Warpage Minimisation on Side Arm using Response Surface Methodology (RSM)

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LIST OF ABBREVIATIONS

2FI Two factor interaction

3D	Three dimensional
ABS	Acrylonitrile Butadiene Styrene
AMI	Autodesk Moldflow Insight
ANN	Artificial neural network
ANOVA	Analysis of Variance
CAD	Computer aided drafting
CAE	Computer aided engineering
CCD	Central composite design
CH_2Cl_2	Methylene Chloride
DOE	Design of experiment
GA	Genetic algorithm
PA	Polyamide
PC	Polycarbonate
PP	Polypropylene
PROB > F	Probability value
PSO	Particle Swarm Optimisation
PVC	polyvinylchloride
R^2	Coefficients of correlation
RSM	Response surface methodology
S/N	Signal to noise
SA	Simulated Annealing
SAO	Sequential approximation optimisation
SM	Shot material
TQM	Total Quality Management

LIST OF SYMBOLS

X_i	Various independent inputs
Y	Output or response
n	Design variables number
Bo	Unknown coefficient of constant
Bι	Unknown coefficient of linear
Bιι	Unknown coefficient of quadratic
Bιj	Unknown coefficient of interaction of terms
D	Diameter of reciprocating screw (mm)
L_1	The length of shot material covered by the reciprocating screw in order to inject the molten material into the sprue, runner and gate in the mould (mm)
L_2	Length of shot material covered by the reciprocating screw in order to inject the molten material into side arm cavity in the mould (mm)
L_T	Total length of shot material covered by the reciprocating screw in order to inject the molten material into the sprue, runner, gate and the side arm cavity in the mould (mm)
L_{MS}	Length covered by reciprocating screw in order to pack the part with additional molten material (mm)
$\vec{V}$	Ram speed (mm/s)
$\dot{V}$	Volume flow rate of the injected molten material (mm^3/s)
A	Cross-sectional area of reciprocating screw (mm^2)

Meminimumkan Keledingan pada Side Arm Menggunakan Response Surface Methodology (RSM)

ABSTRAK

Proses pembuatan alat perubatan seperti kateter memerlukan penggunaan acuan digelar '*side arm*', melalui operasi pencelupan susu getah. Proses pembuatan side arm yang diperbuat daripada bahan Nylon PA66 melalui proses pengacuan suntikan sering menghasilkan kecacatan yang tidak diingini terutamanya keledingan. Kajian ini bertujuan untuk menentukan parameter pemprosesan yang optimum bagi proses pengacuan suntikan '*side arm*' yang membawa kepada pengurangan kecacatan keledingan tersebut. Parameter pemprosesan yang dipertimbangkan adalah tekanan pemampatan, masa pemampatan, masa penyejukan, suhu acuan dan suhu leburan. Selain itu, kajian ini juga cuba untuk mengenal pasti parameter pemprosesan yang paling berpengaruh terhadap keledingan. Model tiga dimensi '*side arm*' dianalisis terlebih dahulu melalui simulasi perisian Moldflow untuk menjangka kejadian keledingan pada '*side arm*' dan parameter-parameter berkenaan kemudiannya dioptimumkan melalui kaedah '*Response Surface Methodology*'. Hasilnya, tetapan optimum parameter pemprosesan yang diperoleh bagi tekanan pemampatan, masa pemampatan, masa penyejukan, suhu acuan dan suhu leburan adalah 76.57 MPa, 0.60 s, 8.30 s, 34.45 °C dan 275.00 °C. Selain itu, isu keledingan pada '*side arm*' didapati paling banyak dipengaruhi oleh parameter masa penyejukan dengan kadar sumbangan sebanyak 4.01 % berbanding parameter pemprosesan yang lain. Keledingan yang dihasilkan berdasarkan tetapan parameter pemprosesan yang disyorkan oleh simulasi perisian juga dibandingkan dengan keledingan yang dihasilkan berdasarkan tetapan optimum parameter pemprosesan. Kesimpulannya, keledingan dapat dikurangkan kira-kira 22.8 % selepas pengoptimuman dibuat berbanding tetapan parameter pemprosesan yang asal.

Warpage Minimisation on Side Arm using Response Surface Methodology (RSM)

ABSTRACT

Catheter manufacturing process requires the use of mould called side arm through latex dipping process. Manufacturing process of a nylon PA66 - side arm via an injection moulding often leads to undesirable warpage. This research tends to determine the optimum processing parameters that can be used for manufacturing side arms in minimizing the warpage issues. The considered processing parameters were packing pressure, packing time, cooling time, mould temperature and melt temperature. Apart from that, this research also tries to find the most significant factor affecting the warpage. The side arm model was developed via computer aided drafting (CAD) software and the whole analyses on the warpage was executed via a simulation software while the parameters concerned were optimised through response surface methodology. As a result, the optimised parameter settings are 76.57 MPa, 0.60 s, 8.30 s, 34.45 °C and 275.00 °C acquired for packing pressure, packing time, cooling time, mould temperature and melt temperature respectively. On top of that, cooling time has been found to be the most influential parameter affecting the warpage with contribution factor of 4.01 % compared to others. The warpage based on parameter settings recommended by the simulation software has also been compared with that after the optimisation. It can be concluded that the warpage after optimisation is 22.8 % reduced compared to the original recommended setting.

CHAPTER 1

INTRODUCTION

1.1 Introduction to the Research

This research is an extended work based on a collaboration project between a urinary-catheter manufacturer located in Perlis, Malaysia and School of Manufacturing Engineering, Universiti Malaysia Perlis in 2009/2010. This project has been initiated between both parties since the manufacturers had an issue with one of its dipping mould called as side arm in manufacturing catheters. A research group was invited to take part in solving the problem that the company had in reducing the reject rate of the side arm; an aluminium part that was used as a mould in dipping processes for manufacturing catheters. At the end of that project, a new design of side arm had been proposed which was made from very-much cheaper plastic materials that solved design issue of the traditional aluminium side arm (Fathullah, Shayfull, Azaman, Shuaib, & Manan 2010; Fathullah, Shayfull, Shuaib, Nasir, & Salleh, 2011a). In this work, the new design of side arm was analysed further in reducing warpage issues occurred during its manufacturing process.

1.2 Introduction of Catheter

A catheter (in this case an indwelling Foley-type catheter) is a rubber-based tool that aids patients transfer their urine from urine bladder during urination. The process of depleting the urine is done by inserting the tube into the bladder through a duct called urethra and then the catheter is allowed to stay within the bladder. The catheter is extensively demanded globally and practically applied by trained medical specialist and surgeons. There are three common types of catheter which are straight, indwelling and suprapubic catheters (Fathullah et al., 2010). The example of indwelling catheter is shown in Figure 1.1.

Figure 1.1: Indwelling catheter (Fathullah et al., 2010)

1.2.1 Catheter Manufacturing Process

As reported in previous work published (Fathullah et al., 2010), the process of manufacturing catheter begins with a combination of two distinct parts namely aluminium former and side arm employed as the mould for the medical tool. The operator then put the former-side arm mould onto a jig that is readily available. After that, a rubber thread is put into the hole within the side arm (see Figure 1.2). At this stage, the process is called threading where the rubber thread is secured at the X1 spot and afterward the thread drawn out from the side arm until it is fastened at the X2 spot, as shown in Figure 1.3. The next stage is the lubrication of the mould which is to prevent the latex from attaching to the mould by immersing the mould into a type of solution called METHCELL. Then, the former-side arm catheter mould is dipped into latex where this particular process is called latex dipping process. The process is then followed by the curing at 60 °C which is aimed to dry the latex coating surrounding the rubber thread and the former-side arm mould. Later, the coating of latex becomes hardened around the rubber thread and former-side arm mould. This hardened latex coating is actually known as catheter. The catheter then finally pulled out from the former-side arm mould (Fathullah et al., 2010).

Figure 1.2: Threading process on side arms

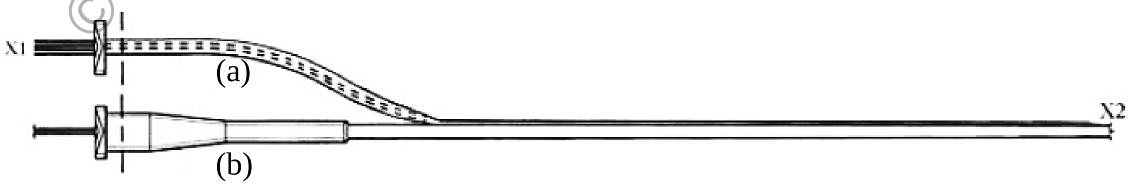
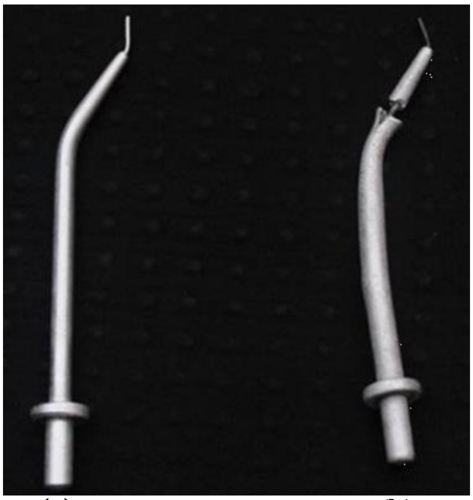


Figure 1.3: (a) Side arm, and (b) Former (Fathullah et al., 2010)

1.3 Background of Catheters Manufacturing Issues

The real problem of the catheter production arises in the threading process where the thread is difficult to be drawn out and is easy to tear while being inserted and pulled out manually from the side arm. Therefore, a piece of the thread usually left inside the side arms which lead the whole side arm needed to be fired at 600 °C to melt the rubber thread left inside. When the firing process is repeatedly done onto the side arm, the structure of the material is affected causing shrinkages and functional failures. The new and rejected side arm due to repetitive burning process are shown in Figure 1.4 (a) and (b) respectively. This particular issue is reported to cost the catheter manufacturer RM 9000.00 per annum, in order to replace 1000 units of the new side arms. The other issue causing the rubber thread to get trapped inside the side arms is due to different diameter of rubber thread and inner hole at the edge of the side arm which are 1.10 mm and 0.85 mm respectively. The aluminium side arm is deliberately designed to avoid the latex solution from entering inside the side arms during the dipping process takes place (Fathullah et al., 2010).



(a) (b)

Figure 1.4: (a) New side arm, and (b) Rejected side arm (Fathullah et al., 2010)

1.4 Injection Moulding Process for New Process of Manufacturing Catheters

The research work reported herein is on the new side arm which is made through injection moulding process as reported by (Fathullah et al., 2010). It was reported that injection moulding process was the correct solution to replace machining operation in order to manufacture the side arm (Fathullah et al., 2010; Fathullah et al., 2011a). This decision was made since the new design of the side arm needed to fulfil several criteria e.g. the inner hole diameter at the tip of side arm needs to be at 0.85 mm and at the same time the inner hole diameter must be made larger. Further advantages of choosing an injection moulding process rather than the conventional machining processes are discussed in 1.4.1.

1.4.1 Injection Moulding Process: A New Process in Manufacturing Side Arm

There are four steps needed in machining processes of manufacturing conventional aluminium side arms. The steps of are as below;

i) Drilling process (to create a through hole)
ii) Turning process (using lathe machine to shape the body of the side arm)
iii) Metal Tip Insertion (a metal tube inserted to control the hole size at the tip of the side arm)
iv) Bending operation (to create an appropriate bending angle on the side arm)

The bending operation causes the inner hole diameter at the bending location become tighter than it was before bending takes place. The diameter of the hole at the curved location was smaller than that of the rubber thread (0.35 mm diameter) therefore it led the rubber thread to get trapped when it was pulled out by the operator after the curing process (Fathullah et al., 2010).

Therefore, applying this process in making side arm can reduce the risk of the rubber thread to tear-off inside the side arm as the diameter hole inside the side arm can now be maintained at 0.85 mm which is wider than the inner hole at the tip of the side arm, making the rubber thread to be smoothly inserted inside the side arm. The diameter of the hole is very crucial to be controlled as if the diameter at the tip is left wider than 0.85 mm, it will allow latex solution to get into the hole and therefore the whole product will be rejected. This is the main reason why injection moulding process is selected as the new process to replace conventional side arm production. The benefit that come from this is that the new side arm does not has to undergo heating process at 600 °C in order to melt the trapped thread (Fathullah et al., 2010).

There are a number of additional benefits using injection moulding process such as low cost, short duration of cycle time, large capacity of production, excellent quality of surface dimension and precise tolerance (C. C. Chen, Su, & Lin, 2009). Apart from that, injection moulding process is also commonly used due to its ability in producing parts with complicated shapes (Nasir, Ismail, Shayfull, & Fairuz, 2015). Although this process is the most preferable in producing plastic materials, manufacturers regards it as a tough process in maintaining the quality at the cheapest cost. The rise of shape complexity demand and factor manipulation therefore leads to higher production cost and at the same time influencing the product quality (Kumar, Gaur, Kasdekar, & Agrawal, 2015).

1.4.2 Nylon PA66 as the New Material for the Side Arm

The material used in this report is from the type of Nylon PA66. The material is selected as it was reported to have no reaction with a solution called METHCELL solution; the solution used as the lubricant in order to prevent the latex from sticking onto the side arm during dipping processes (Fathullah et al., 2010). The selection of the Nylon PA66 for the side arm would be cancelled out if it reacted with the METHCELL solution. Besides, Nylon PA66 does not react with Methylene Chloride (CH_2Cl_2) which is used as a solvent on the latex. This criterion is very important as the material on side arm may have a chemical reaction and therefore pollutes the whole latex solution when the process is taking place. Nylon PA66 has also been tested and passed the aging test where it is dry heated at 70 °C in a furnace for seven consecutive days. This resistivity test was done on the material as the side arm needs to be dried at 60 °C after it is immersed in METHCELL solution as mentioned earlier. Moreover, it was selected due to a few other advantages it has such as the capability to reduce the rate of oxidation and thermal deterioration during its exposure to highly temperature for long extent of time. Besides, the physical properties of this material offers permanent enhancement under disclosure to continuous heat. Furthermore, this polymeric material is considered relevant for medical appliances which is concurred by Birkinshaw, Buggy and Daly (1987) who suggested that it can be utilized in medical fracture fixation utensils especially in certain situation (Fathullah et al., 2010).

On top of the reason why the material is selected, Nylon PA66 offers lower cost as compared to the previous material used. For instance, a side arm made by Nylon PA66 only cost RM 1.50 including the cost of manufacturing and assembling whereas the cost of a side arm produced from aluminium is much higher which is RM 9.00 (Fathullah et al., 2010). Figure 1.5 shows the Nylon PA66 side arm.

Figure 1.5: Nylon PA66 side arm

1.5 Problem Statement

Although manufacturing side arm via an injection moulding process has solved the issue of reject rates, however it was reported that warpage occurred on the Nylon PA66 side arm produced (Fathullah et al., 2011a). An attempt was made previously by Fathullah et al. (2011a) to reduce the defect occurred on the side arm by implementing a classical method, Taguchi in optimising processing parameters from affecting warpage on the side arm. However, a major issue from the Taguchi technique is that it is not sufficient for full prediction yet it needs further verification from a different optimisation method. A new optimisation method is needed to answer the significant parameters as well as to determine best set of parameters influencing the warpage occurrences. Taguchi is also unable to anticipate on the levels in-between the given values rather than only selecting the exact levels set in the Taguchi orthogonal array. As previous studies have yet to anticipate the best combination parameters out of it therefore, another optimisation method is needed to anticipate the exact parameter levels influencing the warpage.