PENGOPTIMUMAN PARAMETER PENGACUAN SUNTIKAN DALAM PENGHASILAN DULANG PLASTIK POLIPROPELIN DENGAN MENGGUNAKAN KAEDAH TAGUCHI

(OPTIMIZATION OF INJECTION MOLDING PARAMETERS FOR PRODUCTION OF POLYPROPYLENE PLASTIC TRAY USING TAGUCHI METHOD)

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ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my main supervisor, Dr. Shahrul Kamaruddin and my co-supervisor, Dr. Zahid Akhtar Khan, who have been very motivating and supportive since the first day I start my final year project. They gave me valuable advices on learning ethics and guide me along the way for my final year project.

I am also grateful to technical support from the plastic injection molding laboratory personnel, Mr. Abdul Hamid Pahmi who has taught me about operation of the Batenfeld TM 750/210 injection machine system and the related information. In addition, I would also like to express my thanks to Mr. Amri, Mr. Baharom and Mr. Hasnor, who have given me advice and suggestions for the completion of my project. Their criticism has been invaluable.

Finally, warmest thank to my parents whom has given me moral support in completion of this project. In addition, I would like to thank my friends who encouraged me along the way of my final year project. To those that I may have left out, your presence and indirect support will be heart felt. Thank you very much to all of you.

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ACRONYM

PP = Polypropylene
DOE = Design of Experiment
ANOVA = Analysis of Variance
OA = Orthogonal Array
S/N = Signal to Noise
MSD = Mean Square Deviation
DOF = Degree of Freedom
C.F = Correction Factor

ABSTRAK

Di dalam kajian ini, kaedah Taguchi (diperkenalkan oleh G. Taguchi) merupakan satu alatan untuk mengoptimasikan proses digunakan untuk mencari parameter proses yang optimal bagi mesin pengacuan suntikan TM 750/210, yang diguna untuk menghasilkan dulang plastik daripada bahan polipropelin (PP). Satu tatasusun ortogon (OA), kesan utama, nisbah isyarat hingar (S/N), dan analisis varians (ANOVA) digunakan untuk mengkaji sifat lentur dulang di bawah beban yang sekata untuk memperolehi kekuatan lentur yang maksimum. Di samping itu, ia juga digunakan untuk mengkaji sifat pengecutan dulang untuk memperolehi sifat pengecutan yang minimum. Melalui kajian ini, bukan sahaja parameter optimal proses untuk proses pengacuan suntikan boleh diperolehi, tetapi juga parameter proses utama yang memberi kesan kepada prestasi lentur dan pengecutan dulang juga boleh diperolehi masing-masing. Keputusan ujikaji diberikan untuk membuktikan keberkesanan kaedah ini.

ABSTRACT

In this study, the Taguchi method as a powerful design of experiments (DOE) tool developed by G. Taguchi is used to find the optimal process parameters for Battenfeld TM750/210 injection molding machine that was used to produce polypropylene (PP) plastic tray. Therefore, an orthogonal array (OA), main effect, the signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) are employed to investigate the process parameters in order to achieve optimum bending deflection performance and optimum shrinkage behavior of a PP plastic tray so as to get maximum bending strength and minimum shrinkage respectively. Through this study, not only can the optimal process parameters for injection molding process be obtained, but also the main process parameters that affect the bending performance and shrinkage behavior of the PP plastic tray can be found respectively. Experimental results are provided to confirm the effectiveness of this approach.

CHAPTER 1: INTRODUCTION

1.1 Background

The main objective of this project is to optimize injection molding parameters for optimum performance of plastics trays which made from polypropylene material using Taguchi method. The performance of these plastic trays is evaluated in terms of their bending strength and shrinkage behavior. Basically, the polypropylene (PP) plastic tray is produced to use as a toolbox for keeping a small quantities of different kinds of screws, nuts, bots, nails and blades. Besides that, it also can be used as a container for putting stationery like pencils, pens, rulers and rubbers onto it. This project presents the concept of Taguchi method, Design of Experiment (DOE) to determine and analyze the optimal injection molding parameters for producing high quality of polypropylene plastic trays.

1.2 Objectives

The objectives of this project are;

a. To determine the optimal process parameters for an injection molding machine.
b. To estimate each injection molding process parameters to the contribution of the bending strength and total shrinkage quality characteristics, respectively.
c. To predict the bending strength and total shrinkage quality characteristics based on the optimal process injection molding parameters.

1.3 Scope

In this project, plastic injection molding process was carried out on a Battenfeld TM750/210 machine and plastic trays were produced from polypropylene material. Only four injection molding parameters i.e. melting temperature, injection speed, cooling time and holding pressure, each with two levels, have been investigated and interaction between the parameters was not considered in present study. Therefore, L_8 orthogonal arrays (OA) are used in the experiment. The results were analyzed by employing signal-to-noise ratio, main effects and analysis of variance.

1.4 Taguchi Design of Experiment

"Taguchi Methods" is the American Supplier Institute's trademarked term for the quality engineering methodology developed by Taguchi, who was named an honorary member in 1997. In this engineering approach to quality control, Taguchi calls for off-line quality control, on-line quality control, and a system of experimental design to improve quality and reduce costs. In this method, he proposed that engineering optimization of a process or product should be carried out in a three-step approach which that, system designs, parameter design, and tolerance design.

In system design approach, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, planned product parameter values and so on are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, planned process parameter values and so on are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. Next, after the system design is parameter design. The objective of parameter design is to optimize the settings of the process parameter values for improving quality characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from parameter design are insensitive to variation in the environmental conditions and other noise factors. Finally, tolerance design is used to determine and analyze tolerances around the optimal settings recommend by the parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the required performance, and involves tightening tolerances on the product parameters or process parameters for which variations result in a large negative influence on the required product performance. Typically, tightening tolerances means purchasing better-grade materials, components, or machinery, which increases cost.

Therefore, based on the above discussion, parameter design is the important step in the Taguchi method to achieving high quality of product without increasing cost. The Taguchi method uses a special design of orthogonal arrays (OA) to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

1.5 Plastic Injection Molding Process

Plastic injection molding is the primary process for producing plastic parts. In other words, injection molding is a technique for converting thermoplastics as well as thermosetting materials into all types of products. Although the tooling is expensive, the cost per part is very low. This technology has met the current needs of industry owing to its shorter design cycles and improved design quality. Its area of application is wide which includes manufacturing, military, automobile, aerospace and other industries.

In this project, the main equipment used in produced the PP plastic trays are Battenfeld TM 750/210 injection molding machine. TM750/210 means toggle machine with maximum unit size clamping, 750 and maximum unit size injection, 210. This machine is driven by hydraulics, pneumatics and electrics system. Besides, Battenfeld TM 750/210 injection molding machine has four operating modes that are setup mode, manual mode, semi-automatic mode, and automatic mode.

Setup mode is used to set up the mold in this machine. In this mode, the clamp will move slowly so the machine can be adjusted. Manual mode allows any operation to be performed with the machine. This helps in checking parameters for the mold and the mechanical operation of the machine. Semiautomatic mode allows the user to run one complete molding cycle. This gives a good indication of what type of parts a continuous molding operation will yield. Parameters such as melting temperature, cooling time, injection speed and holding pressure can be fine tuned to yield an optimum part. Automatic mode runs the machine continuously without stopping between cycles. At the beginning of a run, final minor adjustments are made to molding parameters. The Battenfeld TM 750/210 injection molding machine is shown in Figure 1.51 below.

Figure 1.51: Battenfeld TM 750/210 injection molding machine

The Battenfeld TM 750/210 machine has some important parts on it. This injection machine has clamping unit, injection unit, and control unit (Refer Figure 1.52). However, the injection machine can not function without the mold. Simply described, a mold is made of two halves, where the cavity is depressed into the one half, and the core sticks out from the other. The space formed between them is filled with heated plastic that is cooled before leaving the mold.

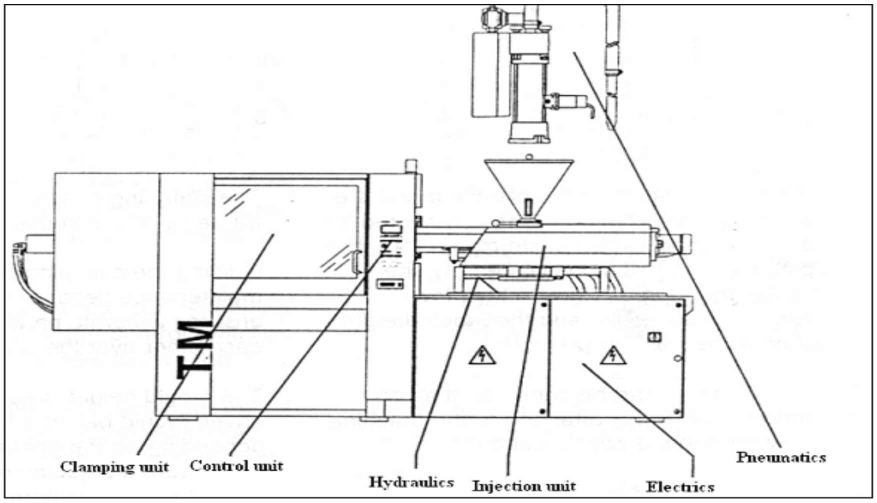


Figure 1.52: Structure of the Battenfeld TM 750/210 Machine

In injection unit, the main components are the barrel, the electric barrel heater, the nozzle contact cylinders, the injection cylinder, the drive and bearings, hydraulic motor, the material hopper and the support. The injection unit is borne on two guide rails. The Figure 1.53 and Figure 1.54 show the injection unit of this injection molding machine.

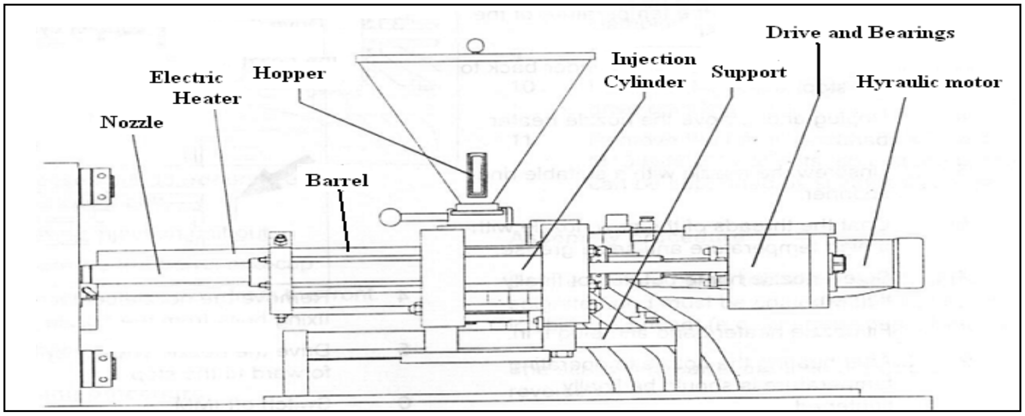


Figure 1.53: Schematic diagram of injection unit

Figure 1.54: Injection unit of the Battenfeld TM 750/210 Machine

In clamping unit, the main components are the clamping platen on which is mounted the hydraulic ejector, the nozzle platen, the end platen, the closing cylinder, the tie bars, the toggles with their low-maintenance bushes and the mold height adjustment mechanism. The clamping unit can be considered as an independent assembly attached to the machine frame by bolts in the nozzle platen. Next, the hydraulic ejector is built into the clamping platen in the form of a double acting hydraulic cylinder. Figure 1.55 and Figure 1.56 show the clamping unit of this injection molding machine.

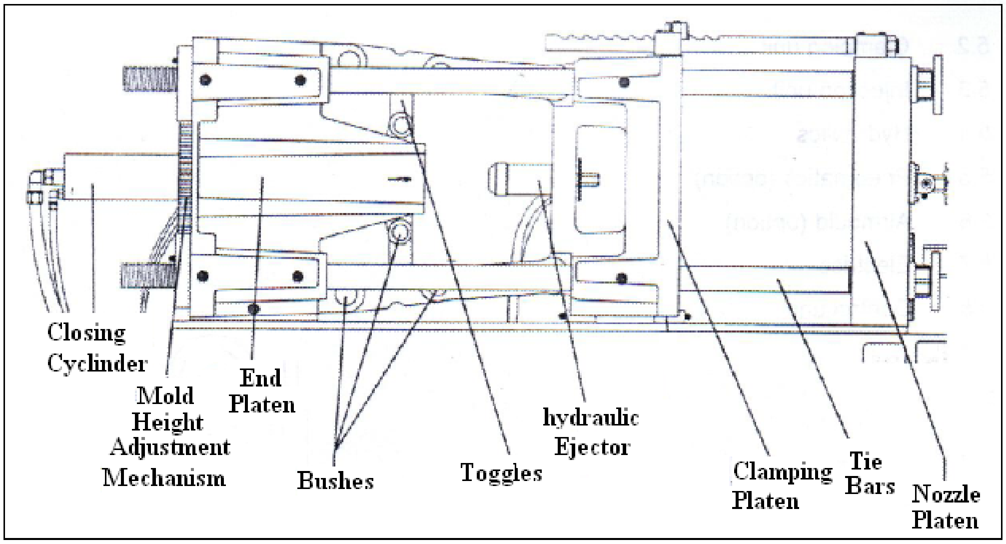


Figure 1.55: Schematic diagram of clamping unit

Figure 1.56: Clamping unit of the Battenfeld TM 750/210 Machine

Therefore, the injection unit will combined with clamping unit and desired mold to perform the injection molding process. Firstly, the granules PP material plastics are put into the material hopper and dry it by drying machine. After drying, the injection molding machine rotates the screw in barrel, pumping the plastics from the hopper towards the front of the barrel, creating a reservoir of melted plastics. The screw is driven directly by a hydraulic motor. This process called as the feeding process. At the same time, the clamp cylinder piston closes the mold.

Next, the plastic granules are melted during screw rotation by an electric barrel heaters and friction generated between screw/wall and granules in the melting process. The plastic granules which have been melted become molten plastic are continue moved ahead, forces by the forward screw rotation. Once enough molten plastic has accumulated in front of the screw, the injection process begins. The Figure 1.57 shows the injection molding with reciprocating screw.

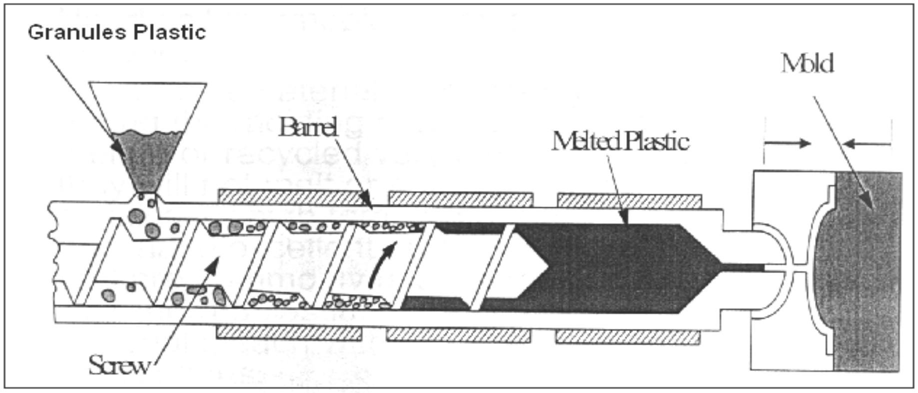


Figure 1.57: The injection molding with reciprocating screw

In the injection phase, the molten plastic is inserted into the mold through a sprue (refer Figure 1.58), while the pressure and speed are controlled by the screw. The sprue connects the injection head of the cylinder with the mold. Then, the molten plastic has been injected into the closed mold and the holding pressure is applied to make sure the entire mold cavities are filled.

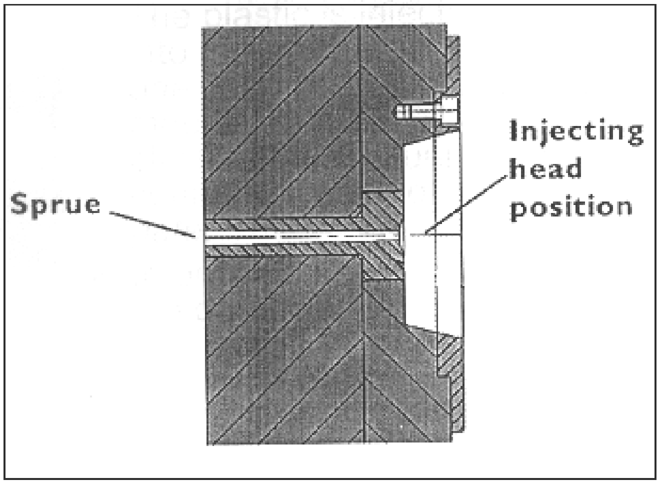


Figure 1.58: The sprue of injection molding machine

Next, the cooling water in the mold draws away the plastic's heat during the cooling phase (refer Figure 1.59). After the plastic has been held a long enough to solidify, the clamping unit of injection molding machine is opened the mold. The hydraulic ejector push out the newly formed plastic part (plastic trays) and it is removed. Finally, the PP plastic trays have been produced by injection molding process.

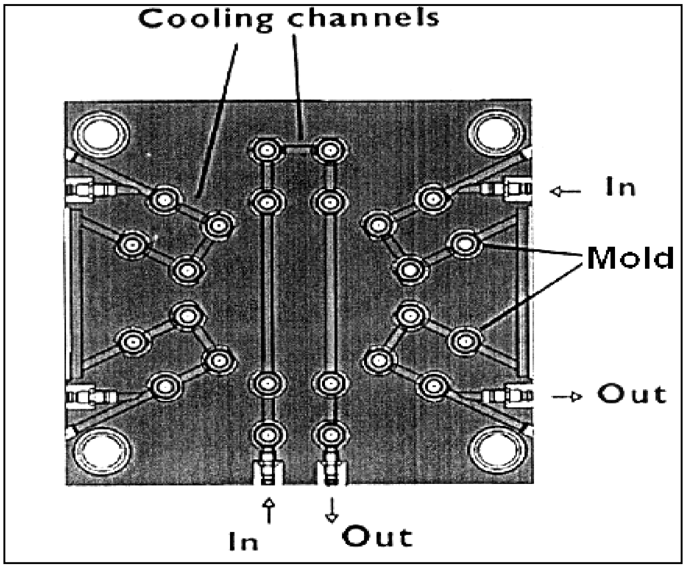


Figure 1.59: The structure of the cooling system in mold

1.6 Plastic Material

Plastics are a subset of materials called polymers. Polymers are high molecular weight molecules that consist of repeating units called monomers. The development of a variety of polymers combined with the ability to blend or mix different polymers has made available a wide selection of plastics. This range of choices allows product designers to tailor the materials they use to possess specific properties, processing characteristics and costs.

However, plastics offer extraordinary advantages in product manufacturing. This is because they are easily softened or melted and can be molded into almost any shape. In addition, plastics have replaced traditional materials like metals and wood in countless applications because of their cost effectiveness and property attributes.

Plastics can be divided into two processing groups, thermoplastics and thermosets. Thermoplastics are heated to a state where they flow and then are processed by pressure or vacuum forming, extrusion through a die or injection into a mold. Thermoplastics solidify by cooling to ambient temperatures. However, thermosets are heated until reactive agents compounded into them cause the material to set up.

In this project, polypropylene (PP) - thermoplastics material is selected to be used in injection molding process for manufacturing a plastic tray. The good mechanical characteristics and the low cost make it a first material choice and PP has grown in some cases by displacing other polymer. PP is a crystalline polymer and the crystal formation after processing can lead to significant dimensional changes for some time after ejection from the mold. On other hands, it has a good combination of rigidity and toughness, high rigidity at elevated temperature up to 121°C, good abrasion resistance and low coefficient of friction, excellent electrical properties, unique flexible properties, good chemical resistance without stress cracking, high surface gloss, and ease of fabrication.

Therefore, a description of some of the characteristics of the PP stated as following:-

a. PP has the highest tensile strength over 5000 psi. It has high tensile modulus which can be increased from 160,000 to 550,000 psi by reinforcements such as asbestos. Its notched impact test is relatively low for most grades though special impact materials are as high as 15. PP is very notch sensitive and care should be taken in part design to eliminate sharp corners.
b. It has excellent abrasion resistance and a very low coefficient of friction, comparable to that of nylon. However, lubricating nylon surfaces reduces the friction much more than for polypropylene.
c. Because of its high melting point, about 170°C, and its high crystalline. It has excellent high temperature properties. It is usable up to 130°C, and can be readily steam sterilized.
d. It has poor weatherability which can be improved by UV stabilizers or carbon black.
e. PP has typical excellent chemical resistance of the alkenes. It is also resistant to dilute acids, concentrated acids (except oxidizing acids), alkalis, alcohols, detergents, and water. Additionally, its water absorption is very low with equilibrium immersed water content of 0.03%.
f. PP is an excellent electrical insulator and has extremely low dielectric losses. Because of the self-extinguishing properties of certain grades it has found wide use as support for electrical components.
g. With proper treatment it can be electroplated or vacuum metallized. It can be hot stamped, painted, and printed as well.

CHAPTER 2: LITERATURE REVIEW

Optimization of process parameters for meeting the better quality requirements in injection molding has been studied for many years. Generally, the most popular and easily techniques used by quality engineering department to control the quality since past is Taguchi Methods (developed by Dr. Genichi Taguchi) *(Ross, 1989).*

Fung (2002) proposed a study to optimize injection molding process parameters for wear property of fiber-reinforced polybutylene terephthalate composites using Taguchi method and grey relational analysis. Four controllable process factors (filling time, melt temperature, mold temperature and ram speed) are investigated at three levels each in the manufacturing process. The L9 orthogonal array used to determine the optimum process factor/level combination for single quality of wear property. Next, by analyzing the grey relational grade matrix, the most influential process factor and the most easily influenced wear property could be identified. The result from the study showed that melt temperature was found to be the most influential factor in wear property.

Chang (1999) proposed a study for improving the quality of a weld line in injection molding using an experimental design approach. Weld lines are sometimes inevitable when large and complex parts are being processed by injection molding. Therefore, a design of experiments approach (Taguchi Method) was utilized to study the influence of seven processing variables (melt and mold temperatures, injection and hold pressures, cooling and holding times, and back pressure) on the weld line width and the tensile impact properties of injection molded dog-bone bars. As the result, the prediction values well matches with the experimental value.

Ji, et.al. (2000) proposed a study for sintering 316L stainless steel metal injection molding parts in final density using Taguchi method. Taguchi method is used in characterizing and optimizing the process factors for sintering water-atomized 316L stainless steel (of average size 6 m). The effects of four sintering factors: sintering temperature, heating rate, sintering time and sintering atmosphere on the final density were studied. The various factors were assigned to an L9 orthogonal array. It was found that all the chosen sintering factors have significant effects on the final density. Additionally, optimum fractional final density of 96.14% of wrought material was achieved with a sintering temperature of 1250°C, a heating rate of 20°C min-1 and isothermal heating at

1250°C for 90 min in a vacuum atmosphere. Confirmatory experiments have produced results that lay within the 90% confidence interval.

Chang (2001) proposed a study to improve an injection molding condition due to systematically investigate the effects of process conditions on the shrinkage (along- and across-the-flow directions) of three plastics: high-density polyethylene (HDPE), general-purpose polystyrene (GPS), and acrylonitrile-butadiene-styrene (ABS) using Taguchi Method. The results show that HDPE, a semi crystalline plastic, shrinks more than GPS and ABS, two amorphous materials. The extent of anisotropic shrinkage in the along-the-flow and across-the-flow directions for HDPE is different from GPS and ABS. More shrinkage occurs in the across-the-flow direction of HDPE than in its along-the-flow direction. The reverses is true for GPS and ABS. Mold and melt temperatures, along with holding pressure and holding time, are significantly have an influences on the shrinkage behaviors of three materials. The optimal conditions for reducing shrinkage identified by the Taguchi method are experimentally verified and validated by the statistic tests. The prediction matches very well with the experimental value for the along-the-flow shrinkage of GPS.

Aurrekoetxea, et. al. (2003) proposed a study on the effects of injection molding induced morphology on the fracture behavior of a virgin and recycle polypropylene (PP). Skin-core had been analysed by microhardness measurements, since the microhardness and the degree of crystallinity are directly related. Virgin PP has shown higher microhardness values and bigger plastically deformed zone at the crack tip than recycled one. These two different are due to the higher crystallinity of the recycled PP. On other hands, in both materials, skin layer has shown lower microhardness values and smaller plastic zone extension than the core region. The former phenomenon is suggested to be governed by the different degrees of crystalinity between both regions, whereas the latter is related to the stress-state rather than to morphological parameters.

Hung and Tai (2001) proposed a study on the effective injection molding factors that influence the warpage problem of an injection-molded part with a thin shell feature. This research used the experimental design of Taguchi method to determine the injection molding conditions, and the injection processes were simulated using the commercial software C-MOLD. The result showed that the packing pressure had greatest influence on the warpage, followed by the mold temperature, melt temperature, and packing time. The warpage was only slightly influenced by the gate dimension and the filling time in thin shell injection molding. In a subsequent study (*Hung and Tai, 2001*), applying the experiment design of Taguchi method is a quite effective method to obtain the optimum set of effective factors in injection molding to produce plastics parts with minimum warpage.

Chen, et. al. (1997) proposed a study on the optimal process design of an injection molded polycarbonate/ poly(butylenes terephthlate) automobile bumper using Taguchi method. The main objective of this studied is to eliminate silver streaks on the surface of the product. In this study, there are preliminary experiment and principal experiment. In preliminary experiment, a set of process parameters were selected (fill time, injection speed, coolant flow rate, hot runner temperature, holding pressure, injection temperature, mold temperature, etc.) and L_{12} orthogonal array to screen the significant factor was used, then the validity of the data fitting model was checked, and an improved process condition to overcome the filling difficulties was predicted. After preliminary experiment, a principal experiment was conducted with an L_{18} orthogonal array to predict optimal process conditions that solve the quality problem. Finally, the predicted process condition was tested on the 2500-ton injection molding machine to confirm the prediction. The results from this study proved that the main factors that directly relate to generation of the silver streaks are the mold temperature, the fill time, the fill/postfill switch over control, and the injection rate.

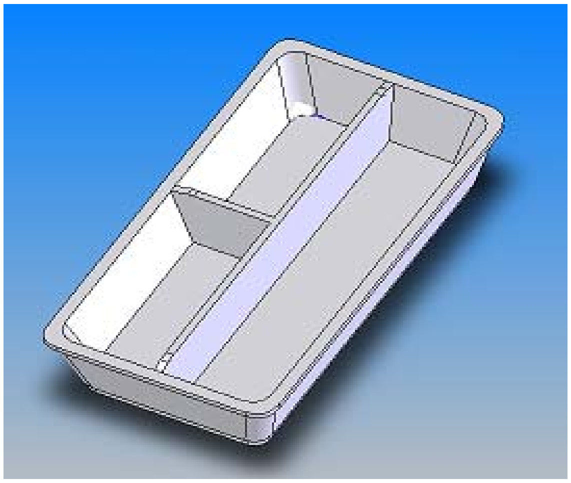
Beside of optimization for injection molding process, Taguchi method is also used by some researchers to optimize other processes such as cutting, turning, rapid prototyping, grinding, thermal spraying, laser-cutting and etc. *Anitha, et. al. (2001*) proposed a study to assess the effect of the parameters on the surface roughness of the component produced by Fused Deposition Modelling process using Taguchi method.

Therefore, the literature review shows that there were various researches have used Taguchi, Design of experiment for optimization of process parameters. It provides a simple, efficient, and systematic approach to optimize designs for performance, quality and cost. The methodology is valuable when process parameters are qualitative and discrete. Thus, there is need to use the above mentioned powerful techniques to propose the methodology for optimization of injection molding process parameters for optimum performance of plastics trays which made from polypropylene material in this project.

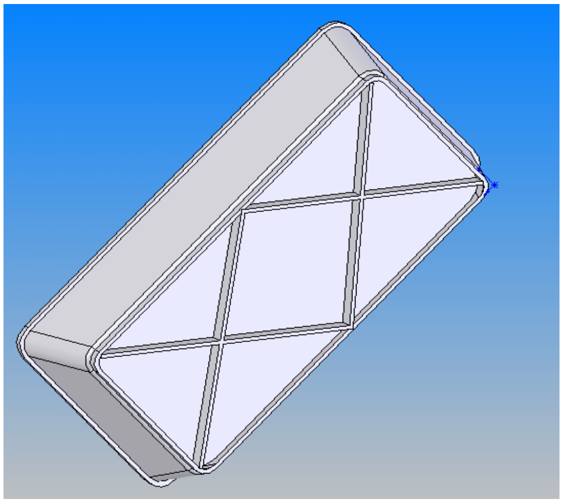
CHAPTER 3: METHODOLOGY

3.1 Introduction

In this project, Taguchi method is applied on optimization of plastics injection molding parameters to obtain the optimal performance of plastic trays. The Figure 3.11 is shown the shape of plastic trays produced by injection molding process. The plastic material utilizing is a polypropylene (PP). Generally, four phases are involves in the optimization of injection molding parameters that are planning phase, experimental phase, analysis phase and confirmation phase. Figure 3.12 presents the flow chart of the project phases.

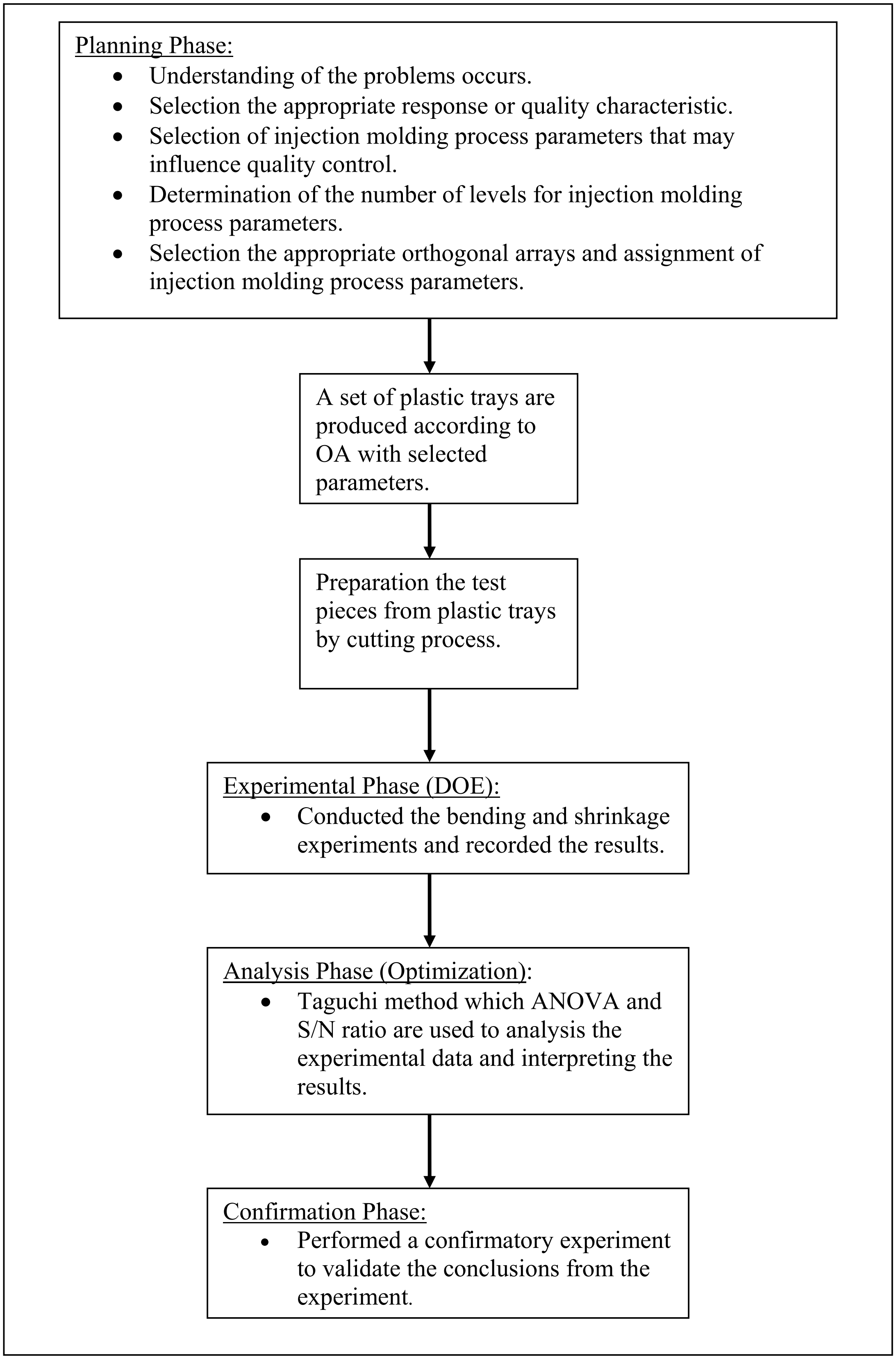


Top view



Back view

Figure 3.11: The shape of plastic tray



Planning Phase:

- Understanding of the problems occurs.
- Selection the appropriate response or quality characteristic.
- Selection of injection molding process parameters that may influence quality control.
- Determination of the number of levels for injection molding process parameters.
- Selection the appropriate orthogonal arrays and assignment of injection molding process parameters.

A set of plastic trays are produced according to OA with selected parameters.

Preparation the test pieces from plastic trays by cutting process.

Experimental Phase (DOE):

- Conducted the bending and shrinkage experiments and recorded the results.

Analysis Phase (Optimization):

- Taguchi method which ANOVA and S/N ratio are used to analysis the experimental data and interpreting the results.

Confirmation Phase:

- Performed a confirmatory experiment to validate the conclusions from the experiment.

Figure 3.12: The flow chart of project phases

3.2 Process Factors of a Plastic Injection Molding

An Ishikawa diagram (Figure 3.21) was constructed to identify the injection molding process factors that have an affect to the performance of an injection-molded tray. The process factors can be listed in four categories as follow:

1) Material types
2) Geometry parameters
3) Machine types
4) Manufacturing parameters.

Based on figure 3.21, manufacturing parameters such as cooling time, injection speed, melting temperature (similar with screw temperature) and holding pressure have been selected for this project. It is because these manufacturing parameters can be change in varied and it is a significant way to minimize the cost process compare with changing the machine types, material types or geometry parameters (*Rubin, I.I., 1972*).

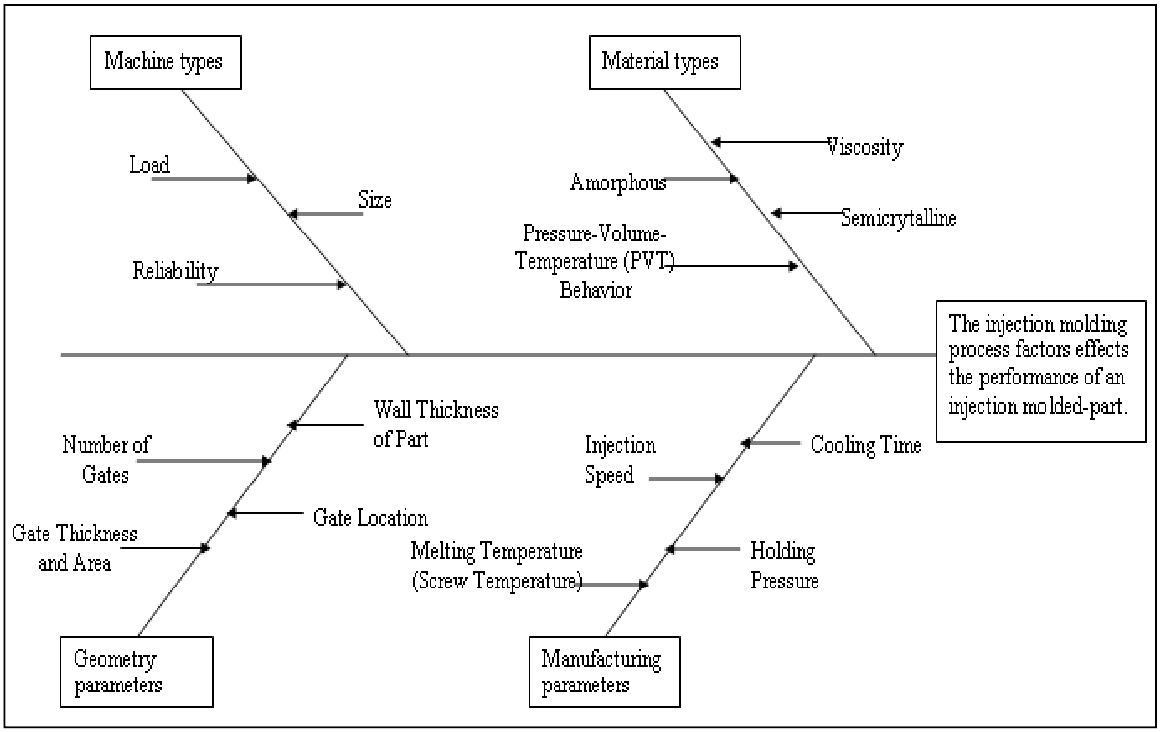


Figure 3.21: Cause and effect diagram of the injection molding process factors

3.3 Selection of the Injection Molding Parameters and Their Levels

Plastic injection molding process was carried out on a Battenfeld TM750/210 machine. Only four injection molding parameters i.e. melting temperature, injection speed, cooling time and holding pressure were investigated in this project.

Melting temperature can be defined as the temperature of the cylinder of the machine which determines the temperature of the material that will be injected into the mold. On the other hand, injection speed is the speed of advance of the screw which is driven by a motor coupled with it. Cooling time can be defined as the time needed for the circulated water around the mold to cool and solidify the plastic part. Finally, holding pressure is the pressure used for regulating and closing the mold.

The range of the melting temperature was selected to be 200 – 230°C and the injection speed was selected in the range between 203 – 261 rpm. The cooling time and holding pressure were chosen to be in the range of 10 – 20 sec. and 110 – 120 psi (pound per square inch) respectively. The above ranges of the process parameters were selected in light of the data available in the literature, machine technical data, and plastics injection molding handbooks. The selected injection molding process parameters along with their levels are given in Table 3.31. Each parameter had two levels and interaction between the parameters was not considered in the present study.

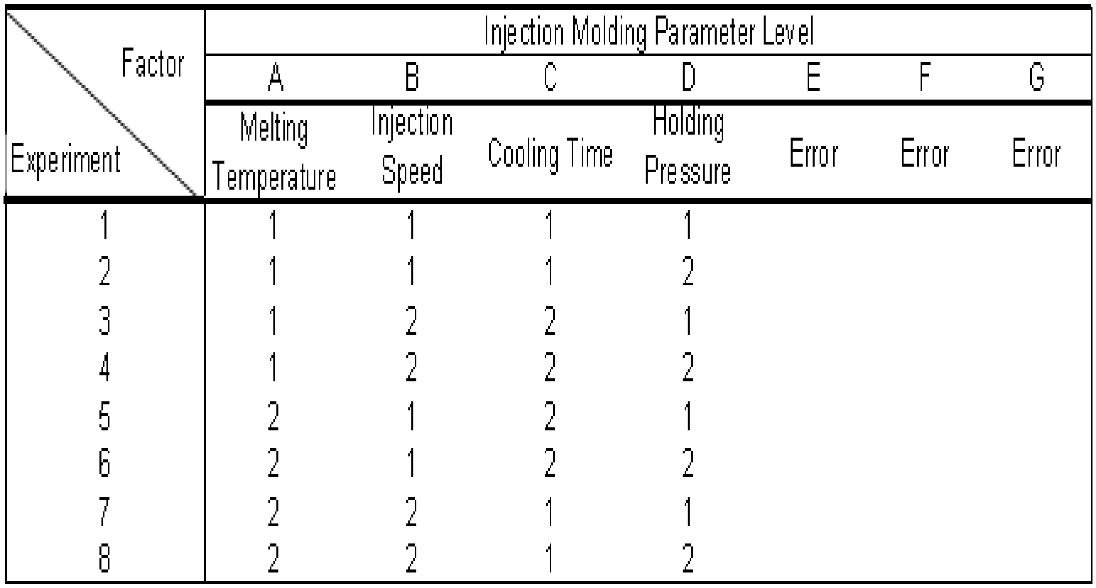
Table 3.31 Injection molding parameters and their level

Symbol	**Parameters**	**Unit**	**Level 1**	**Level 2**
A	Melting Temperature	°C	200	230
B	Injection Speed	rpm	203	261
C	Cooling Time	sec.	10	20
D	Holding Pressure	psi	110	120

3.4 Selection of Orthogonal array (OA)

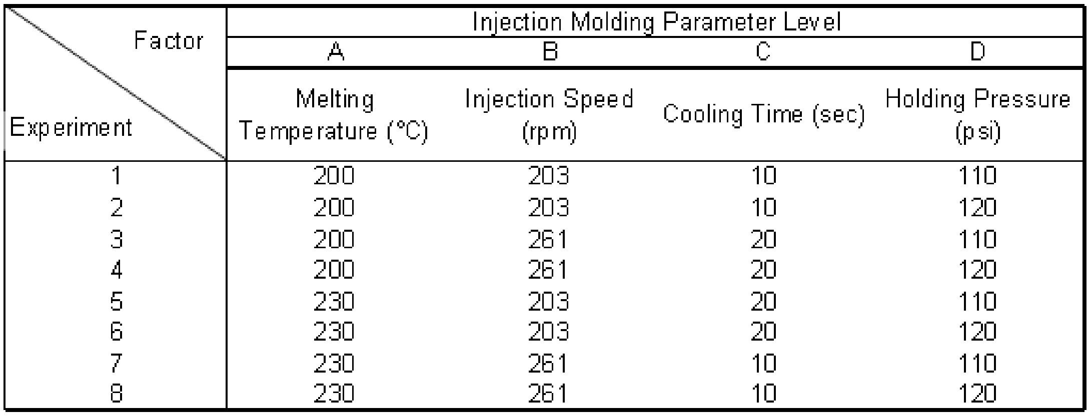
The selection of an appropriate orthogonal array (OA) depends on the total degrees of freedom of process parameters. Degrees of freedom (DOF) are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. In this project, since each parameter has two levels therefore, the total degrees of freedom for the parameters are equal to 4. Basically, the degrees of freedom for the OA should be greater than or at least equal to those for the process parameters. The standard L_8 orthogonal array has seven 2 level columns with 7 DOF. Therefore, an L_8 orthogonal array with seven columns and eight rows was appropriate and used in this project. Since the L_8 orthogonal array has seven columns, three column of the array is left empty for the error of experiments; orthogonally is not lost by letting three column of the array remain empty. The experimental layout for the injection molding parameters using the L_8 OA is shown in Table 3.41. The experimental layout after assigning the values of the parameters is shown in Table 3.42. Each row of this table represents an experiment with different combination of parameters and their levels.

Table 3.41: The experimental layout according to the L_8 OA



Factor / Experiment	Injection Molding Parameter Level						
	A	B	C	D	E	F	G
	Melting Temperature	Injection Speed	Cooling Time	Holding Pressure	Error	Error	Error
1	1	1	1	1			
2	1	1	1	2			
3	1	2	2	1			
4	1	2	2	2			
5	2	1	2	1			
6	2	1	2	2			
7	2	2	1	1			
8	2	2	1	2			

Table 3.42: Experimental layout after assigning the values of the parameters



Factor / Experiment	Injection Molding Parameter Level			
	A	B	C	D
	Melting Temperature (°C)	Injection Speed (rpm)	Cooling Time (sec)	Holding Pressure (psi)
1	200	203	10	110
2	200	203	10	120
3	200	261	20	110
4	200	261	20	120
5	230	203	20	110
6	230	203	20	120
7	230	261	10	110
8	230	261	10	120

3.5 Analysis of the Injection Molding Parameters

3.5.1 Application of the Signal-To-Noise (S/N) ratio

As mentioned earlier, Taguchi used the S/N ratio to measure the quality characteristic deviating from the desired value. In the Taguchi method, the term ‘signal' represents the desirable value (mean) for the output characteristic and the term ‘noise' represents the undesirable value (signal disturbance, S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. The S/N ratio is defined as:

S/N ratio, $\eta = -10 \log (MSD)$ [1]

Where MSD = the mean-square deviation for the output characteristic

However, the Mean Square Deviation is defined differently for each of three quality characteristics considered, smaller is better, nominal is the best and bigger is better. In this project, bigger is better characteristic is considered to obtain optimal bending strength of the plastic trays. Besides that, smaller is better characteristic is considered to obtain optimal shrinkage behavior of the plastic trays.

Thus, the bigger is better quality characteristic can be expressed as:

$$MSD = {}^{1}\!/_{n} \sum {}^{1}\!/_{y^2} \quad [2]$$

For the smaller is better quality characteristic can be expressed as:

$$MSD = {}^{1}\!/_{n} \sum y^2 \quad [3]$$

Where n = number of observations and y = the observed data.

For each type of the characteristics, with the above S/N ratio transformation, the higher the S/N ratio the better is the result. The higher value of S/N ratio is desirable because greater S/N ratio will result in smaller product variance around the target value.

3.5.2 Application of the ANOVA

The analysis of variance (ANOVA) technique was used to establish the relative significance of the parameters. Generally, the larger is the variance of a factor, the larger its ability to influence the quality characteristic. There are several steps to follow in order to establish for completing the ANOVA table. The steps shown below are for calculating all the quantities involved such as total mean S/N ratio, correction factor, total sum of squares, factor sum of squares, degree of freedom, mean square, *F*-ratio and percentage contribution to establish for completing ANOVA table.

Step 1: Total mean S/N ratio, *T*

The total mean S/N ratio is the sum of mean S/N ratio from each experimental.

$$T = \sum_{i=1}^{n} \eta_i \qquad [4]$$

Where n is number of experiments in OA and η_i is the mean S/N ratio for the *i*th experiment.

Step 2: Correction Factor, *C.F*

$$C.F = T^2/n \qquad [5]$$

Step 3: Total Sum of Squares, S_T

The total sum of square is a measure of the total deviation of the experiment from the computed value.

$$S_T = \sum_{i=1}^{n} \eta_i^2 - C.F \qquad [6]$$

Step 4: Factor Sum of Squares, S

Factor sum of square gives an estimate of the sum of deviation of the individual factor about the computed value.

$$S_A = A_1^2/N_{A1} + A_2^2/N_{A2} - C.F \qquad [7]$$

Where A = One factor of experiment with 2 level

A_1 = Sum of mean S/N ratio where factor A_1 is present

N_{A1} = Total number of experiments in which factor A_1 is present

$$S_e = S_T - (\textit{Factor sum of squares involved in experiment}) \quad [8]$$

Where e = error in experiment

Step 5: Total and factor Degree of Freedom, (*DOF*)

DOF total = (Number of experiments in OA) – 1

$$f_T = n - 1 \quad [9]$$

DOF of each factor is 1 less than the number of levels

$$f_A = (\textit{number of level of factor A}) - 1 \quad [10]$$

DOF of the error

$$f_e = f_T - (\textit{DOF of each factor involved in experiment}) \quad [11]$$

Step 6: Mean Square (Variance), *V*

The variance of each factor is determined by the factor sum of the square divided by the degree of freedom of the factor. Thus:

$$V_A = S_A / f_A \quad [12]$$

$$V_e = S_e / f_e \quad [13]$$

Where e = error in experiment

Step 7: Factor F Ratio (Variance Ratio), *F*

The variance ratio is the ratio of variance due to the effect of a factor and variance due to the term of error. The *F* value obtained in the analysis is compared with a value from standard *F*- tables for given statistical level of significance.

$$F_A = V_A / V_e \quad [14]$$

Step 8: Percentage Contribution, *P*

The percentage contribution of each factor is the ratio of the factor sum to the total sum and it is expressed in percentage.

$$P_A = S_A / S_T \times 100\% \quad [15]$$

$$P_e = 100 - (\textit{Percentage contribution of each factor involved in experiment}) \quad [16]$$

3.5.3 Projection of the Optimum Performance

The optimum value for the injection molding parameters can be determined using mean S/N ratio. As a general rule, optimum performance will be calculated using the following expression.

$$Y_{opt} = \overline{T}/N + (\overline{A} - \overline{T}/N) + (\overline{B} - \overline{T}/N) + (\overline{C} - \overline{T}/N) + (\overline{D} - \overline{T}/N) \quad [17]$$

Where $\overline{T}$ = Grand total of all mean S/N ratio of result

N = Total number experiment in OA

Y_{est} = Performance at optimum condition with S/N ratio unit

$\overline{A}, \overline{B}, \overline{C} and \overline{D}$ are mean S/N ratio of optimum condition levels for each factors.

When the S/N ratio is used, the estimated result can be converted back to the scale of units of the original observations. This converting projected the optimal average result of the deflection PP plastic under constant loads. However, the converting can be calculated as the following equations.

Y_{opt} = S/N = -10 log (MSD) and $MSD = 10^{-(Y_{opt}/10)}$

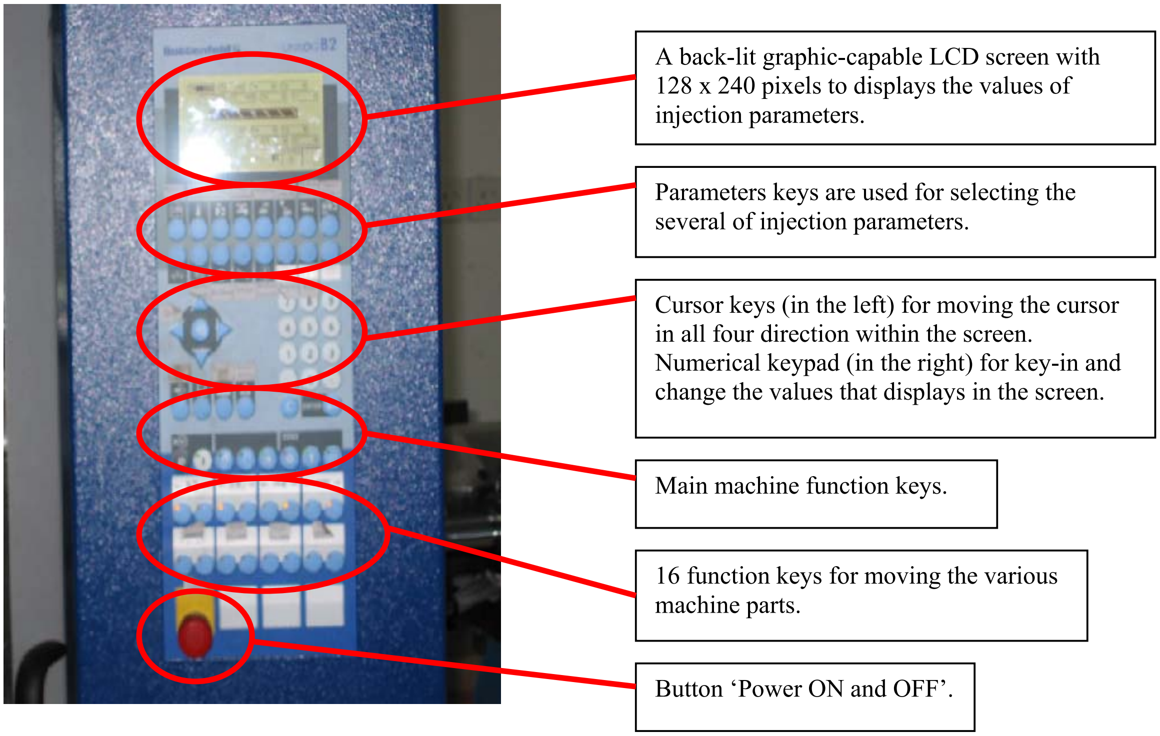
$MSD = (1/y^2_{expected})$ and $y_{expected} = \sqrt{1/MSD}$ (For “bigger is better”) [18]

$MSD = (y^2_{expected})$ and $y_{expected} = \sqrt{MSD}$ (For “smaller is better”) [19]

When the optimum is not one of the experiment runs already completed, this projection should verify by running a confirmation test. Confirmation testing is a necessary and important step in the Taguchi method as it is direct proof of the methodology. Generally, the average result from the confirmation tests should agree with the optimum performance ($Y_{expected}$) estimated by the analysis.

3.6 Production of Plastic Trays by Injection Molding Process

According to the experimental plan shown in Table 3.41, eight PP plastic trays were produced on the Battenfeld TM 750/210 injection molding machine. These eight PP plastic trays only can use in conducting one testing. So, a total of sixteen PP plastic trays need to produce to conduct the two testing which are bending test and shrinkage test. Therefore, this injection molding machine used to produce the PP plastic trays is regulated by the UNILOG B2 control panel. Figure 3.61 shows the function keys of UNILOG B2 control panel. This control panel unit need to use for selecting the desired values of melting temperature, injection speed, cooling time and holding pressure based on the Table 3.42 to produce the PP plastic trays. The Figure 3.62, Figure 3.63 and Figure 3.64 show the injection molding parameters menu that need to key in the values based on L_8 OA.



A back-lit graphic-capable LCD screen with 128 x 240 pixels to displays the values of injection parameters.

Parameters keys are used for selecting the several of injection parameters.

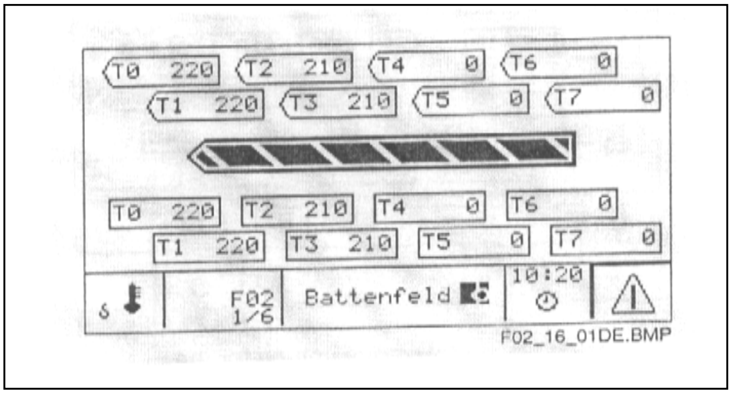
Cursor keys (in the left) for moving the cursor in all four direction within the screen. Numerical keypad (in the right) for key-in and change the values that displays in the screen.

Main machine function keys.

16 function keys for moving the various machine parts.

Button 'Power ON and OFF'.

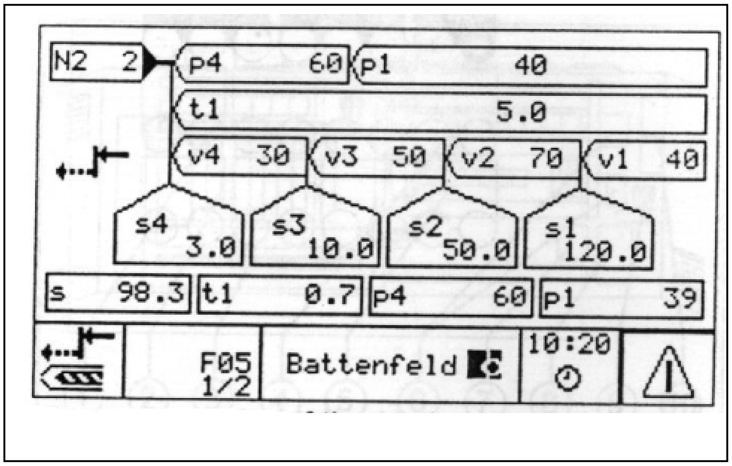
Figure 3.61: The function keys of UNILOG B2 control panel



T0 220
T2 210
T4 0
T6 0
T1 220
T3 210
T5 0
T7 0

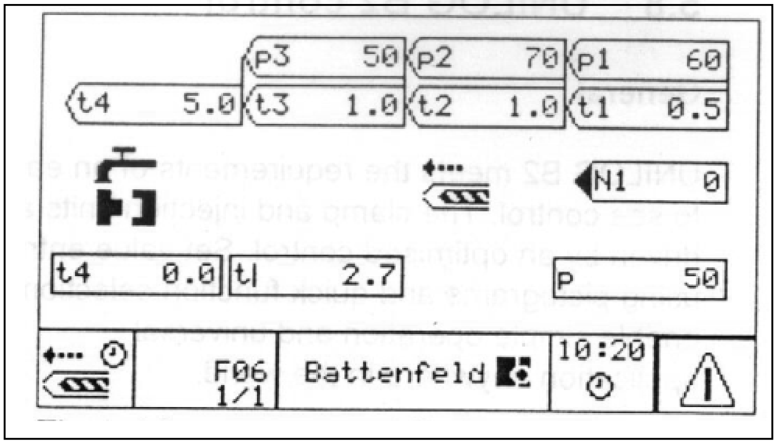
T0 220
T2 210
T4 0
T6 0
T1 220
T3 210
T5 0
T7 0

Figure 3.62: Temperature control zone menu (melting temperature)



N2 2
p4 60
p1 40
t1 5.0
v4 30
v3 50
v2 70
v1 40
s4 3.0
s3 10.0
s2 50.0
s1 120.0
s 98.3
t1 0.7
p4 60
p1 39

Figure 3.63: Injection speed menu



p3 50
p2 70
p1 60
t4 5.0
t3 1.0
t2 1.0
t1 0.5
N1 0
t4 0.0
tI 2.7
P 50

Figure 3.64: Holding pressure and cooling time menu