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Poor-Man Injection-Compression Moulding Technique

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ABSTRACT

This research is aimed to find the economical technique to increase the backing pressure in injection-compression moulding (ICM) of a PMMA lens. The ICM possess advantages for lens and optical parts such as reduced warping of finish lens, reducing residual stress and improving lens clearity. But the ICM machine is very expensive. So the researcher tried to including an actuator such as hydraulic, pneumatic and/or mechanic system into the injection mould. The actuator is operated likely the compression functionality of injection-compression machine. This name "Poor-man Injection Compression Moulding Technique" In this research work, the systematic design was used as a guideline to design the mould with the actuator inside. The Moldex 3D software was simulated the flow and fluid dynamics of ICM within the mould cavity before mould prototyping. The experimental results are accordingly to FEM result. This research demonstrates, that technique could be possibly to use in the PMMA lens manufacturing.

Keywords: Injection-Compression Moulding, Injection Coining Process, Low Residual Stress Injection Moulding;

INTRODUCTION

Injection moulding (IM) is the most commonly method that used for mass production of a various polymer parts, which widely used in daily life. In this process the melted polymer is injected into the die cavity and cooled to form the polymer parts in the mould cavity. The injection moulding was modified to an injection-compression moulding (ICM). The ICM process is an extension of conventional injection moulding, it's combining the techniques of both injection moulding and compression moulding together. In this process the mould is not closed completely (open cavity or die gap) at the filling stage of injection. This mean, the die gap is larger than the desired thickness of the moulding part. After amount of melted polymer is partially injected into the cavity, the clamping mechanism starts operating to fully close the mould, its compresses the melted to the desired thickness. As a result, the filling process is completed by the compression of melted in cavity (See Fig. 1). The compression motion of the mould is also applies holding pressure to uniformly compensate for polymer parts shrinkage. Injection-compression moulding is sometimes called coining, stamping, compressive-fill, or hybrid moulding. [1]

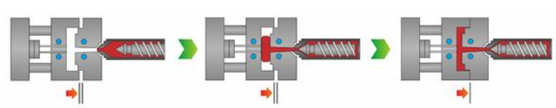


Fig. 1. Injection Compressing Moulding

There are essentially three mould configuration variants of ICM method, parallel injection-compression moulding, Expansion injection-compression moulding, and Wedge injection-compression moulding. As shown in Fig. 2.

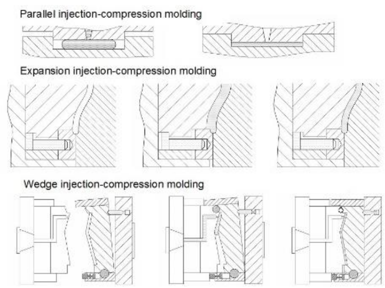


Fig. 2. The three mould configuration variants of ICM method [2]

With the ICM process, the required filling pressure (or moulding pressure), the levels of moulding stress and flow (or molecular) orientation and flow distance/wall thickness ratio are reduced. The primary advantage of this process is the ability to produce dimensionally stable, increasing the reproduction of micro-surface feature, relatively stress-free parts (lower parts residual stress) with low clamp force. The ICM is commonly used for produced both large-area (thin wall) components and thick-walled components. production of precision parts, such as optical components, and high-precision components, long-glass fiber components, insulating components, exposed to heat cycles components and fragile or light-weight components, which the conventional injection moulding couldn't be meet produced the product requirements. However, there are also used an expensive special injection or extruder machine which could control the backing pressure or coining pressure (compression), and more processing parameters needed to be carefully adjusted to get a well-moulded part. This research proposed the alternative way in injection-compression moulding which used the generally injection or extruder machine, but the mould is specially design to extend the capability of process control, such as backing or coining pressure in the last stage of injection-compression moulding. The technique is name "poor-man injection-compression mould".

LITERATURE REVIEWS

While processing amorphous thermoplastics, it's important to ensure that the components have low internal stresses to prevent stress cracking in subsequent practical use. The injection compression moulding (ICM) is the specialty methods, which are used for production of low residual stress high-quality components such as polycarbonate automotive glazing and focusing lenses. There are many factors lead to the defects of thin shell feature parts, the packing pressure had the greatest influence on the warpage, followed by mould temperature, melt temperature, and packing time. [3] With ICM process, the melt is first injected into a cavity whose cavity gap at the time of injection is larger than the target thickness of the require component. Subsequent closing of the mould compresses the melt to the desired thickness thereby reducing the required filling pressure and lessening the levels of component stress and flow orientation. The motion of the mould also applies holding pressure over a large area to uniformly compensate for shrinkage. [2] Chen et., al. 1998 [4] 2000 [5] 2002 [6] was developed a numerical algorithm to simulate of the disk part injection compression moulding (ICM) process such as melt-front advancement and the distributions of pressure, temperature, and flow velocity dynamically during the injection melt filling, compression melt filling, and post filling stages of the entire process. A Hele–Shaw fluid-flow model combined with a modified control-volume/finite-element method [5] and a Leonov viscoelastic fluid model combined with a modified control-volume/finite-element method [6] is implemented to predict the melt-front advancement and the distributions of pressure, temperature, and flow velocity dynamically during the injection melt filling, compression melt filling, and post filling stages of the disk part injection-compression moulding. By adjusted process parameters including compression speed, switch time from injection to compression, compression stroke as well as initial cavity thickness. The simulation results of ICM were compared with the conventional injection moulding (CIM) with the same entrance flow rate. The simulated pressures for both ICM and CIM show good coincidence with those obtained from cavity pressure measurements, it was found that the compression speed and compression stroke are the most significantly two factors affecting the moulding pressure. The switch time effect on the pressure profiles, higher switch time, lower compression speed and higher compression stroke will lower cavity pressures. Higher switch time, a lower compression speed, and a higher compression stroke may lower moulding pressure. However, lower switch time, higher compression speed, and lower compression stroke were result in an improvement in shrinkage reduction. ICM not only shows a significant effect on reducing part shrinkage but also provides much more uniform shrinkage within the whole part as compared with CIM. The melt velocity far from the gate was higher than near the gate during the compression stage contrary to that of CIM resulting in different part residual stress and melt temperature distribution. Part birefringence was then calculated from residual stresses following the thermal-mechanical history of the entire moulding process. ICM part shows a significant reduction of part birefringence near the gate area as compared with CIM parts. However, ICM parts exhibit higher birefringence values near the rim of the disk. The minimum birefringence occurs around the location where injection is switched over to compression. Ming Shyan Huang et., al. 2011 [7] investigated the feasibility of injection moulding (IM) and injection compression moulding (ICM) for fabricating 3.5 in. light guided plates (LGPs). The LGP was 0.4 mm thick with v grooved micro-features (10 µm wide and 5 µm deep). The following parameters were considered: barrel temperature, mould temperature, packing pressure, and packing time. Increasing the barrel temperature and mould temperature generally improved the polymer melt fill in the cavities with micro-dimensions. The height of the v grooved micro-features replicated by ICM was more accurate than those replicated by IM. Additionally, the flatness of the fabricated LGPs showed that ICM was better than IM for thin walled moulding. Nagato, 2014 [8] As a breakthrough in the cost and durability of moulds for ultraviolet nano-imprint lithography ((UV)-NIL) with structures smaller than 60 nm, the replica moulds are fabricated by injection compression moulding (ICM) of cycloolefin polymer. The degree of replication by UV-NIL in the first usage of each replica mould had good repeatability. Because ICM is a high-throughput, low-cost process, the replica mould can be disposed of after a certain time for UV-NIL. [9] Guo Fan JIN et., al. developed a piezo actuator two-stage micro injection compression moulding to fabrication of plastic diffractive optic elements (DOE) which was designed with the spherical coefficients and the Fresnel lens. The piezo actuator was installed inside the mould plate for activating the mould insert for the second compression motion. The results showed that DOE fabric from this technique can obtain the highest TRG than that of IM and conventional ICM processes. A hybrid finite element / finite difference method is employed to model the temperature and pressure fields of the process using a non-isothermal compressible flow model. Simulation results for CD-R moulding with respect to injection pressure and mould displacement are compared with experimental observations using an optical grade of polycarbonate. The simulation shows similar trends as experimental observations on the dependence of various processing parameters such as melt temperature, mould temperature, and packing pressure. However, the mould displacement measurement does not show the effect of punch delay time as does the simulation and needs further investigation. [10] The moulding process parameters such as injection time, packing time, packing pressure and process temperature etc. from CAE simulation and the actual experiments were almost the same, and then CAE is a tool which can reduce experimental works, to identify critical parameters and to save substantial costs. [11] For injection moulding of a plastic lens. Some experimental trials were carried out for verifying of the CAE simulation results with checking of the lens shrinkage and birefringence etc. as well.

MATERIAL AND CONFIGURATION OF EXPERIMENTAL PART

The main objective of this research is the design of an economic mould for fabric of a small optical clarity lens with “Polymethyl Methacrylate (PMMA)”. The part to be injected is dimensions OD 40 mm Thk. 5 mm. PMMA also known as acrylic or acrylic glass which is a transparent and rigid thermoplastic material widely used as a shatterproof replacement for glass. PMMA has many technical advantages over other transparent polymer (PC, PS etc.), a few of their advantage including, high resistance to UV light and weathering, excellent light transmission, unlimited coloring options. PMMA is produced from monomer methyl methacrylate. It is a clear, colorless polymer available in many forms, which are then formed with all thermoplastic methods including injection moulding, compression moulding, and extrusion. Rubber toughening has been used to increase the toughness of PMMA owing to its brittle behavior in response to applied loads. PMMA is 100% recyclable. [12]

PMMA is one of the versatile transparent plastics which offer good mechanical and optical properties. Some of these characteristics have enabled it to replace glass in several applications.

SYSTEMATIC MOULD DESIGN

A Poor-man Injection-Compression Mould is designed to equipped in the conventional injection machine. The design process is following the systematic design procedural [13, 14]

4.1 Start off with product planning and a clarification of the task

The aim of this research is to making the special mould for produce PMMA optical lens by the used of ICM technic without any used of special injection machine. The experimental lens design model (CAD) are shown in the Fig. 3 With ICM technic, the melt is first injected into a cavity whose die gap at the time of injection, larger than the target thickness of the moulding. Subsequent closing of the mould compresses the melt to the desired thickness thereby reducing the required filling pressure and lessening the levels of moulding stress and flow orientation. The motion of the mould also applies holding pressure over a large area to uniformly compensate for shrinkage.

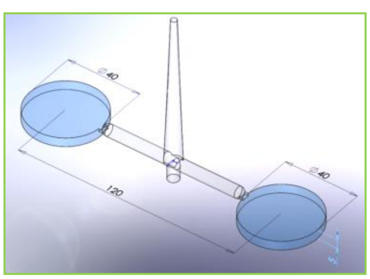


Fig. 3. The experimental lens design model (CAD)

The PMMA lens mould design, using the Moldex 3D Injection Compression Moulding (ICM) software (CoreTech System Co., Taiwan) to simulate injection compression moulding process, for example, to simulate the flow and fluid dynamics of ICM within the mould cavity, aims to predict possible problems in the mould cavity and provide the analysis results of filling, cooling, and warpage. The limitation of this software is supports only solid mesh models, and the mesh of compression region setting in Moldex 3D Mesh should be set as injection compression surface. Also, a better solid mesh quality is required. Only the hybrid and hexa mesh types are accepted for simulation. Note that ICM does not support pure tetra and pyramid mesh. [1] There were three conservation laws taking as governing equations, first the conservation of mass, second the conservation of linear momentum and third the conservation of energy. These equations are expressed as follows.

Conservation of Mass:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho U) = 0$$

Conservation of Momentum:

$$\rho \frac{DU}{Dt} = -\nabla p - \nabla \tau + \rho g$$

Conservation of Energy:

$$\rho C_p \left\{ \frac{\partial T}{\partial t} + U \nabla T \right\} = \nabla(k \nabla T) + \varphi$$

$$\varphi = \eta \dot{\gamma}^2 + \Delta \dot{H} + \cdots$$

VOF (Volume-Of-Fluid) function is adopted in tracking the melt front during mold-filling.

$$\frac{\partial f}{\partial t} + U(\Delta f) = 0$$

$$\begin{cases} f = 0 & \text{fluid1(air)} \\ f = 1 & \text{fluid2(melts)} \\ 0 < f < 1 & \text{melt front} \end{cases}$$

Base on the experimental lens model, an injection compression moulding was created in Moldex3D. The element type used in this model was mixed mash, the number of mashes were 394582 elements, the node number were 86787 nodes. The result from Moldex3D analysis were demonstrate the process parameters of ICM lens process as shown in Fig. 4 to Fig. 5.

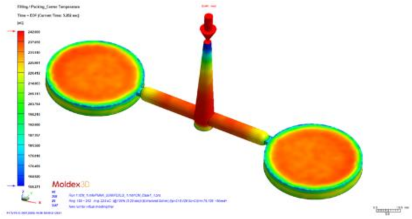


Fig. 4. Demonstrate the center temperature of the middle layer in the thickness direction.

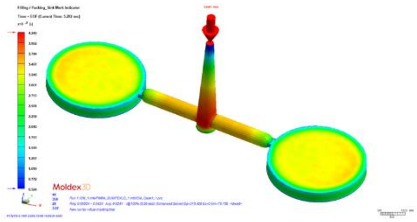


Fig. 5. Demonstrate packing effect by the sink mark indicator

4.2 Conceptual design phase

4.2.1 Abstract the task to identify the essential problem

A Poor-man Injection-Compression Mould is designed to equipped in the conventional injection machine for produce PMMA optical lens by the used of ICM technic. The ICM technical process start by the melt is first injected into a cavity which die gap are larger than the target thickness of the parts. Then subsequent closing of the mould to compressed the melt to the desired thickness.

4.2.2 Establish the functional structures

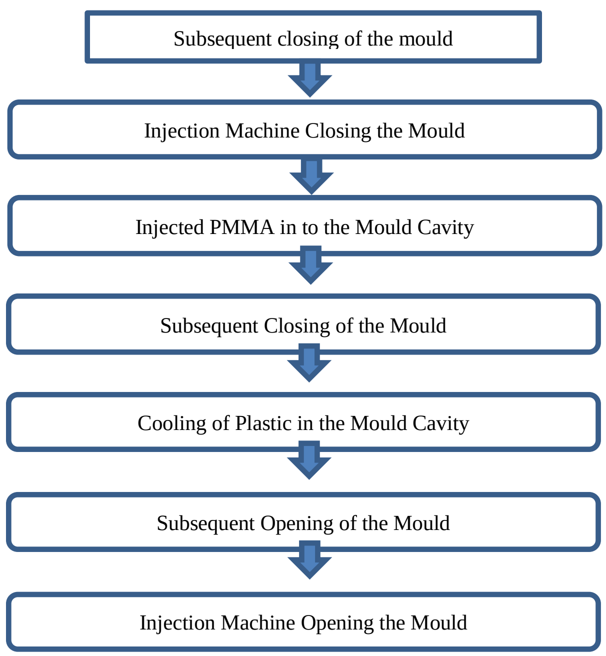
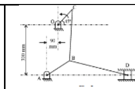
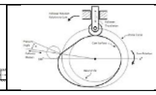
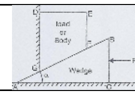
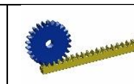
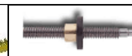
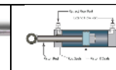


Fig. 6. Functional structures

4.2.3 Search for solution principles

Table 1. Morphological of subsequent closing of the mould

Function principle	Subsequent closing of the mould							
Technology	Toggle	Cam	Wedge	Gear	Tread	Piston	Solenoid	Magnetic

								
Power source	Injection Machine Motion			Fluid power			Electric power	

4.2.4 Combine the solution principles into concept variants

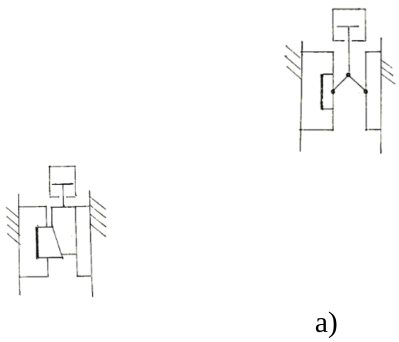


Fig. 7. Combine the solution principles into concept variants. (a) Concept 1, Toggle and piston

(b) Concept 2, Wedge and piston

4.2.5 Evaluation of concept variants using technical and economic criteria

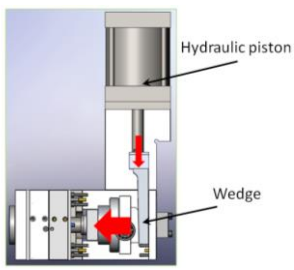


Fig. 8. The poor-man injection-compression mould concept design

4.3 Embodiment design

Roughly Calculation for Mould Design Parameter. The PMMA data that used in the calculation [12].

The weight, volume and surface area of the experimental PMMA lens is 7.41 g, 6283.19 mm^3 and 3141.59 mm^2 respectively. The theoretical parameter and the practical parameter used in mould design [15, 16, 17]

The core compression, the free body diagram extends from the concept design (Fig. 9 and Fig. 10)

Is used to calculate. The wedge tapper is 1:50 for the self-locking. The require compression force is 30 ton. After calculation follow static engineering calculation. The hydraulic piston force is 3.6 ton.

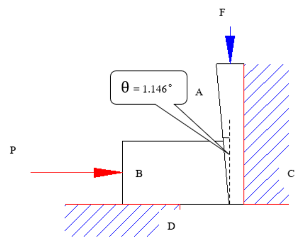


Fig. 9. Free body diagram of wedge system

(A) bar slide compression ratio 1:50 top (B) bar slide compression ratio 1:50 bottom
(B) stationary plate (D) slide way bar
(C)

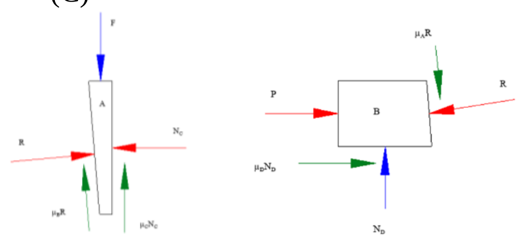


Fig. 10. Free body diagram of components (A) Free body diagram of bar slide (B) Free body diagram of bar slide

4.4 Detail design

Detailed design is the phase where the design is refined and plans, its involves completing the product's design specifications for the production and its subassemblies, product elements, and manufacturing processes. Detailed design will include outputs such as 2D and 3D models, cost build up estimates, procurement plans etc.

EXPERIMENTAL

After the detail design was completed, the poor-man ICM mould was built. And installation in the injection machine as shown in Fig. 11. In the experimental part, a virgin "Polymethyl

Methacrylate (PMMA)" was used as a raw material. Experiments were performed on an injection moulding machine (Engel ES 200/50 HL 50 Ton Tiebarless Injection Moulding Machine) equipped with a reciprocating injection screw having a diameter of 30 mm, capable of a maximum clamping force of 500 kN, injection pressure 1450 bar.

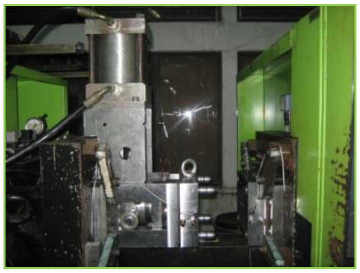


Fig. 11. The installation of poor-man injection-compression moulding in conventional injection machine.

The aim of experimental is to verified the performance of the poor-man injection-compression moulding. Then the process parameters were fixed, such as, injection temperature was 220 ^{O}C, mould temperature was 120 ^{O}C, injection pressure was 363 bar, injection speed was 60 mm/s, mold clamping force 50 tonnes and compression force was 30 tonnes.

In experiment, the 60 pieces of lens is produced, the molten PMMA is injected into the mould cavity, in a closed state with a 50 tonnes clamping force. The mould cavity is then compressed by an externally designed hydraulic system to executes the compression action, thereby reducing the cavity thickness to final part thickness. The all of lens were measured it weight, dimension and residual stress as shown in Fig. 12 to Fig. 14.

Fig. 12. Injection-compression moulding specimen's weight

Fig. 13. Injection-compression moulding specimen's dimensions

Fig. 14. Moldex3D Stress Viewer [18] and injection-compression moulding specimen's residual stress

RESULTS AND DISCUSSION

60 pieces or 30 shot ICM were performed, and all samples were measured, and averaged for the quality control including the weight (mass) and dimension measurements via the fine digital weighing machine and digital vernier caliper. (Fig. 12 and Fig. 14) The average thickness error was approximately 3.00%, the average diameter error was 2.514%. ICM part shows a significant reduction of part birefringence near the gate area as compared with CIM parts. However, ICM parts exhibit higher birefringence values near the rim of the disk. The minimum birefringence occurs around the location where injection is switched over to compression. Ming Shyan Huang et., al. 2011 [7] investigated the feasibility of injection moulding (IM) and injection compression moulding (ICM) for fabricating 3.5 in. light guided plates (LGPs). The LGP was 0.4 mm thick with v grooved micro-features (10 µm wide and 5 µm deep). The following parameters were considered: barrel temperature, mould temperature, packing pressure, and packing time. Increasing the barrel temperature and mould temperature generally improved the polymer melt fill in the cavities with micro-dimensions. The height of the v grooved micro-features replicated by ICM was more accurate than those replicated by IM. Additionally, the flatness of the fabricated LGPs showed that ICM was better than IM for thin walled moulding. Nagato, 2014 [8] As a breakthrough in the cost and durability of moulds for ultraviolet nano-imprint lithography ((UV)-NIL) with structures smaller than 60 nm, the

replica moulds are fabricated by injection compression moulding (ICM) of cycloolefin polymer. The degree of replication by UV-NIL in the first usage of each replica mould had good repeatability. Because ICM is a high-throughput, low-cost process, the replica mould can be disposed of after a certain time for UV-NIL.

The important subject was the residual stress which remain in the lens sample, because it could change the optical properties of lens products and result in critical failure in secondary processing such as coating, plating process. The Moldex3D's latest exclusive patent "Stress Viewer", a non-destructive qualitative method which applies the principle of photo-elastic response is used to analyzed the residual stress in the lens. The observation result shown the clear and transparent lens without any the areas with higher density of color fringe lines (residual stress).

CONCLUSION

The new designed "poor-man injection-compression mould" can be used to produce stress-free lens elements very well. This mould can help the manufacturer to reduce the use of cost expensive new technology injection-compression machines. This "poor-man injection-compression mould" geometry is compact, and cost effective, it has a higher cost of production than the normally mould from only 15-30%. And can be used with traditional machines. They are extremely useful in the mass production of optical lens, for speed and cost. Then manufacturer can used the "poor-man injection-compression mould" to produce a very high-quality optical lens at low cost and time consumption. Compared to investing in a new ICM machine which is higher price. It can be seen that the use of this mould is more economically appropriate. Especially in the situation that Thailand is still in the spread of the COVID 19 virus. And in situations where the price of plastic pellets increases according to oil prices. Making an investment in new machines has to halt.

ACKNOWLEDGEMENT

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