AMM - Applied Mechanics, Materials, and Manufacture Mechanical Engineering

A Determination of the Optimized Conditions for Rubber Injection Moulding

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Abstract

Rubber injection moulding is one of the processing methods widely used to manufacture rubber products which generally have complex geometries such as motor boots, engine hoses, steering wheels, automotive glass runs, and automobile tension rod bushes. However, most processing parameters chosen for injection process are often obtained using trial-and-error as well as operator's experience resulting in unsatisfied product quality. Consequently, in order to gain further understanding of the determination of those injection variables, an investigation of the optimized injection conditions of the EPDM bellow used in washing machines was studied in this research. Both numerical flow analysis and empirical work were carried out and then results were analyzed with the 2^4 full factorial method. The results show that the significant factors on rubber injection process are founded as injection pressure, injection temperature, mould temperature, injection time. It can be founded that the optimum levels of factors at the injection time of 17 seconds and the mould temperature of 180 °C. These conditions can be further used for reduction of air traps existed. The optimization of these parameters can lead to less air trap which improves rubber product quality.

***Keywords**:* Optimized condition, Rubber, Injection moulding, EPDM, Full factorial method.

1. Introduction

Currently, rubber product industry has encountered various problems in terms of product quality, lead time, and manufacturing cost. This is largely due to the lack of fundamental understanding of rubber processing methods such as compression moulding, injection moulding, transfer moulding, calendaring, extrusion. The parameters used in those processes usually rely on trial and error and skill of operators leading to uncontrolled quality of parts. Among those rubber manufacturing activities, injection moulding is one of the processes widely used in production of rubber parts from simple to complex geometries with mass production. The injections conditions are mainly varied based on type of compounding material. Many part defect including air trap, short-shot, excessive flash, weld line, and part shrinkage has been commonly founded. Therefore, in this research work, the optimized condition of rubber injection moulding process using Computer Aided Engineering (CAE) in conjunction with the utilization of Design of Experiment (DOE) as well as a statistical analysis was carried out. In this work, factors and levels of factors affecting the injection condition of Ethylene Propylene Diene Monomer (EPDM) were determined using a case study of the PV bellow used in a washing machine. [1-5]

2. Methodology

2.1 Part Description

In this investigation, the rubber bellow made of EPDM as shown in Fig. 1 was chosen as a case study due to the large amount of defects and wastes reported from a manufacturing plant. The bellow is regularly used as a water protection diaphragm in a washing machine. The major concern on part quality is the air trap occurred in the upper, middle, and lower portion, respectively, as shown in Figs. 2-4.

Fig. 1 Rubber bellow made of EPDM.

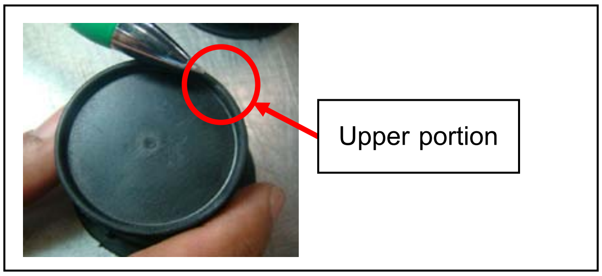

Fig. 2 Air trap on the upper part of the product.

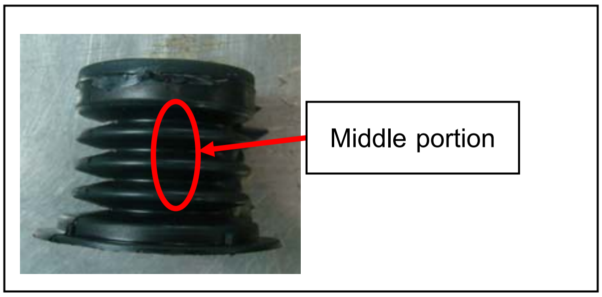

Fig. 3 Air trap on the middle part of the product.

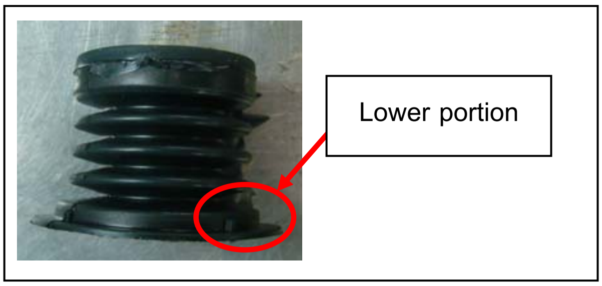

Fig. 4 Air trap on the lower part of the product.

2.2 Part Model Development

In order to perform a flow simulation of rubber in an injection mould using CAE, part modeling in 2D and 3D were constructed. A part drawing and a solid model are shown in Figs. 5-6.

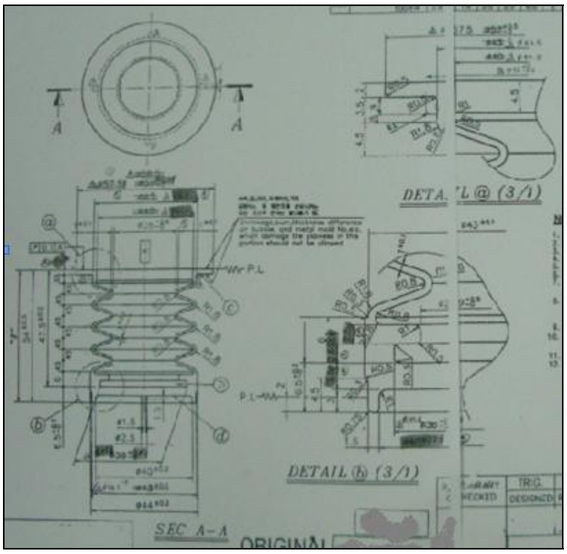

Fig. 5 Part drawing in 2-D.

Fig. 6 A part solid model.

2.3 Design of Experiment

2.3.1 Determination of Factors and Levels of Factors

In this study, there are a total of four controlled factors and each factor consists of two levels as described as follows: injection time (7 and 17 seconds), injection pressure (80 and 100% of the maximum value), injection temperature (60 and 80 degree Celsius), and mould temperature (160 and 180 degree Celsius), respectively. Details of factors and their levels are shown in Table 1. [6-7]

Table. 1 Factors and levels of factors.

Factors		Levels	
		Low (-)	High (+)
A	Injection time (sec)	7	17
B	Injection pressure (%)	80	100
C	Injection temperature (°C)	60	80
D	Mould temperature (°C)	160	180

2.3.2 Determination of Output

The completeness of the final moulded part geometry resulting from the existing of air traps in all cavities was selected as an output of the analysis.

2.3.3 Determination of Experiment

The preliminary step is to carry out the screening experiment to choose the proper parameters. In this case, a 2^4 (16) full factorial experiment was performed using results from

CAE analysis. The constants of the experiment are shown in Table 2.

Table. 2 Contrast constants used for 2^4 full factorial.

	A	B	AB	C	AC	BC	ABC	D	AD	BD	ABD	CD	ACD	BCD	ABCD
(1)	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+
a	+	-	-	-	-	+	+	-	-	+	+	+	+	-	-
b	-	+	-	-	+	-	+	-	+	-	+	+	-	+	-
ab	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+
c	-	-	+	+	-	-	+	-	+	+	-	-	+	+	-
ac	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+
bc	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
abc	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
d	-	-	+	-	+	+	-	+	-	-	+	-	+	+	-
ad	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+
bd	-	+	-	-	+	-	+	+	-	+	-	-	+	-	+
abd	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-
cd	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+
acd	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-
bcd	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
abcd	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

2.4 Flow Simulation of Injection Moulding Process

A STL (Stereolithography) solid model of part was constructed and then followed by an enmeshment process. Then, the gates and runners for moulds were then designed based on the product geometry as shown in Fig. 7. Subsequently, the material properties were experimentally determined and injection conditions were founded as shown on Figs. 8-9 and Table 3. Finally, the comparison between the empirical and simulated results was done. [8]

Table. 3 Material Properties and injection conditions

Material Properties	EPDM 50 Shore A
Injection time (sec)	7, 17
Injection pressure (%)	80, 100
Injection temperature (°C)	60, 80
Mould temperature (°C)	176, 180
Injection time (sec)	200
Clamping force (tons)	300
Minimum cure rate (%)	75
Mean cure rate (%)	95
Volume short size (cm^3)	410

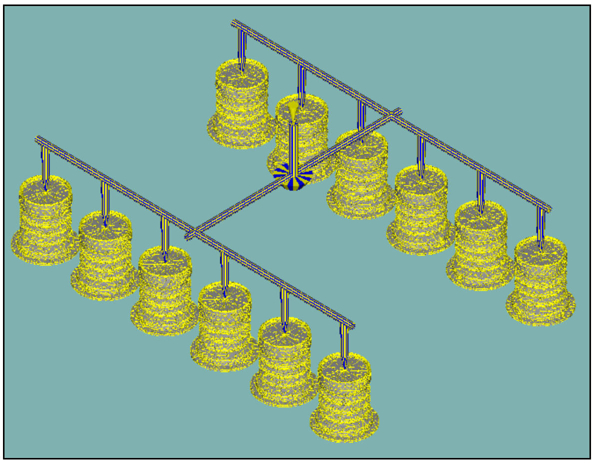

Fig. 7 3D solid models of gates, runners, and part after enmeshment.

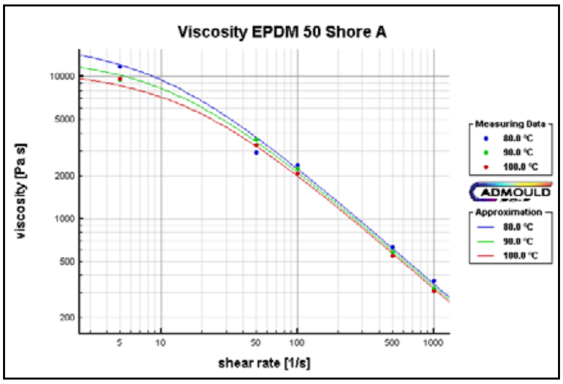

Fig. 8 Relations between viscosity and shear rate at temperatures of 80, 90, and 100 °C.

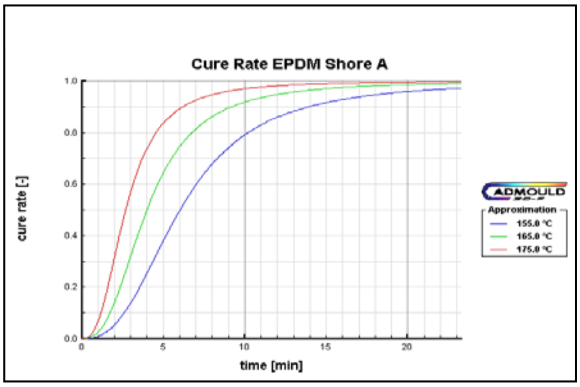

Fig. 9 Relations between cure rate and time at temperatures of 155, 165, and 175 °C.

3. Results and Discussions

The results from the 2^4 full factorial on the part quality in the aspect of the air trap is shown in Table 4 where Y is the overall number of points of air trap occurred on the part. Then the effect values of factor in injection simulation are shown in Table 5.

Table. 4 Simulated injection results based on contrast constants for 2^4 full factorial.

Run No.	Factor				Treatment Combinations	Y
	A	B	C	D		
1	-	-	-	-	(1)	1,216
2	+	-	-	-	a	1,228
3	-	+	-	-	b	1,208
4	+	+	-	-	ab	1,232
5	-	-	+	-	c	1,240
6	+	-	+	-	ac	1,224
7	-	+	+	-	bc	1,232
8	+	+	+	-	abc	1,232
9	-	-	-	+	d	1,232
10	+	-	-	+	ad	1,224
11	-	+	-	+	bd	1,232
12	+	+	-	+	abd	1,224
13	-	-	+	+	cd	1,240
14	+	-	+	+	acd	1,220
15	-	+	+	+	bcd	1,232
16	+	+	+	+	abcd	1,220

Table. 5 Effect values of factor in injection simulation.

Factor	Effect	Factor	Effect
A	-3.50	BD	-0.50
B	-1.50	CD	-0.50
C	5.50	ABC	1.50
D	1.50	ABD	-2.50
AB	4.50	ACD	4.50
AC	-8.50	BCD	-1.50
AD	-8.50	ABCD	0.50
BC	-0.50	-	-

The normal plot of effects and the interaction effect plot on air trap are demonstrated in Figs. 10-11, respectively.

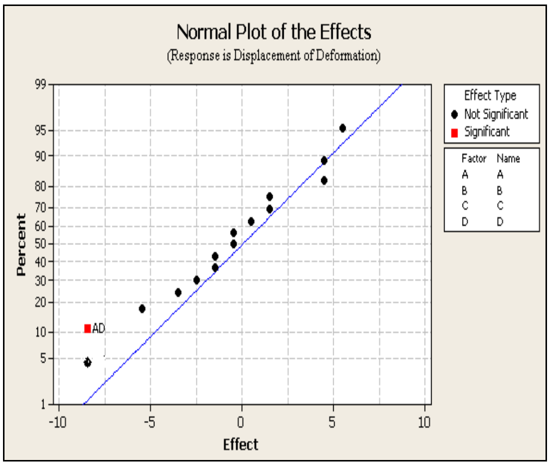

Fig. 10 Normal plot of effects.

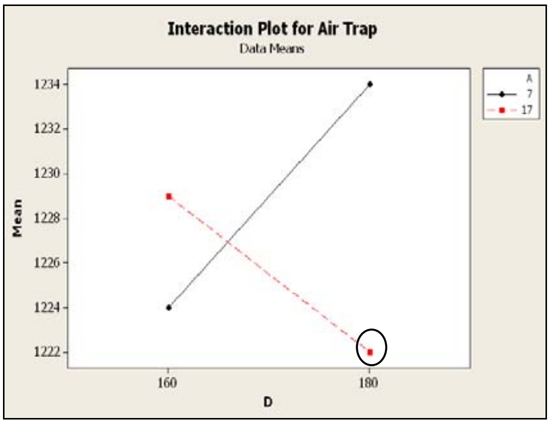

Fig. 11 Interaction plot for air trap between injection time and mould temperature.

It can be founded that the optimum levels of factors at the injection time of 17 seconds and the mould temperature of 180 °C. These conditions can be further used as settings in order to reduce the number of air traps in the mould.

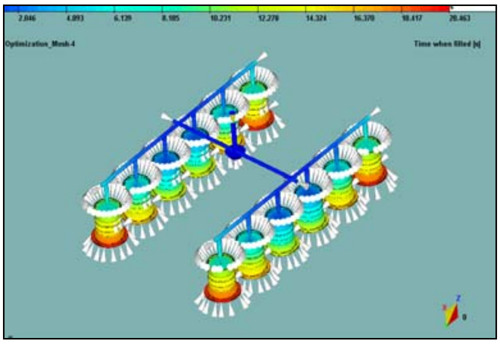

Fig. 12 Positions and number of air traps obtained from simulation.

4. Summary

In this study, the optimized condition of rubber injection moulding process using Computer Aided Engineering (CAE) and the utilization of Design of Experiment (DOE) as well as the 2^4 full factorial was carried out. In this work, factors and levels of factors affecting the injection condition of Ethylene Propylene Diene Monomer (EPDM) were determined using bellow used in a washing machine as a case study. The optimum levels of factors are founded at the injection time of 17 seconds and the mould temperature of 180 °C. This can lead to less air traps in the mould. As a result, the part quality can be improved.

5. Acknowledgements

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6. References

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