IMPROVE COOLING EFFECT OF INJECTION MOLDING BY PULSED-COOLING METHOD

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Abstract

In recent years, the variotherm molding technologies is more and more popular; and the pulsed cooling approach is one of the variotherm processing. However, the complicated cooling control system and the transient behavior of the mold made it difficult to optimize the process. In this study, through applying the comprehensive consideration with various operation specifications in simulation method, including pulsed time, coolant temperature, mold open and mold close temperatures, the cycle time can be dramatically reduced comparing to that of conventional method. In addition, experimental study will also perform to verify and realize the core issues in the near future.

Introduction

The mold surface temperature has great influence for plastic injection molding. With high mold surface temperature, the surface quality of part will be better, but the cooling time will increase and accordingly the cycle time will rise as well. The decreasing of the mold surface temperature will reduce the cooling time, but there is no benefit for the surface quality of part. Therefore, how to shorten cooling time and maintain mold surface temperature meanwhile is a crucial issue for current studies.

For the cooling process, two cooling systems, namely, traditional cooling and pulsed cooling are used for the mold temperature control without changing cooling system design. With the traditional cooling method, const coolant flow is employed in the overall molding process. Generally, the coolant temperature is almost the same as the mold temperature by this approach. For the pulsed cooling method, applying variable coolant flow time to interrupt cooling processing shows the cooling time decrease, but the mold surface temperature keeps high. By means of less cooling time, lowering the usage of power contributes to saving more. [1-4].

Independent studies to validate some of the above claims have been carried out using experimental techniques. These studies have all concluded that there are benefits to employing pulsed cooling method. For instance, pulsed cooling method advantages 20% reductions of cycle time when compared with conventional cooling method. This conclusion was based on results obtained for particular tool geometry, using various different coolant temperature and four different mold temperature: 20, 25, 35 and 50°C [5]. In a further study, pulsed cooling method was applied for injection-compression molded Blu-ray Disc. The result shows that by using pulsed cooling, warpage was reduced and the accuracy in microgroove replication was higher. Besides, coolant temperature was decreased by 8°C, and the cycle time was shorten by 10% as compared to the conventional cooling process [6]. The near study is comparing the results simulating by Moldex3D with experiment. This study demonstrates that pulsed cooling was applied in the injection and packing process for about 0.3 seconds, and mold temperature can be higher than that in conventional injection molding by about 5°C. [7].

As known the conventional process with stable mold temperature and constant coolant flow, the required cooling time will stable as well. However, if coolant flow stops during cooling phase, the cooling time must increase to reach the ejection temperature. And pulsed cooling is adopted for changing cooling time and pulsed cooling time to find out the mold open and close temperatures close to those required for conventional cooling. In this paper, the tensile specimen model was injected with PC polymer as model for simulation. Mold open and close temperature will be measured by sensor.

Parameters definition

This research concentrates on four key parameters of pulsed cooling method (figure 1):

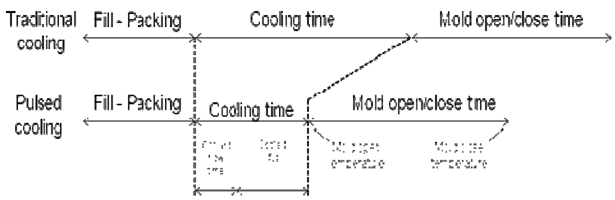


Figure 1: A schematic in comparison of traditional cooling and pulsed cooling

- Coolant flow time (CFT): is the time when coolant flows in cooling channel for moving thermal energy out. While adopting pulsed cooling method, if coolant time is too long, thermal energy will be transferred outside the mold too much, that causes mold temperature drop quickly. On the contrary, if coolant flow time is too short, thermal energy will not be transferred outside the mold too much, that makes mold temperature maintain high.

- Cooling time: in cooling phase of traditional process, thermal energy is transferred continuously from melt through mold to outside by coolant channel. But, applying pulsed cooling, thermal energy is just transferred from melt to mold, and the heat transfer from mold to coolant channel appears only when the coolant flows in cooling channel.
- Mold open and close temperature: are temperatures on cavity surface when mold opens and closes. They are strongly affected by coolant flow time. If CFT is too short, the cooling effect will be weaker, which results in higher mold open and close temperature. On the other hand, if CFT is too long, the cooling effect will be significant, that incurs lower mold open and close temperature.

Simulation work

The governing equations used to describe the heat transfer during the cooling process are the steady-state Laplace equations expressed [8] as:

$$k_m\left(\frac{\partial^2 T_m}{\partial x^2}+\frac{\partial^2 T_m}{\partial y^2}\frac{\partial^2 T_m}{\partial z^2}\right)=0$$

The heat transfer phenomena nearby shell plastic can be governed by a Poisson equation:

$$\rho C_p\frac{\partial T}{\partial t}=k_m\left(\frac{\partial^2 T_m}{\partial x^2}+\frac{\partial^2 T_m}{\partial y^2}+\frac{\partial^2 T_m}{\partial z^2}\right)$$

Where T_m is the mold temperature; k_m is the moldbase thermal conductivity; ρ is the density; C_p is specify heat; t is time; x, y and z are the Cartesian coordinates.

Heat transferred from moldbase to water when coolant stop may also affect mold temperature. However, its contribution is much less than the heat transferred from melt to mold when coolant flows [9]. Therefore, it is neglected in the analysis.

Here, a 3D model built according to the real mold (figure 2) is adopted for this simulation study. Mold material is P20, and density and specific heat of mold plate is 7750 kg/m3 and 465 J/kg°C, respectively. The polycarbonate (PC) produced by Teijin was used for injection.

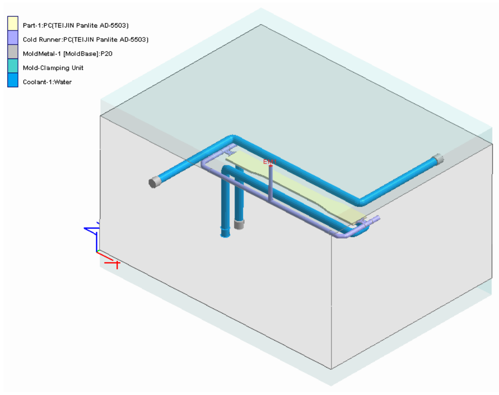


Figure 2: Model for simulation

In this research, both cases of traditional cooling and pulsed cooling will be simulated by the Moldex3D software. Model for simulation is shown in figure 2. Firstly, in the process with traditional cooling, the mold open and close temperatures are measured. Following, those temperatures in the process with pulsed cooling will be recorded as well. Set the open and close temperatures measured in the traditional process as standard, and then make the comparison with those in the process with pulsed cooling. If the temperature difference is higher than ±5°C, it represents the coolant flow time or coolant temperature ought to be modified. Figure 3 shows the flowchart of simulation. Figure 4 shows the sensor locations and schematic tensile specimen. The simulation will be done with the process parameters in table 1 and the variation of coolant flow time, mold temperature, and melt temperature (table 2).

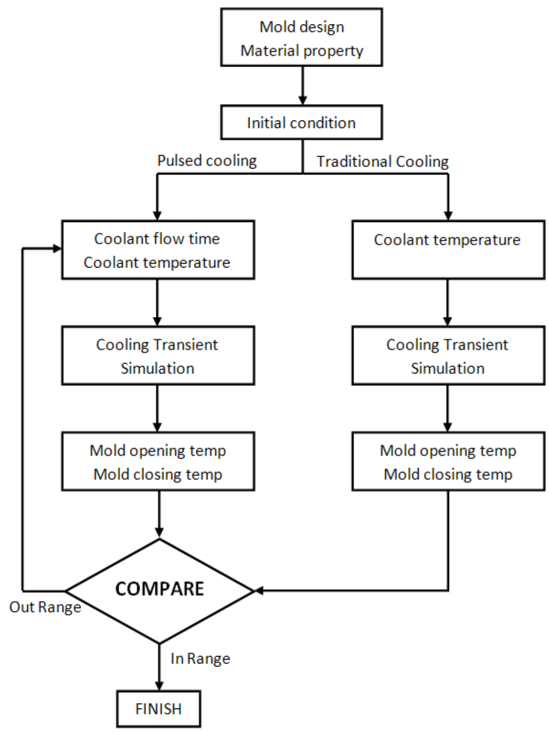
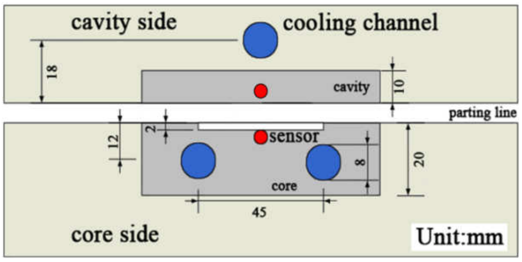
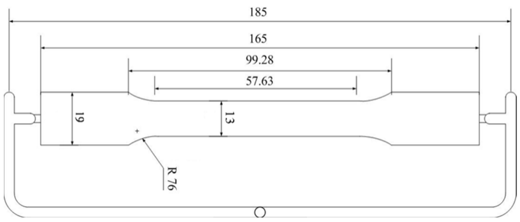


Figure 3
Flowchart of pulsed cooling and traditional cooling



(a)



(b)

Figure 4: (a) The sensors location (in red)
(b) Schematic of Tensile specimen

Table 1: Process parameters

Process parameters	
Filling time	0.18 (s)
Packing time	0.2 (s)
Cooling time	15(s)
Mold open and close time	9 (s)
Injection speed	300 mm/s
Packing pressure	120 MPa

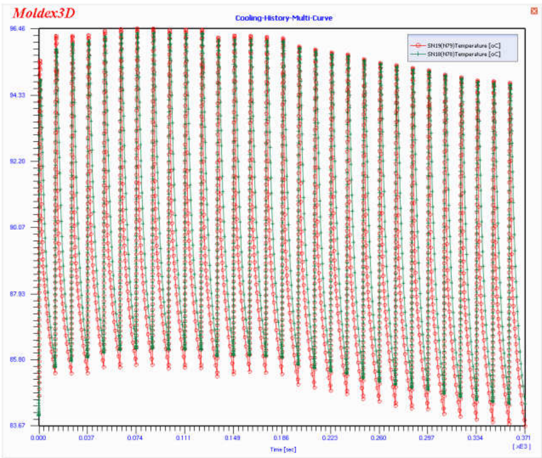
Table 2: Simulation and experiment method

Group	Coolant flow time (s)	Mold temperature (°C)	Melt temperature (°C)	Cooling process
1	Continuous	84	330	Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
2	Continuous	84	330	Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
	Continuous	99		Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
	Continuous	114		Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
3	Continuous	84	330	Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
	Continuous		345	Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed
	Continuous		360	Traditional
	1.0 ; 1.5; 2.0 ; 2.5			Pulsed

Result and discussion

By simulation, the mold open and close temperature will be collected after 30 cycles for obtaining the values under stable situation. Figure 5 shows the temperature variation at the mold and melt.

(a)



(b)

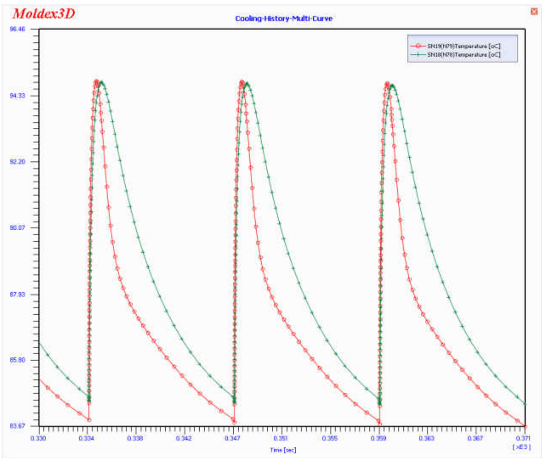


Figure 5: Change of temperature of 2 sensors.
(a) 30 cycles; (b) 3 end cycles
Mold temp = 84°C; Melt temp = 330°C; Coolant temp = 38°C; Coolant flow time = 1 (s); Cooling time = 3 (s); Cycle time = 12 (s)

The variation of CFT at different coolant temperature under the same mold condition (mold temperature 84°C, melt temperature 330°C, cooling time 3 (s) and cycle time 12 (s)) is presented in figure 6. Table 3 displays the simulation results. These results were compared with traditional cooling by simulation. In the case using traditional cooling, mold open temperature is 85.63°C, and mold close temperature is 84.5°C. In the case adopting pulsed cooling, its mold open and close temperatures are close to those in the case with traditional cooling method, with the ±2°C tolerance. Based on this result, it is apparent that the longer coolant flow time is, the higher coolant temperature needs to keep mold temperature close to 84°C. When CFT increases from 1 (s) to 2.5 (s), the coolant temperature increases from 38°C to 63°C. With the longer CFT, there is a more thermal energy transferred to coolant, and that makes mold temperature decrease faster. In order to keep mold temperature close to initial value, coolant temperature must increase. On the other hand, figure 6 also shows that the shorter the CFT is, the faster the coolant temperature raised. In table 3, cooling time decreases from 15 (s) to 3 (s), and cycle time reduces from 24 (s) to 12 (s) when mold open and close time is 9 (s).

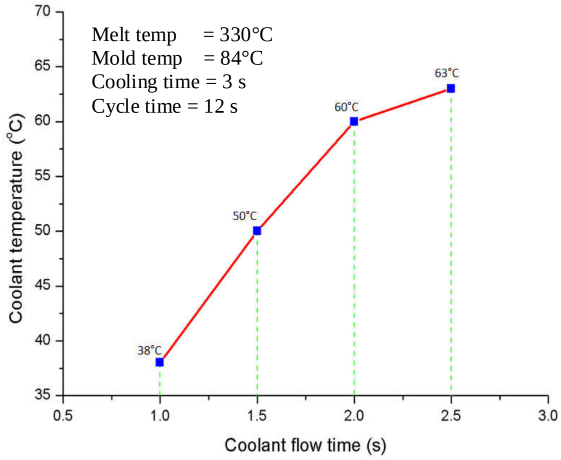


Figure 6: Relation of coolant flow time and coolant temperature

Table 3 Effect of pulsed time on coolant temperature

Case		CFT (s)	Temperature (°C)					cooling Time (s)
			Mold	Melt	Coolant	Open	Close	
	Traditional	15			84	85.63	84.5	15
1		1			38	87	83	
2	Pulsed Cooling	1.5	84	330	50	86.79	83.15	3
3		2			60	86.75	84.09	
4		2.5			63	87.16	83.66	

Next, applying various mold temperature (84°C; 99°C and 114°C) with pulsed cooling parameters (CFT and coolant temperature) and the same injection conditions (melt temperature 330°C, cooling time 3 s, cycle time 12 s) are shown in figure 7. It shows that the coolant temperature increase with the increase of CFT, no matter which mold temperature is adopted. And, with the same CFT and melt temperature, the higher mold temperature is, the higher coolant temperature is. If mold temperature is higher, the temperature difference between melt and mold temperature will be smaller. Then, heat energy spreads outside less. And with the same CFT and higher mold temperature, the rate of heat transfer must be slower. As a result, when mold temperature increases 15°C; the coolant temperature may increase about 20°C.

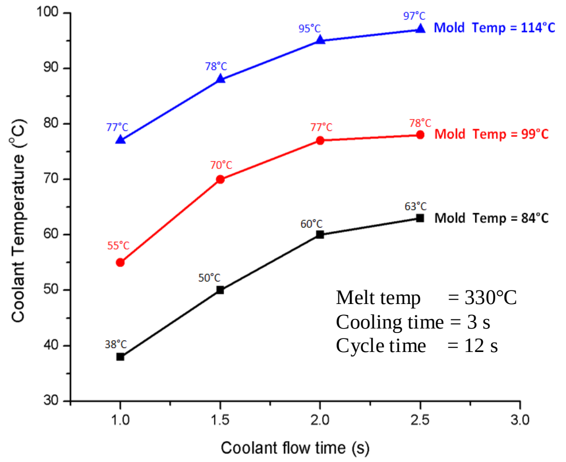


Figure 7: Plot of mold temperature against pulsed cooling parameters

Following, we will investigate the relationship of melt temperature against CFT and coolant temperature. Three melt temperature values - 330°C; 345°C and 360°C are applied. Figure 8 shows that with these melt temperatures, coolant temperature increases if the CFT increases. However, if CFT is the same and melt temperature increases, the heat energy will increase. Under the above situation, to maintain mold temperature, coolant temperature must decrease. When melt temperature increases 15°C, the coolant temperature should decrease about 2°C. As a result, the effect of melt temperature is not so significant as that of mold temperature

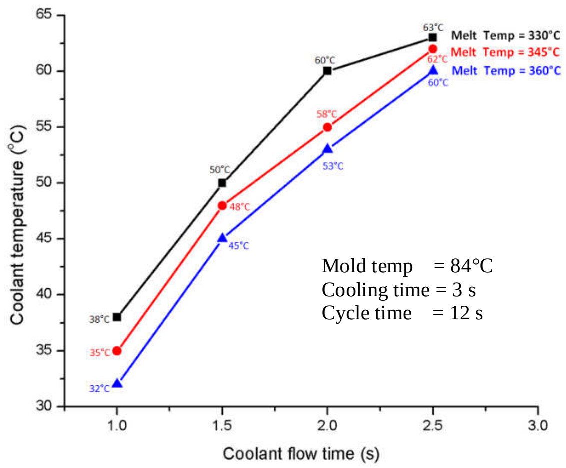


Figure 8: Plot of melt temperature against pulsed cooling parameters

Conclusions

In this study, molded PC tensile specimen with two side gates and 2 mm thickness was used as model for investigating the effect of applying pulsed cooling in process. Through the simulation, the variations of the parameters of coolant flow time, coolant temperature, mold temperature and melt temperature respectively, all variations can satisfy the requirement of the cycle time being 12 (s), which is greatly less than 24 (s), that is the cycle time of adopting conventional process. These effects of coolant flow time, coolant temperature, mold temperature and melt temperature will be observed by experiment in the coming future for further comparison with simulation results in this study.

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Key Words: injection molding, cooling, pulsed cooling, mold temperature, melt temperature.