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DERIVATION OF NEW MODEL FOR INJECTION MOLDING COOLING TIME

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Abstract: **Injection molding is one of the most flexible and important operation for mass production of plastic parts. In injection molding process, cooling system design is very important as it largely affects the cycle time. A good quality cooling system design can reduce cycle time and attain dimensional stability of the part. In this study used heat transfer analysis during polymer processing, the equation for calculating the cooling time inside the injection mold was derived, and the same empirical equation that was obtained through experiments was reached**

*Keywords—***Injection Molding, cooling time.**

I. INTRODUCTION

The injection molding is an important manufacturing process to polymers; it provided high dimensional products with low manufacturing cycles and low cost[1]The most widely used technique for fabricating thermoplastic materials is “Plastic Injection Molding” which is a rate production process and has great dimensional controls[2]. The plastic injection molding process is cyclic process which consists of three stages. These stages are tilling and packing stage, cooling stage and ejection stage [3].The process parameter like till time, packing parameter, injection speed, mold temperature etc. is the greatest importance because it significantly affects the productivity and the quality of final product. Plastic Injection Molding is one of the most important methods for forming thin shell plastic products. It has many advantages such as short product cycle. High quality part surfaces good mechanical properties and light weight.[4]

The process of PIM can be described:-
□ □ Polymer materials heated up to melting temperature and melted polymer is injected into the cavity by a gate under high pressure.
□ □ When filling is about to complete, the cavity is kept at a constant pressure for the packing pressure.
□ □ In order to fill the remaining volume of the cavity and to reduce the shrinkage due to cooling the packing pressure is used extensively, the plastic is extruded from mold once the inner cavity is of stable case .[5]

In addition to mold, raw material, and machine costs, the cost of injection molded articles depends on the molding cycle. Mold cooling time is the biggest contributor to the overall cycle time in almost all plastic molding applications (could be as high 70-80% of total cycle time). [6]

Mold cooling analysis will helps optimize cooling layout, reduce cooling time, avoid hot spots, avoid filling/processing issues and most importantly save money [7]

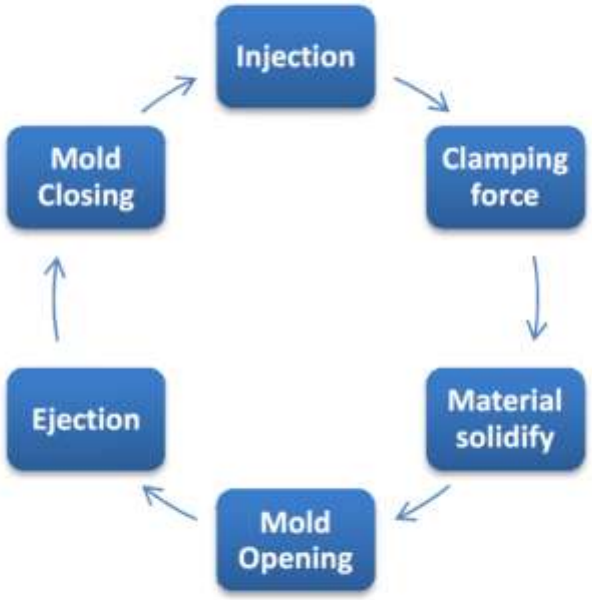

Fig 1 . Injection Cycle[8]

Many research about cooling system in plastic injection mold geometry has been conducted. Experimental analysis Some researcher calculated cooling time by using empirical equation Omar A. Mohamed, S.H. Masood, Abul Saifullah(2013) studied of different types of cooling channels in an injection molded plastic part and compared the performance in terms of time to ejection temperature, shrinkage, temperature profile, and part war page and determined which configuration is more appropriate to provide uniform cooling with minimum cycle time. Autodesk Mold flow Insight (AMI) simulation software is used to examine the results of the cooling channels performance[9].

D Mate, VL Kadlag S - Int. Journal for Research in (2016)focused on the complete analysis of the buckle using a Mold flow software and the determined of optimum gate locations for it. it considers identification and improved of parameters such as fill time, quality, extent of packing and reduced defects .[10]

Gao,G F Xu, J Xu - Machines, (2022) - were applied Mold Flow Advisor (MFA) is used to study & verify the effect to process parameters and optimize the filltime. Optimization of process parameters done used design of experiments (DOE) and analysis of variance(ANOVA) optimum combination of process parameter is governed by signals to noise (S/N) ratio and analysis of variance (ANOVA) and using the fuzzy logic approach[11] .

Miroslav Halilovič Kristjan Krebelj (2019)Modeled the cooling rat effect and the discrepancy is quantified for amorphous polystyrene. A rate equation is used to model the specific volume relaxation within the scope of three-dimensional computational fluid dynamics. The modelcorporates the mold compliance to allow a comparison to the experimental results. The cavity pressure evolution and the final residual stresses are calculated for both the modeled and the neglected cooling rate effects. This provides argumentation for either neglecting or modeling the phenomenon. variance (ANOVA) and using the fuzzy logic approach[12].

Raphael CorneChandra Nat (2016) proposed to replace traditionally designed straight cooling channels in dies (for plastic injection molding) with optimally designed conformal cooling channels. First, a numerical model is developed to represent the thermal behavior and predict the cycle time. Next, the model is validated experimentally and used in conjunction with DOE (Design of Experiments) to study the effect of different design parameters of the channels on the die performance. Based on this study, an optimal design is identified. Future work includes using DMLS (Direct Metal Laser Sintering) additive manufacturing to print dies with optimal conformal cooling channels for testing and validation[13].

Singh S.Deepika Bhushan T.Patil (2020) investigated of cooling time has been done for a door handle. The cooling pattern for the conventional cooling channels and the parameters affecting cooling time has been studied. The mold and cooling channels have been designed of U-shaped cooling channel and conformal cooling channel in SolidWork software. The results showed a reduction of cooling time by 18.2% over U-shaped cooling channel[14]..

II. ANALYSIS OF HEAT TRANSFER DURING POLYMER PROCESSING

Most polymer processing methods involve heating and cooling of the polymer melt. So far the effect of the surroundings on the melt has been assumed to be small and experience in the situations analyzed has proved this to be a reasonable assumption. However, in most polymer flow studies it is preferable to consider the effect of heat transfer between the melt and its surroundings. It is not proposed to do a detailed analysis of heat transfer techniques here, since these are dealt with in many standard texts on this subject. Instead some simple methods which may be used for heat flow calculations involving plastics are demonstrated[15].

Table 1: Process Conditions of Injection Molding[16]

Plastic	Molding temperature C^0	Mold temperature C^0	Freeze off temperature C^0	Thermal diffusivity m^2 /s
LDPE	230	30	90	$1.1X10^{-7}$
PP	250	40	135	$1.1X10^{-7}$
PS	230	50	130	$0.8X10^{-7}$
PVC	180	40	140	$1.2X10^{-7}$
POM	210	60	130	$0.9X10^{-7}$
Acrylic	250	50	160	$0.9X10^{-7}$
PC	300	90	200	$1X10^{-7}$
Nylon66	290	80	240	$1.3X10^{-7}$
ABS	230	60	140	$0S.9X10^{-7}$

.

A. The Heat Transfer in The Mold.

Plastic is injection molded into a rectangular cavity having dimensions of **b** cm thick. Plastic enters the cavity at T_i C^0 and the filling process occurs so rapidly that the drop in temperature during filling can be considered to be negligible. Determine the time required to drop the centerline temperature of the melt to T◦C^0 (neglect crystallization) if the mold temperature is T_m◦C and the heat transfer coefficient between the mold wall and the polymer W/m2 ·K[17].in many reference calculated cooling time by using empirical equation $t = \frac{4b^2}{\pi^2\alpha} \ln \frac{4}{\pi\theta}$this equation that was obtained through experiments.Where θ is temperature gradient depend onPlastic enters the cavity at T_i C^0 and drop the centerline temperature of the melt to T◦C^0 and the mold temperature is T_m[18]

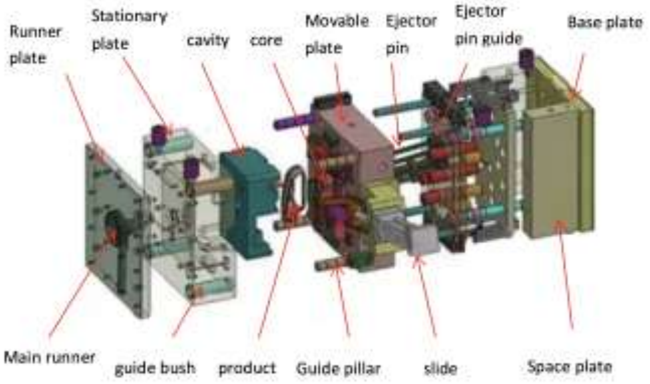

Fig.2 Injection Mold [19]

B. Mathmatical model and Drivation of cooling time equation

In this paper, heat transfer analysis were used to derive the empirical equation that is used to calculate the cooling time of the injection mold.

Step (1):

Notes the cooling in the both side, the temperature it dimensionless

$\theta = \frac{T-T_m}{T_i-T_m}$----------------------------- (1)

Where $\theta$is temperature gradient . T is Freeze off temperature. T_m is mold temperature and T_i is Molding temperature.

Differentiate eq (1):

$d\theta = \frac{dT}{T_i-T_m}$ ------------------------------ ----(2)

The distance is dimensionless

$h = \frac{x}{b} dh = \frac{dx}{b}$ ----------------- (3)

Step (2):

Dividing (1) by by∂t (heat transfer differential equation):

$\frac{dT}{\partial t} = (T_i - T_m)\frac{d\theta}{\partial t}$ ---------------------------- (4)

$\frac{dT}{\partial X} = (T_i - T_m)\frac{d\theta}{\partial X} . \frac{dX}{b\,\partial h} = \frac{(T_i-T_m)\frac{d\theta}{\partial h}}{b}$ -------- --(5)

$\frac{d^2T}{\partial X^2} = (\frac{T_i-T_m}{b})\frac{d}{\partial X}\frac{d\theta}{\partial h} . \frac{dX}{b\,\partial h} = \frac{(T_i-T_m)\frac{d^2\theta}{\partial h^2}}{b^2}$ --------(6)

$(T_i - T_m)\frac{d\theta}{\partial t} = \frac{a\ (T_i-T_m)\frac{d^2\theta}{\partial h^2}}{b^2}$ --------------------(7)

$\frac{d\theta}{\partial t} = \frac{a\frac{d^2\theta}{\partial h^2}}{b^2}$ --(8)

Step(3):

Initial condition for process:

1. t =0 $\theta(h,0) = 1$ …………1
2. h=0 $\frac{d\theta}{\partial h}$= 0 => retract point => great limit…..2

that is second derivative it negative

3. h =1 $\theta(1,t) = 0 \dots\dots\dots\dots (3)$

As we mentioned previous function $\theta(h,t)$as:

$$\theta = H(h).\tau(t)$$

$$\frac{d\theta}{\partial t} = H.\dot{\tau}\frac{d^2\theta}{\partial h^2} = \overset{=}{H}.\tau$$

$H.\dot{\tau}\frac{a}{b^2}\overset{=}{H}.\tau$------------------------- --------------(9)

Step(4):

Separation of variables

$$\dot{\tau}\overset{=}{H}.b^2$$

At boundary condition the function has maximum that’s mean the equation equal to the negative value

$\frac{H}{H} =. \dot{\tau}\frac{b^2}{a}.\frac{\tau}{\tau} = -\lambda^2$-------------------------------- (10)

$\theta = (ACos\lambda h + BSin\lambda h)e^{\frac{-\lambda^2}{b}}\alpha t$ ---------------(11)

$$\frac{d\theta}{dh} = H(h).\tau(t)$$

$\theta = (-A\lambda Sin\lambda h + B\lambda cos\lambda h)e^{\frac{-\lambda^2}{b^2}}\alpha t$ ---------------(12)

When h=0 $\frac{d\theta}{dh}$ =0 B = 0

⇨ $\theta = (ACos\lambda h)e^{\frac{-\lambda^2}{b^2}}\alpha t$ ----------------------------(13)

Step (5):

Boundary Conditions for process from equation(13):

On (3) $h = 1 \quad \theta(1,t) = 0sss$

$0 = (ACos\lambda h)e^{\frac{-\lambda^2}{b^2}}\alpha t$ =>$Cos\lambda = 0$

$\lambda = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{(2n+1)\pi}{2}$ --(14)

Step (6):

Initial conditions for process :

$1 = \sum_{n=0}^{\infty} A_n \left[Cos(\frac{2n1}{2}\pi h)\right]$ -------------------------(15)

On (1) $t = 0 \quad \theta(h,0) = 1$

$1 = \sum_{n=0}^{\infty} A_n \left[Cos(\frac{2n1}{2}\pi h)\right]$ --------------------------(16)

$A_n = \frac{2}{1}\int_0^1 \left[Cos(\frac{2n1}{2}\pi h)\right] dh$ -------------------------- (17)

$A = 2\left[\frac{2}{(2n1)\pi} Sin(\frac{2n1}{2}\pi h)\right]_0^1$-----------------(18)

$A = \frac{\pi}{4} Sin(\frac{\pi}{2}) = \frac{\pi}{4})$ ----------------------------------- (19)

Step (7):

take over the first boundary of Fourier:

$\theta = \frac{4}{\pi}(ACos\frac{\pi}{2}h)e^{\frac{-\pi^2}{b^2}}\alpha t$ ------------------------ (20)

Center of mold so that h =0

$\theta = \frac{4}{\pi}e^{\frac{-\pi^2}{b^2}}\alpha t$----------------------------(21)

$\frac{4}{\pi\theta} = e^{\frac{-\pi^2}{b^2}}\alpha t$ -- (22)

$\ln\frac{4}{\pi\alpha} = \frac{4\pi^2}{b^2}\alpha t$ --- (23)

$t = \frac{4b^2}{\pi^2\alpha}\ln\frac{4}{\pi\theta}$ -- (24)

This the time require for the center of the molding to reach the freeze temperature .

III. DISCUSSION

The cooling process is very important in injection molding, and the cooling time plays a big role in the total time of the injection cycle, and all of you depend on the quality of the product. Therefore, most researchers were interested in determining the optimal cooling time suitable for the injection cycle and product quality. An empirical equation was determined to determine the cooling time, since the cooling time depends on heat transfer in this The research was derived equation for calculating the cooling time according to the analysis of heat transfer during polymer processing and reached the equation for calculating the cooling time the same empirical equation.

IV.CONCLUSION

In this study, the equation for calculating the cooling time inside the injection mold was derived, and the same experimental equation that was obtained through experiments was reached. This equation helps the designers of injection molds to determine the optimal cooling time inside the mold that maintains the quality of the product and the injection cycle, and it is determined according to the conditions to which the material is exposed during manufacturing.

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