

# Fuzzy Logic-Based Moldability-Confirming System in Injection Molding

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## Abstract

Short shot is a molded part that is incomplete since insufficient material was injected into the mold. Remedial actions to solve short shot can be done by injection molding experts based on their empirical knowledge. Modifying mold and part, changing resin to less viscous one, and adjusting process conditions are general remedies. Experts of injection molding might try to adjust process conditions such as mold temperature, melt temperature, injection time based on their empirical knowledge as the first remedy because adjustment of process conditions is the most economic way in time and cost. However it is difficult to find appropriate process conditions as they are highly coupled and there are so many elements to be considered. In this paper, a fuzzy logic algorithm has been proposed to find an appropriate mold temperature. With the percentage of the insufficient quantity of an injection molded part, an appropriate mold temperature can be obtained by the fuzzy logic algorithm.

**Key words :** Fuzzy Logic, Injection Molding, Short Shot, Filling Analysis, Process Conditions

## I. Introduction

Injection molding is one of the most important polymer processing method which can produce net shape products with high quality and high production rate without additional machining. Among the variety of quality problems with injection molded plastic parts, short shot has top priority[1,2]. Short shot is an incomplete molded part caused by insufficient material injection into the mold. Once short shot has occurred, the cause should be found and probable remedies for the problem should be done immediately. As the first remedy, experts of injection molding might try to adjust process conditions such as temperature, pressure, and injection time based on their empirical knowledge because it is a convenient and economic way to solve the problem. But it is not an easy task to determine appropriate process conditions because process conditions are highly coupled, or they affect each other.

In the recent years, many researches on intelligent approaches for optimization of process conditions have been studied. For example, Pandelidis and Zou used optimization methodology to determine appropriate molding conditions in injection molding[3]. They adopted the Sequential Unconstrained Minimization Technique(SUMT), integrated with CAE software to optimize the following process conditions: injection time, melt temperature, and mold temperature.

In this paper, a fuzzy logic algorithm has been proposed to find an appropriate mold temperature focusing on trouble shooting for short shot. According to insufficient quantity of injection molded part, an appropriate mold temperature is generated through the fuzzy logic. To evaluate the fuzzy logic,

a cell phone flip has been selected as a model for the application and then computer simulations with a CAE software named C-MOLD[4] have been performed.

## II. Application of fuzzy logic algorithm

Mold temperature is well known as one of the most important process conditions to be adjusted when short shot has occurred[5]. But it is difficult to get an appropriate mold temperature to solve short shot problems. In general, experts of injection molding process adjust the mold temperature to find an appropriate mold temperature by trial and error, which is very demanding in time and cost, and even harder for non-experts to carry out as it depends on empirical knowledge. A fuzzy logic algorithm has been proposed to reduce troubleshooting time of short shot by finding an appropriate increment of the mold temperature quickly. With the percentage of the insufficient quantity of an injection molded part, an appropriate mold temperature can be obtained by the fuzzy logic algorithm as shown in Figure 1. The obtained  $e$  and  $\dot{e}$  at the end of the injection molding become input data for the fuzzy logic algorithm. In Figure 1,  $e$  is the percentage of insufficient quantity of an injection molded part and  $\dot{e}$  is the change rate of  $e$  which is calculated by dividing  $e$  by fill time and  $\Delta T_m$  is the necessary increment of mold temperature determined by two input data.

The processes of the fuzzy logic algorithm are as follows.

### Step 1. Fuzzifier

In the first step, the fuzzifier has the effect of transforming crisp input data into suitable linguistic values[6]. As a two-input and single-output system,  $e$  and  $\dot{e}$  are input data and  $\Delta T_m$  is the output.

Membership functions of each input and output are shown

in Figure 2, Figure 3, and Figure 4.

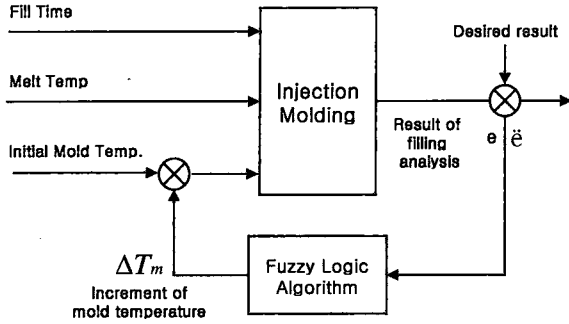


Fig. 1. Schematic diagram of fuzzy logic algorithm application to injection molding

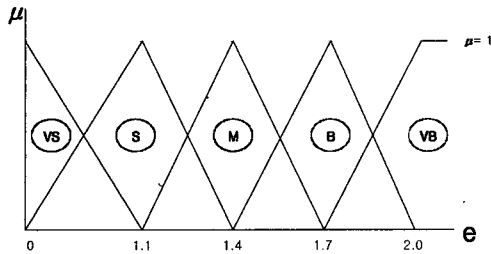


Fig. 2. Membership functions of  $e$

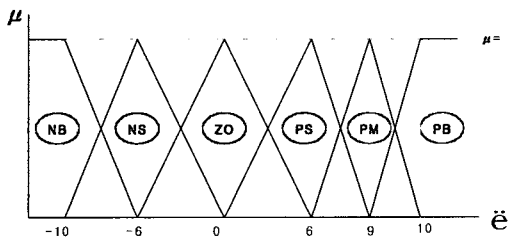


Fig. 3. Membership functions of  $\dot{e}$

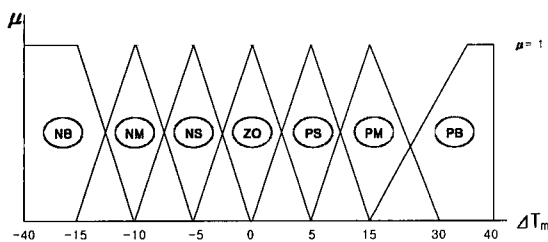


Fig. 4. Membership functions of  $\Delta T_m$

In the figures above, linguistic variables are defined in Table 1.

**Step 2. Fuzzy rules**

Table 2 shows the fuzzy rules of the output,  $\Delta T_m$ , which can be read, for example,

- "IF  $e$  is VS and  $\dot{e}$  is NB THEN  $\Delta T_m$  is ZO"
- "IF  $e$  is VS and  $\dot{e}$  is PS THEN  $\Delta T_m$  is NS"

- "IF  $e$  is VB and  $\dot{e}$  is ZO THEN  $\Delta T_m$  is PM"
- "IF  $e$  is VB and  $\dot{e}$  is PB THEN  $\Delta T_m$  is PB"

Table 1. Definition of linguistic variables used in the fuzzy logic

Variables	Definition	Variables	Definition
VS	Very Small	NM	Negative Medium
S	Small	NS	Negative Small
M	Medium	ZO	Zero
B	Big	PS	Positive Small
VB	Very Big	PM	Positive Medium
NB	Negative Big	PB	Positive Big

Table 2. Fuzzy rules

$\Delta T_m$		$\dot{e}$					
		NB	NS	ZO	PS	PM	PB
$e$	VS	ZO	ZO	ZO	NS	NM	NB
	S	PS	PS	PS	PS	PS	PM
	M	PM	PM	PS	PS	PM	PM
	B	PB	PM	PM	PM	PM	PB
	VB	PB	PB	PM	PB	PB	PB

**Step 3. Fuzzy inference and defuzzifier**

Mamdani's MAX-MIN compositional rule of inference has been applied in the fuzzy logic algorithm[7,8]. And as a defuzzifier, COG(Center Of Gravity) method has been used to get  $\Delta T_m$  as follow[9].

$$y^* = \frac{\sum_{j=1}^n \mu_c(y_j) y_j}{\sum_{j=1}^n \mu_c(y_j)} \tag{1}$$

Where n is the number of quantization levels of the output,  $y_j$  is the increment of mold temperature,  $\Delta T_m$ , at the quantization level j, and  $\mu_c(y_j)$  represents its membership value in the output fuzzy set C.

**III. Evaluation of the fuzzy logic algorithm**

**3.1 Filling simulation with a CAE tool**

For evaluation of the fuzzy logic algorithm, filling simulations of a cell phone flip were conducted instead of experiments in injection molding.

The simulations were conducted in two ways; one was based on Golden Section Search method which simulates the expert's behavior in troubleshooting of short shot, and the

others on the fuzzy logic algorithm.

Figure 5 shows the finite element model of a cell phone flip.

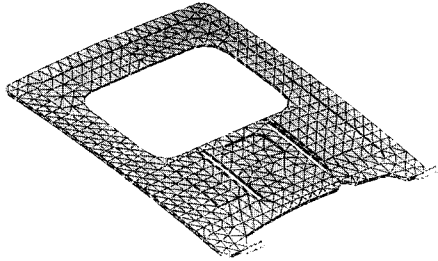


Fig. 5. Finite element model for the simulations

Process conditions used in the simulations are in Table 3. As shown in Table 3, melt temperature and fill time have the ranges, but not specified because they were used as variables in the simulations. In the case of the cell phone flip, the fill time range was estimated from 0.16(s) to 0.28(s). The simulations were conducted with 10 cases as shown Table 4.

Table 3. Process conditions

Injection pressure	120 MPa
Packing pressure	100 MPa
Gate type / number	Side gate / 2
Melt temperature	Variable(200~280°C)
Fill time	Variable(0.16~0.28sec)
Mold temperature	Output variable

Table 4. The simulation data

No.	Fill time (sec)	Melt temperature (°C)
01	0.16	220
02	0.17	260
03	0.18	230
04	0.19	280
05	0.20	240
06	0.21	220
07	0.22	280
08	0.23	230
09	0.24	260
10	0.25	270

### 3.2 Simulation results

For the simulation data, Figure 6 graphically shows the iteration number of the two ways for the simulation data.

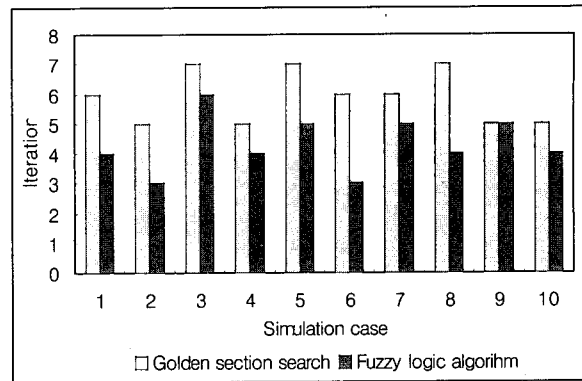


Fig. 6. Iteration number of the simulations

As shown in Figure 6, average iteration number of filling simulation conducted by Golden Search Method is 5.9 and by the proposed fuzzy logic algorithm is 4.3.

## IV. Conclusions

A fuzzy logic algorithm has been applied to injection molding system to reduce troubleshooting time of short shot. As a result, the fuzzy logic algorithm helped to reduce the troubleshooting time by 27% within reliable mold temperature range.

The proposed fuzzy logic algorithms is expected to give not only non-experts but also experts of injection molding an easy and reliable way to determine mold temperature so that short shot can be solve quickly.

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