From the above comparison between simulation and experiment, the simulation tool used in this research is feasible for sink mark evaluation.

In the current research, the influence of EGAIM on surface quality is considered. By exporting the results from the injection molding analysis software to structural analysis software with boundary condition and gas pressure, the EGAIM can be carried out. By comparing the simulation results of CIM and EGAIM, the application of EGAIM can exactly improve the sink mark happened in CIM (Fig. 12).

Conclusion

In this study, the exact injection experiment had been conducted as well as the injection simulation. By comparing the results of CIM and EGAIM, the sink mark is exactly improved in the case of using EGAIM. Moreover, the tool and the process of EGAIM simulation is feasible for sink mark evaluation. The application can also serve as the reference for the injection molding industry to evaluate the product quality.

References

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Keywords

External Gas-Assisted Injection Molding, EGAIM, sink mark, surface quality

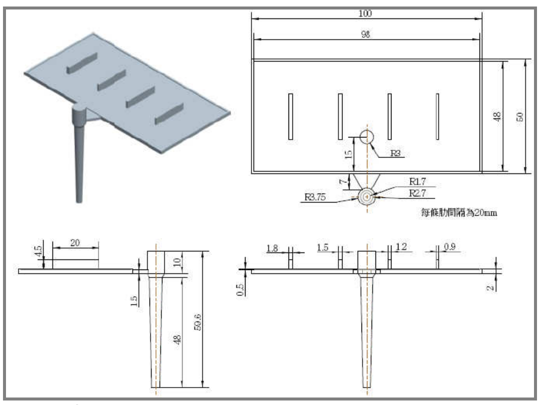

Fig.1 flat part design with runner system and ribs

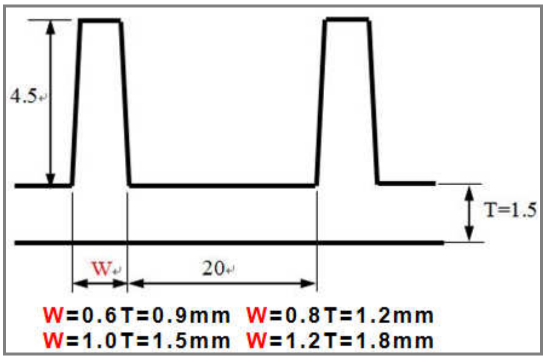

Fig. 2. Schmatics of ribs design

Table 1. Experimental molding conditions

Experimental molding conditions	
Material	ABS-CHIMEI:PA757
Inject velocity	80 mm/s
Packing pressure	40MPa
Packing time	3 seconds
Melt temperature	210℃
Mold temperature	55(℃)

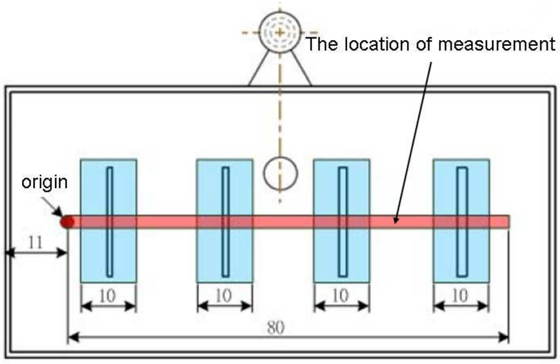

Fig. 3. The location of measurement

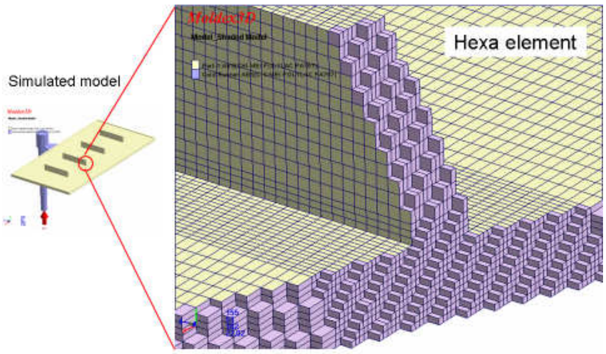

Fig. 4. Schematics of 3D mesh

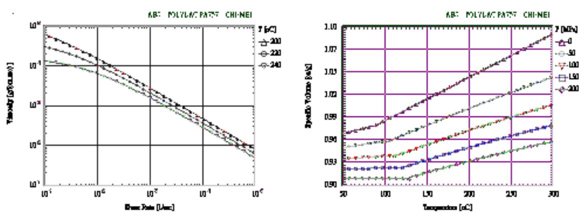
(a) (b)

Fig. 5. Material properties used in this analysis
(a) viscosity (b) pVT

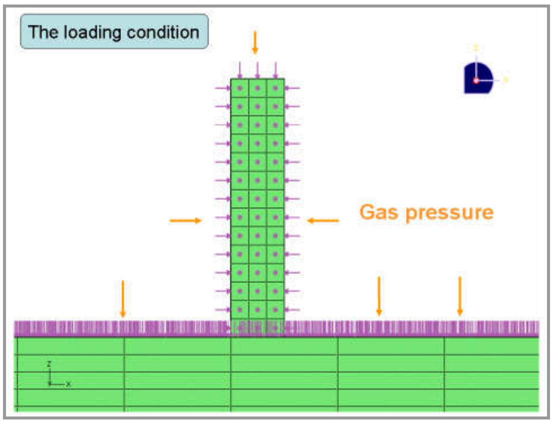

Fig. 6. The loading condition

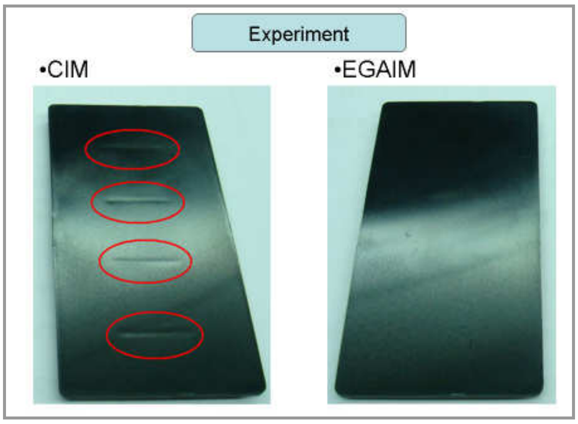

Fig. 7. The experiment results with CIM and EGAIM

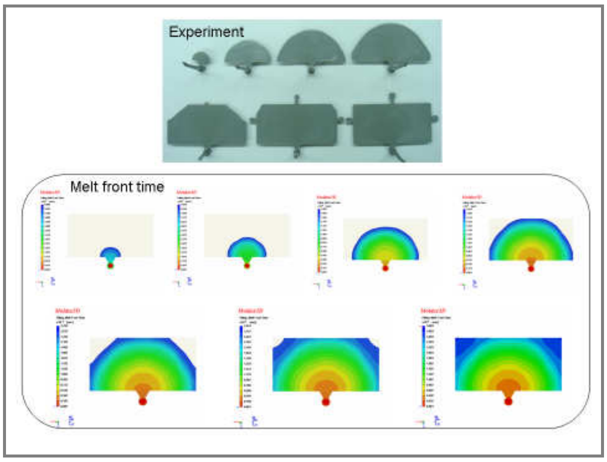

Fig. 8. The simulated melt advancement

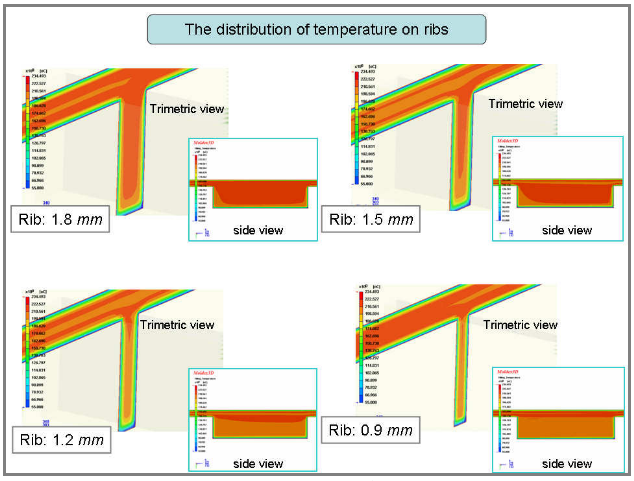

Fig. 9. The distribution of temperature

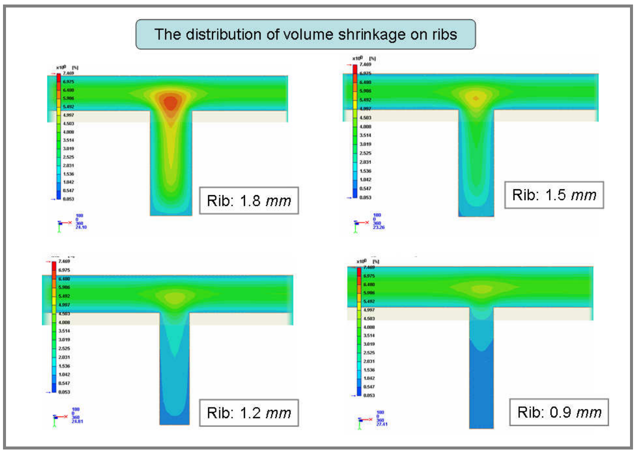

Fig. 10. The distribution of volume shrinkage on ribs

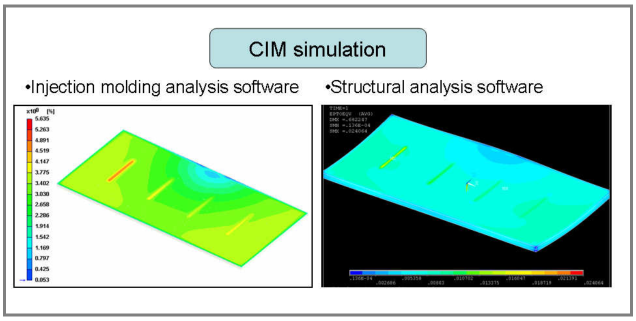

Fig. 11. The intensity of deformation with CIM simulation

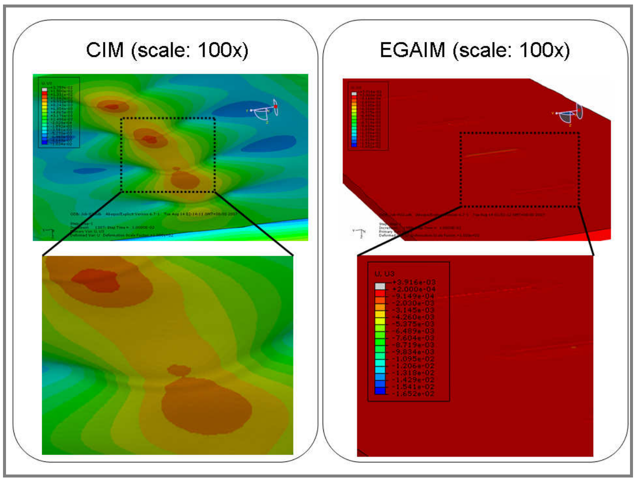

Fig. 12. The simulation of CIM and EGAIM

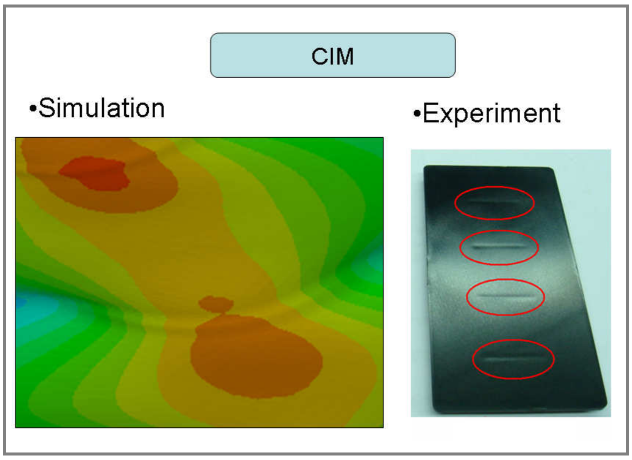

Fig. 13. The deformation of simulation and experiment with CIM

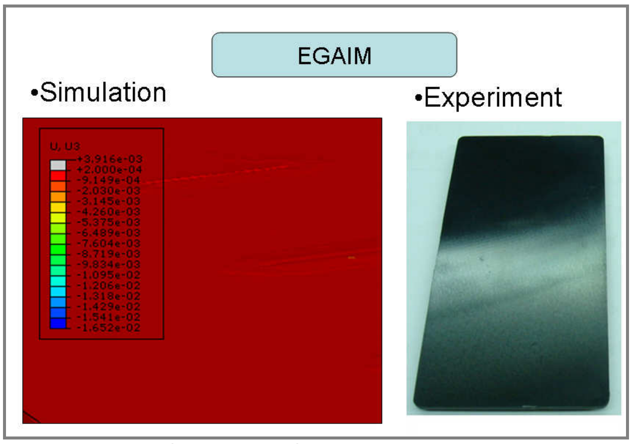

Fig. 14. The deformation of simulation and experiment with EGAIM