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# An optimization of Injection Moulding Process

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**ABSTRACT:** Mass-production of microfluidic devices is important for fields in which disposable devices are widely used such as clinical diagnostic and biotechnology. Injection molding is a well-known, promising process for the production of devices on a mass-scale at low-cost. The major objective of this study is to develop a technique for repeatable, productive and accurate fabrication of integrated microfluidic devices on a mass production scale. To achieve this, injection molding process is adapted for the fabrication of a microfluidic device with a single microchannel. During the design procedure, numerical experimentation was performed using Moldow simulation tool. To increase the product quality, high-precision mechanical machining is utilized for the manufacturing of the mold of the microfluidic device. A conventional injection molding machine is implemented for the injection molding process of the microfluidic device. Injection molding is performed at different mold temperatures. The warpage of the injected pieces is characterized by measuring the part deformation. The effect of the mold temperature on the quality of the final device is assessed in terms of part deformation and the bonding quality. From the experimental results, one-to-one correspondence between the warpage and the bonding quality of the molded pieces is observed. As the warpage of the pieces' decreases, the bonding quality increases. A maximum point for the breaking pressure of the bonding and the minimum point for the warpage was found at the same mold temperature. This mold temperature was named as the optimum temperature for designed microfluidic device. The experimental results are also used to discuss the assessment of the simulation results. It was observed that although Moldow can predict many aspects of the process, all the physics of the injection molding process cannot be covered.

**KEYWORDS:** Polymeric disposable devices, microfluidics, injection molding, warpage characterization, direct bonding

## I. INTRODUCTION

The injection moulding process is one in which hot molten polymer is injected at high pressure and temperature into a metal cavity to form the shape of the required part. [1,2] This process can be used to produce a variety of complex objects from a number of different thermoplastic materials and is considered the most important industrial method for the production of plastic parts, for the following reasons

- The process can be operated in a highly automated mass production environment.
- Highly complex shapes can be made with great speed.
- A high level of accuracy in repetitively producing the same object can be obtained.
- A number of different materials can be used to create parts with varying properties.

In general, an injection-moulding machine will consist of the following parts:

**Hopper:** The conical container for feeding the solid plastic pellets into the injection moulding machine.

**Plunger or Screw:** The device used to force the plastic into a heating cylinder, for melting, and then into the mould.

**Platen:** The back plates of the mould used to connect the mould to the machine.

The injection moulding process is completed in the following stages.

**Mould Closing.** This stage should be as quick as possible, but not so fast as to cause damage to the parting surface of the injection mould.

**Mould Filling.** The plastic melt is forced to fill the cavity of the mould.

**Mould Packing.** After the plastic is injected, the pressure is increased to consolidate the plastic in the cavity.[3]

**Cooling.** This stage consists of cooling the plastic from its injection temperature to its ejection temperature.

**Ejection.** In this stage the mould is opened and automatically ejected.

In the years before the dawn of computer technology, the design of injection moulds out based on the experience of the designer. The lack of precise design techniques led to the following problems:

**Premature Scorch - solidification of plastic before the injection process is complete.**

**Material Defects - defects due to the difference in cooling rates throughout the plastic part.**

The optimisation of the size and position of the cooling lines, to give the most efficient cooling process is the main challenge of the computer-aided engineer in the design of the injection mould cooling system.

An injection mould consists of a number of parts, the design of each influencing the others. For this reason, the methodology of mould design must be understood so that an efficient cooling system can be incorporated.

- Clamp Plates - one on each side of the mould attaching it to the injection moulding machine.
- Cavity Plate - this plate contains the fixed side of the cavity.
- Core Plate - this plate contains the moving element of the cavity.
- Support Plates - these plates are used to guide and support the movement of the moving portion of the mould.
- Ejector Pins - these pins are used to eject the plastic part away from the moving side of the mould.
- Ejector Plate - this plate is used to support and guide the ejector pins.
- Sprue - the part of the mould through which the plastic is injected.[4,5]
- Runners - the channels through which the plastic flows from the sprue to the cavity.
- Gates - the opening connecting the runner and the cavity.

Plastic is injected through the sprue and flows through the runners into the cavity or cavities. When the plastic has reached its ejection temperature the moulded component is ejected. The ejection mechanism is operated when the moving half of the mould is retracted causing the ejection pins to push forward, forcing the plastic component away from the mould.

It is important to analyse the way in which the cooling system design is incorporated into the overall injection mould design. For a long time, the cooling system consisted of drilling holes for cooling lines, after the mould was completed, hence producing an inefficient cooling system. Nowadays it is important to determine the optimum size and position of these cooling lines before the mould is made. [6]

## II. RELATED WORK

This section of paper presents the earlier work done by the various researchers for the optimization of injection molding.

**K. GiridharReddy and K. Rajagopal**, Blow Mould Tool Design and Manufacturing Process for 1litre Pet Bottle. The concepts of Blow molding is a process used to produce hollow objects from thermoplastic. The basic blow molding process has two fundamental phases. First, a parson (or a perform) of hot plastic resin in a somewhat tubular shape is created. Second, compressed air is used to expand the hot perform and press it against mould cavities. The pressure is held until the plastic cools. Blow molding process is used for which has thin wall sections. In this paper, blow mould design is to be done for a bottle having 0.5mm thickness. This thickness cannot be filled in pressure injection molding. So blow molding is considered for pet bottle design. The mould is prepared by first modeling the part, extracting core & cavity and generating CNC program. Blow mould tool design is done in Pro/Engineer according to HASCO standards. A prototype of the pet bottle using blow mould design is also included.[7] **Prof. G. S. Jagushte et al.**, Fabrication of Pneumatic Compression Molding Machine for FRP Composites. This paper deals with the development of pneumatically operated compression molding machine for polymer composites. The main aim of fabricating this machine is to prepare the fiber reinforced polymer composite samples for testing purpose. Researchers working on composites for research work they require the samples of composites with different composition for the purpose of testing. For that this machine is useful for the researchers and also for the manufacturer to produce small sized less complicated plastic components. In this machine temperature of specimen dies can be controlled automatically by using sensors and by using FRL (filter, regulator and lubricator) unit, the pressure can be controlled. The low density, high strength and high stiffness to weight ratio, fiber reinforced composite materials are manufactured by this machine are low cost.[8] **Ahmad Adlie Shamsuri**, Compression Moulding Technique for Manufacturing Biocomposite Products. Biocomposite products are combination between synthetic or natural polymers as matrices and natural fibers as fillers. The products can fully or partially degradable by biological means. The manufacturing biocomposite products can be done by using several techniques such as compression moulding, injection moulding, solution casting, and so forth. This paper discusses briefly the advantages of compression moulding and its procedures. The machines and tools that have usually been used for this technique were also demonstrated. In addition, the types of materials that utilized for manufacturing biocomposite samples were described. The biocomposite products that have been or will be in the market were also indicated. It can be concluded that the compression moulding technique is the best technique for manufacturing biocomposite products since it could mould large products and it also produces less waste compared

with other techniques.[9] *Mohit milind sardare and vaibhav banker* Design of Family Mould Tool for Plastic Box. Injection molding is a cyclic process of forming plastic into a desired shape by forcing the under pressure into a cavity. The shaping is achieved by cooling (thermoplastics) or by a chemical reaction (thermosets). It is one of the most common and versatile operations for mass production of complex plastics parts with excellent dimensiona Injection molding is preferred where high tolerance, good quality and high rate productions are required. The aim of this paper is to model, extract core and develop injection molding tool for manufacturing a plastic box and also to reduce its warpage Core Cavity design the mould flow analysis of the component is done using SOLIDWORK software. The tool will design to produce a good quality component considering the ease of manufacturability, assembly and positive ejection of the component tool design should match the machine specification and should be same for successful life of a component or product.[10]

*Fabrice. M. Schmidt et al.*, Experimental Study Of The Injection Stretch/Blow Molding Process. The performance of Poly(Ethylene Terephthalate) bottles produced by the injection stretch/blow molding process depends on three main variables: the initial preform shape, the initial preform temperature and the balance between stretching and blowing rates. In order to characterize process parameters, experiments have been performed on a well instrumented mold. In addition, preform free inflation have been processed and a simplified model of an air volum free blowing has been developed.[11]

### III. PROPOSED WORK

Injection molding is inherently a complex process due to its physics. During the process, two phase change processes occur and melted material shows a non- Newtonian behavior Therefore, problems experienced during the manufacturing may not be fixed easily by just varying the process conditions unlike the other manufacturing processes. Although the scope is to adjust process conditions to solve one issue, often the change introduces another issue. For instance, increasing the melt temperature which results in decrease in the viscosity of the melt may overcome the filling problem of the mold. However, the increase in the melt temperature may also cause gassing or degradation of the material which may result in unsightly marks on the product.

The filing problem may also be fixed by increasing the number of gates or using a different machine which has a bigger reservoir/plunger. Both of these solutions are economically unfavorable: the former which involves significant retooling is time consuming. The latter one needs the replacement of the original machine with a suitable one which erodes the profit margins. Alternatively, simulations can be performed in a relatively cost-efficient manner in the prestages to evaluate the different design options for the product, material and mold. Moreover, some issues can also be addressed before hand by using simulations. Software's for the simulation of the molding tool and/or the mold filling process itself can provide useful, but not wholly sufficient assistance for the optimization of micro-injection molding .

It is clear that the processing has a strong effect on the properties of the manufactured part; hence, the part quality is directly related to the processing conditions. In the process, the relationship between the process variables and the product quality is extremely complex; therefore, it is very di cult to gain an understanding of the relationship between the processing and the product quality by experience alone . Moreover, rely on experience may also result in costly and time consuming process. Due to these reasons, simulation tools has been developed for injection molding applications to gain an understanding about the relationship between the processing and the product quality. Due to this need, computer aided engineering has been implemented successfully for injection molding than the other areas of polymer processing.

During the injection molding processes filling, packing and cooling), the melted material shows a complicated thermo mechanical history which causes changing in local specific volume . When the melted material is within the mold, it is constrained within the plane of the product and stresses develop in the product during plastification. After ejection, the relaxation of these stresses results in the instantaneous shrinkage which is usually anisotropic and non-uniform throughout the product and extra shrinkage can be seen also during the cooling following ejection . The anisotropic (non-uniform) shrinkage behavior results in some degree of warpage analyses are possible by using simulation tools: Filling and packing analyses: Filling stage of the injection molding process is most thoroughly studied The basic principle is to predict pressure and temperature distributions within the mold cavity and the advancement of the melt front Early work on filling analysis used the note deference method or analytical solutions in simple

geometries, of provided a breakthrough They introduced a hybrid analysis technique for the filling phase where temperature and pressure equations were solved using finite differences and nite elements, respectively .

Often referred as 2.5D analysis, this method remained the cornerstone of commercial simulation tools until the mid-1990's when 3D analysis appeared and in the remainder of this work, it was extended for the packing phase . of micro-injection molding. It is clear that the processing has a strong effect on the properties of the manufactured part; hence, the part quality is directly related to the processing conditions. In the process, the relationship between the process variables and the product quality is extremely complex; therefore, it is very difficult to gain an understanding of the relationship between the processing and the product quality by experience alone . Moreover, rely on experience may also result in costly and time consuming process . Due to these reasons, simulation tools has been developed for injection molding applications to gain an understanding about the relationship between the processing and the product quality. Due to this need, computer aided engineering has been implemented successfully for injection molding than the other areas of polymer processing. During the injection molding processes (filling, packing and cooling), the melted material shows a complicated thermo mechanical history which causes changing in local specific volume. When the melted material is within the mold, it is constrained within the plane of the product and stresses develop in the product during plastication . After ejection, the relaxation of these stresses results in the instantaneous shrinkage which is usually anisotropic and non-uniform throughout the product and extra shrinkage can be seen also during the cooling following ejection. The anisotropic (non-uniform) shrinkage behavior results in some degree of warpage Different analyses are possible by using simulation tools: Filling and packing analyses: Filling stage of the injection molding process is most thoroughly studied .

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- Density, viscosity, mechanical properties (elastic modulus, poissons ratio, shear modulus), thermal properties (specie heat, thermal conductivity, heating/cooling rate), melting temperature, p-v-T relation and rheological parameters of the material
- Maximum injection pressure, maximum clamping force, cooling system and coolant of the machine
- Runner, gate, sprue and mold geometry Process parameters like filling time, packing time, mold temperature, cooling time, eject temperature, coolant temperature and hold time Enable / Disable of Viscous heating Non-isothermal effects Compressible flow Gravitational Force Flow-induced residual stress in warpage analysis In-mold constraint.

#### IV. RESULTS AND DISCUSSION

The measurement results of the cycle time from the experiments are shown in Figure the simulated time to reach the ejection temperature for different mold temperatures are also given in the same figure. Actually, to get the cycle-time for the simulated case, the fill-time and packing time needs to be added up to the time to reach the ejection temperature. As seen from the figure, even the time to reach ejection temperature is much higher than the experimental cycle times. Reason for this is that in the simulations, the time to reach the ejection temperature is calculated to ensure the complete cooling of the sprue. It was observed during the injection molding of the products, the cycle time used actually was low to ensure the complete cooling of the sprue. However, in a practical application, the cooling of the sprue does not affect the quality of the final product, so there is no need to wait for the sprue to be cooled. It was also the case in this study. Although the cycle time was not enough to ensure the complete cooling of the sprue, it was enough to ensure the complete cooling and the solidification of the product.

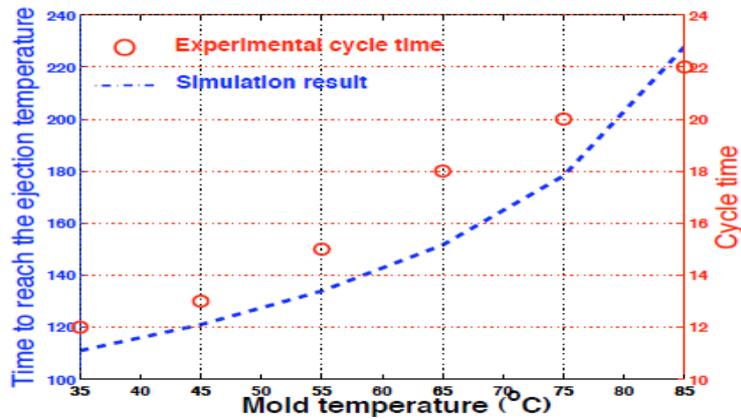


Fig. 1: Comparison of the experimental cycle time and simulated time to reach ejection temperature

The simulation and the experimental results are different; they have similar characteristics. The important conclusion which can be derived from these results is that as the mold temperature increases, the cycle time needs to be increased as well accordingly to ensure the demolding of the products without any deformation. If the cycle time was not sufficiently long enough, the products might be deformed by the pushing pins due to the insufficient solidification/cooling. According to the temperature variance, cooling time variance, cooling quality and warpage analyses, low warpage of the final product was expected.

To characterize the warpage, measurements were performed 3D laser microscope. The photograph of the microscope can be seen in Figure 2. For each mold temperature, randomly selected six samples were measured. To characterize the warpage, following procedure was followed for each sample



Fig.2: 3D laser microscope

The surface area within the scan window was scanned and the surface profile is digitized for the post processing by the software of the microscope. For the warpage measurement, several lines parallel to each other was generated by the software. The location of these lines were selected in accordance with the area where the measurements wanted to be taken (these lines can be seen as blue areas in Figure 3, actually these blue areas are composed of several lines). Different number of lines were selected for x- and y-directions. 70 and 1000 lines were generated x- and y-directions, respectively.

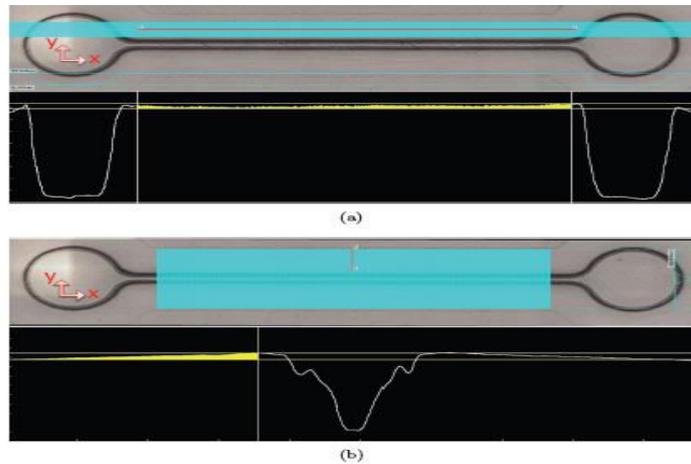


Fig.3: Measured area for the upper side: (a) x-direction, (b) y-direction

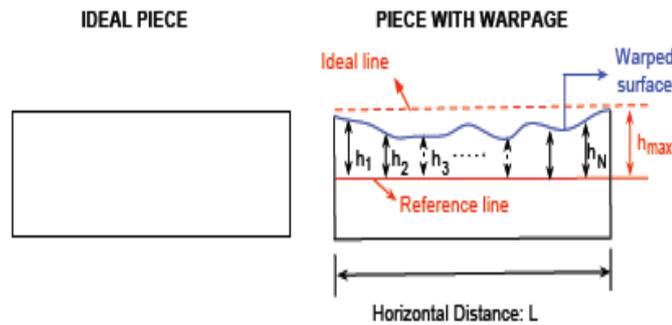


Fig. 4: Schematic drawing to show the parameters in the characterization of the warpage

To restrict the measurements at the upper and the lower sides of the micro channel, a line needs to be defined. The defined lines for the measurements in x-direction for the upper side of the micro channel can be seen as a red line on Figure 5 (a). The selected line for the measurements in y-direction for the upper side of the micro channel can be seen as a red line on Figure 5 (b).

The software determines the average profile of the generated lines. The yellow area shows the shaded area between the line (indicating the average profile of the surface) and a reference line (arbitrary selected, see the schematic drawing in Figure 5.5 (b)).

The software determines the average profile of the generated lines. The yellow area shows the shaded area between the line (indicating the average profile of the surface) and a reference line (arbitrary selected, see the schematic drawing in Figure 5).

The software calculates the area of the yellow area (see the column "C.S. area" in Table 1) which depends on the selection of the reference line (which is the area between the blue line and the solid red line in Figure 5).

The average height of the yellow area ( $h$ ) was calculated by dividing the yellow area by the horizontal distance,  $L$  which can be seen in Figure and listed in the output table in Figure (second column).

To characterize the warpage, parameter called part deformation was defined as the difference between the height difference and the reference line which is indicated.



	Horz. dist.	Hight. diff.	Hight. ave.	Angle	C.S. length	C.S. area	R
All	15140.0...	20.702um	70.433um	0.078°	15407.0...	1066653...	
Seg.1	9696.81...	9.675um	81.054um	0.057°	9729.65...	35414.8...	
Seg.2							
Seg.3							
Seg.4							

Fig.5 (a): A typical tabulated output

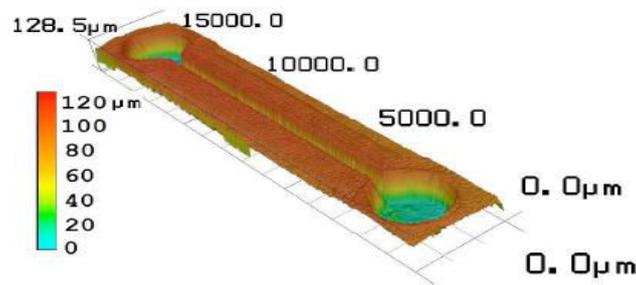


Fig.5 (b): 3D part image

A typical tabulated output of the software can be seen in table 5.2, table 5.3 and table 5.4 also can create 3D part image to show all the height differences and the locations in x- and y-directions Part deformations of the measured samples which were produced at different mold temperatures and the average of the part deformation of the samples for different directions are given in Tables To characterize the overall warpage of the samples the average of the measurements at upper and bottom sides in x- and y-directions were calculated, which can be seen Figure for different mold temperatures. The software outputs for each sample.

Table 1 : Part deformation in x-direction (upper side of the micro channel)

Mold Temperature [°C]	1	2	3	4	5	6	Average [μm]
36.2 (±0.5)	9.270	9.072	8.019	7.709	8.530	8.448	8.51
45.6 (±0.5)	4.628	4.979	2.561	5.037	4.728	4.552	4.41
55.4 (±0.5)	13.429	16.539	13.083	11.395	13.625	12.671	13.46
64.7 (±0.4)	17.744	18.095	20.090	23.307	22.614	17.844	19.95
74.7 (±0.4)	25.999	33.178	34.282	27.758	27.681	26.660	29.26
84.2 (±0.4)	37.019	26.680	44.865	31.076	33.210	33.742	34.43



Table 2: Part deformation in x-direction (bottom side of micro channel)

Mold Temperature [°C]	1	2	3	4	5	6	Average [ $\mu\text{m}$ ]
36.2 ( $\pm 0.5$ )	5.441	6.999	5.749	7.628	6.023	7.596	6.57
45.6 ( $\pm 0.5$ )	5.934	5.614	2.870	6.016	3.925	5.202	4.93
55.4 ( $\pm 0.5$ )	13.378	16.787	11.330	11.067	11.938	13.443	12.99
64.7 ( $\pm 0.4$ )	16.199	17.416	19.810	20.034	20.439	19.178	18.85
74.7 ( $\pm 0.4$ )	20.212	24.386	31.434	23.837	24.418	26.660	25.16
84.2 ( $\pm 0.4$ )	36.962	27.429	33.672	26.667	31.602	52.748	34.85

Table 3: Part deformation in y-direction (upper side of micro channel)

Mold Temperature [°C]	1	2	3	4	5	6	Average [ $\mu\text{m}$ ]
36.2 ( $\pm 0.5$ )	7.012	6.856	10.357	6.826	8.600	13.265	8.82
45.6 ( $\pm 0.5$ )	6.358	5.466	2.730	5.850	4.811	6.542	5.29
55.4 ( $\pm 0.5$ )	11.229	11.042	15.233	17.295	16.154	13.278	14.04
64.7 ( $\pm 0.4$ )	20.627	23.943	20.717	20.708	22.450	19.062	21.25
74.7 ( $\pm 0.4$ )	35.165	28.883	32.111	31.477	27.827	32.707	31.36
84.2 ( $\pm 0.4$ )	34.056	46.421	43.364	47.762	49.768	45.861	44.54

Table 4: Part deformation in y-direction (bottom side of micro channel)

Mold Temperature [°C]	1	2	3	4	5	6	Average [ $\mu\text{m}$ ]
36.2 ( $\pm 0.5$ )	7.834	9.353	12.282	8.957	8.398	8.956	9.30
45.6 ( $\pm 0.5$ )	4.606	6.186	4.298	5.065	5.455	5.602	5.20
55.4 ( $\pm 0.5$ )	15.426	11.897	13.526	18.084	14.981	16.057	15.00
64.7 ( $\pm 0.4$ )	20.556	19.357	24.253	19.754	23.318	21.596	21.47
74.7 ( $\pm 0.4$ )	28.396	25.054	26.869	29.021	23.590	30.812	27.29
84.2 ( $\pm 0.4$ )	39.767	33.174	34.005	35.538	33.882	37.988	35.73

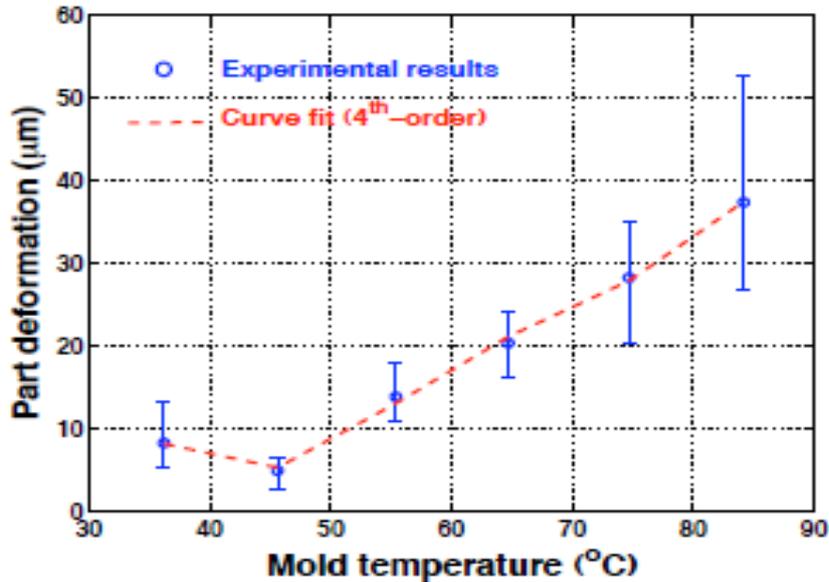


Fig. 6: Overall part deformation

### Bonding Quality Test of The Microfluidic Device

The bonding quality to the warpage, bonding quality tests were performed. For the bonding quality tests, the microfluidic devices bonded with direct bonding were used. Bonding quality were checked by the injecting the pressurized water into the micro channel. The breaking pressure of the microfluidic device used as the indicator of the bonding quality. In order to prepare the experimental set-up, connection elements (capillary tube and its housing) were inserted into the reservoirs of the micro channel and sealed with epoxy. Bonding quality of the microfluidic device was measured in terms of the breaking pressure of the bond. The water within the micro channel was pressurized by means of a micro- for each mold temperature, three samples were used. Flow rate of the micro-pump was increased step by step until the bonding was broken. Once the micro channel is broken, the pressure of the system drops somewhere near atmospheric pressure.

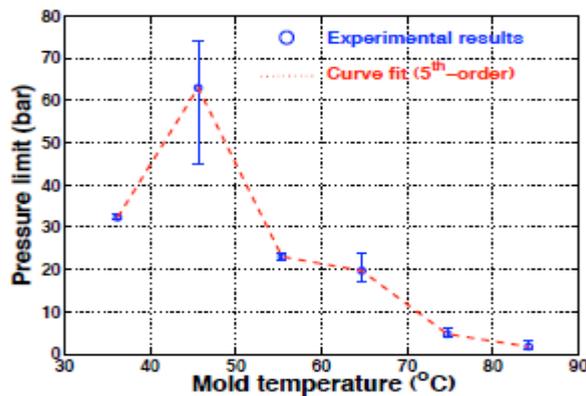


Fig. 7: Breaking pressure of the bonding for different mold temperatures

It can be seen from the results, the stronger direct bonding was achieved when the micro channels were produced at a mold temperature of 45

Table 5: Bonding quality experiment results

Mold Temperature [°C]	Sample#1 [bar]	Sample#2 [bar]	Sample#3 [bar]	Average [bar]
36.2 ( $\pm 0.5$ )	32	32	33	32.3
45.6 ( $\pm 0.5$ )	70	74	45	63.0
55.4 ( $\pm 0.5$ )	23	24	22	23.0
64.7 ( $\pm 0.4$ )	17	24	18	19.7
74.7 ( $\pm 0.4$ )	4	4	6	4.7
84.2 ( $\pm 0.4$ )	1	3	1	1.7

Warpage measurements the minimum part deformation can also be seen at a mold temperature of 45C. In addition to that, the trend of the bonding quality results shows a similarity to that of warpage measurements. Therefore, it can be concluded that there is one-to-one correspondence between the bonding quality and the warpage. The bonding quality increases with the decreasing warpage. There exists an maximum quality for the product which is achieved at the same mold temperature where the minimum part deformation is located. In terms of bonding quality, the corresponding mold temperature can be named as the optimum mold temperature. Maximum breaking pressure of 74 bars was achieved at the optimum mold temperature. The bonding between PDMS and glass/PDMS can withstand up to 5-15 bars. Compared to the PDMS bonding, the current results are very promising especially when the HPLC applications are considered in which pressures around 50 bars are generated. After the bonding quality experiment, leakage test was performed. In order to check the leakage, sample which was produced at a mold temperature of 45C was used. The flow rate of the micro-pump was adjusted to a value less than the breaking flow rate (2 ml/min). In this flow rate, the pressure was observed as 70 bar. Then, the pressurized water flowed couple of minutes within the micro channel. Following these operations, a blue ink manually was injected into the micro channel and flow pattern of the ink was examined to check any possible.



Fig. 8: The microfluidic device loaded

## V. CONCLUSION

The ultimate goal of the microfluidics technology is to develop disposable devices which can accomplish biomedical analyses at much lower manufacturing and operational cost compared to its room-sized or bench top-sized counterparts. In this perspective, micro- and nano-scale fabrication of disposable medical devices is a popular topic both for research and commercial applications. Injection molding of structures with micro-features is a developing process with great potential for the mass-production of micro-scale devices with low-cost. The major focus of this study is to develop a technique for repeatable, productive and accurate fabrication of microfluidic devices on a mass production scale. To achieve this, injection molding process is adapted for the fabrication of a microfluidic device which composed of a single micro channel. A proper mold for the injection molding was designed and manufactured using high-precision mechanical machining. During the design procedure, numerical experimentation was performed using Moldow simulation tool. The microfluidic device was fabricated out of Plexiglass 6N. To analyze the effect of the mold



temperature, both simulations and the injection molding of the microfluidic device were performed at different mold temperatures. The bonding of the microfluidic device is performed by direct bonding and adhesive bonding. The practical aspects of two bonding techniques were assessed, and it was concluded that direct bonding more feasible than adhesive bonding. The warpage and the bonding quality of the final products were characterized for different mold temperatures. It was found that there exists one-to-one correspondence between the warpage and the bonding quality of the molded pieces. As the warpage of the pieces decreases, the bonding quality increases. A maximum point for the breaking pressure (which is the parameter used for the characterization of the bond quality) and the minimum point for the warpage was found which were observed at the same mold temperature. This mold temperature was named as the optimum mold temperature for a better quality. In this study, it was observed that although Moldow can be used as a design tool since it can predict many aspects of the molding process, Moldow cannot predict the optimum mold temperature. Moldow predicted an optimum mold temperature of  $0^{\circ}\text{C}$ , however, in the experiments it was found that the optimum mold temperature is around  $45^{\circ}\text{C}$ . For this optimum mold temperature, it is observed that a microfluidic device can withstand pressure up to 74 bars, which is very promising when HPLC applications are considered. Therefore, although Moldow is one of the powerful simulation tools for injection molding, it is better to use it for design check for the structures with micro-features instead of using for the optimization of the injection parameters. The ideal injection molding parameters depend on the injection molding machine, environmental conditions and complete mold geometry (not only mold cavity), which have considerably effects on the pieces with micro-featured parts compared to macro-sized parts. The production of a single microfluidic device set (two piece) was performed nearly in fifteen seconds (depending on the mold temperature). However, the machining of the mold took approximately 4 hours. For the bonding of the microfluidic device another half an hour is required. However, considering the mold is manufactured for one time, and the bonding process can be automated, the fabrication of the polymeric microfluidic devices can be performed very fast with the injection method presented. Therefore, injection molding is a very promising method for the production of microfluidic device on a mass scale (about 10000 pieces/day with a single injection machine). Although a microfluidic device with a single channel can be used in HPLC applications, generally in the biomedical application microfluidic devices with a rather complex micro channel network are needed. Since the framework of the fabrication of such a structure is similar to that of with a single micro channel, a similar research on a micro -fluidic device with a micro-channel network will be an interesting future research direction. Moreover, the limits of the fabrication can be extended and the investigation of injection molding of products with even submicron features can be one of the key research directions in this field. I believe that, as the field of injection of devices micro-features becomes more mature in terms of commercial applications, the overall manufacturing costs will continue to decrease which will increase the demand for micro-molding techniques.

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