Process Optimization for Plastic Injection Mould. Case Study: Container Mould

Thesis submitted in accordance with requirements of the Universiti Teknikal Malaysia Melaka for Bachelor of Manufacturing Engineering (Robotic & Automation)

By

Nuraida Bt Mohd Ramlee

Faculty of Manufacturing Engineering
April 2007
JUDUL: PROCESS OPTIMIZATION FOR PLASTIC INJECTION MOULD. CASE STUDY: CONTAINER MOULD


NURAI DA BT MOHD RAMLEE

mengaku membenarkan tesis (PSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTEM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)
   - SULIT (Mengandungi maklumat yang berdjarah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
   - TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dilaksanakan)
   - TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

Alamat Tetap:
No 158, Jln Pss 7, Tangan Samudra,
68100 Batu Caves,
SELANGOR.


(Cop Rasm:

ROSIDAH BINTI JAAFAF
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berlunci 1200, Ayer Keroh
75450 Melaka

Tarih: 14/5/07

* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini pertu dikelaskan sebagai SULIT atau TERHAD.
DECLARATION

I hereby, declare this thesis entitled “Process Optimizations for Plastic Injection Mould. Case Study: Container Mould” is the results of my own research except as cited in the reference.

Signature: [Signature]
Author's Name: NUR AIDA BINTI MOHD. RAMLEE
Date: 6 APRIL 2007
ABSTRACT

Injection molding is a manufacturing technique for making parts from thermoplastic material. The injection molding process was studied extensively in attempt to create plastic component at the highest quality possible. This project is to get optimize parameter in injection molding process (container mould). The ARBUG injection molding machines were used in injection molding process to produce the plastic container as a product. The chemical and physical properties of propylene (PP) and also it features made it suitable to be as a material to our product. There have various parameters inside the injection molding process such as pressure, time, force, distance, temperature and other. But in this project, the parameter for temperature only had been considered and experimental. The other parameter is fixed to the lab manual value setting in order to see clearly the relationship between the parameter temperatures with the defect produced. Consecutively to find the optimum parameter setting, the process started with the design of experiments by Taguchi method. It consists of the process flow and description of each step taken. The step indicates the planning experiment, designing experiment, conducting experiment, analyzing result and confirming the result. Lastly, after done this entire step, the optimize parameter for the temperature with no defects at the product were successfully get.
ABSTRAK

DEDICATION

For my beloved mother
(Fatimah Bt Mohd)
Father,
(Mohd Ramlee bin Hj Mohd Rashid)
Brother,
(Saiful Bahari)
Sister,
(Norleena, Norazuwa and Nurhanees).
ACKNOWLEDGEMENT

I would like to thank God for His goodness and grace that sustained me throughout this Projek Sarjana Muda (PSM). Most importantly to my mums, Pn Fatimah Mohd for her support in the whole time period of this project and thanks also to my family members.

I would like to take this opportunity to thank Pn Rosidah Jaafar and express my sincere gratitude for being my advisor and helping me with this project from beginning until it's complete. She gave me almost full guideline to conduct this project, provided me with additional data and knowledge.

Thank you to the lecturer, En Amran for his advice and sharing his knowledge and experience he has on this topic with me. I also wish to extend my thanks and gratitude to technician, En Fauzi for his time, support and for all the arrangement that made all this possible.

Thanks to my entire friend for being a part of my life. As we crossed path during this period of time, the friendship that we build, the joy and laughter that we share and I hope let it be a life lesson that we will cherish for a long time. To all the people that involve indirect or direct in this project, your warmth, generosity and friendship will always remain in my heart.

The opportunity and exposure extended to me would prove invaluable in helping to shape my career as an Engineer.
# TABLE OF CONTENTS

Abstract ........................................................................................................... i
Abstrak ........................................................................................................... ii
Dedication ....................................................................................................... iii
Acknowledgement ........................................................................................ iv
Table of Contents ........................................................................................ v
List of Tables ................................................................................................ x
List of Figures ............................................................................................... xii
List of Abbreviations .................................................................................... xiii

1. INTRODUCTION ................................................................. 1
   1.1 Background ....................................................................................... 1
   1.2 Problem Statements ......................................................................... 2
   1.3 Objectives ....................................................................................... 2
   1.4 Scope of Study ................................................................................ 3
   1.5 Importance of Study ........................................................................ 3
   1.6 Outline of Study ............................................................................... 3

2. LITERATURE REVIEW ......................................................... 5
   2.1 Introduction ..................................................................................... 5
   2.2 Plastic Injection Molding .................................................................. 6
      2.2.1 Evolution of the Process ......................................................... 6
      2.2.2 Three Critical Measurement on Injection Molding Process ....... 7
      2.2.3 The Injection Molding Concept ............................................. 8
      2.2.4 Injection Molding Process .................................................... 10
   2.3 Plastic Injection Molding Materials ................................................. 11
      2.3.1 Introduction ............................................................................ 11
      2.3.2 The Definition of Plastic ....................................................... 13
      2.3.3 Polypropylene (PP) ............................................................... 13
2.3.3.1 Introduction.................................................................13
2.3.3.2 Chemical & physical properties.......................................14

2.4 Injection Molding Machine..................................................18
2.4.1 Introduction..................................................................18
2.4.2 Machine Component.......................................................19
2.4.2.1 Injection system.........................................................19
2.4.2.2 Hydraulic system.......................................................23
2.4.2.3 Clamping System.......................................................23
2.4.2.4 Control System.........................................................23
2.4.2.5 Molded System.........................................................24

2.5 Categorizing the Parameters...............................................25
2.5.1 Temperature..................................................................26
2.5.2 Pressure.......................................................................29
2.5.3 Time.............................................................................32
2.5.4 Distance.......................................................................34
2.5.5 Parameter Effects.........................................................39

2.6 Understanding Defects.........................................................40
2.6.1 Overview.....................................................................40
2.6.2 Causes Defects...............................................................41
2.6.3 Common Defects and Remedies.........................................43
2.6.3.1 Black Specks or Streaks...............................................43
2.6.3.2 Contaminated Raw Material.......................................43
2.6.3.3 Blisters...................................................................43
2.6.3.4 Blush......................................................................44
2.6.3.5 Bowing....................................................................44
2.6.3.6 Improper Handling.....................................................44
2.6.3.7 Britteness..................................................................45
2.6.3.8 Bubbles (Voids)...........................................................45
2.6.3.9 Excessive Moisture.....................................................46
2.6.3.10 Burn Marks...............................................................46
2.6.3.11 Excessive Regrind.....................................................46
2.6.3.12 Clear Spots

2.6.3.13 Inconsistent Cycles

2.6.3.14 Cloudy Appearance

2.6.3.15 Contamination

2.6.3.16 Poor Housekeeping

2.6.3.17 Cracking

2.6.3.18 Insufficient Draft or Polish

2.6.3.19 Crazing

2.6.3.20 Delamination

2.6.3.21 Excessive Mold Release

2.6.3.22 Discoloration

2.6.3.23 Contamination

2.6.3.24 Flash

2.6.3.25 Improper Flow Rate

2.6.3.26 Flow lines

2.6.3.27 Gloss (low)

2.6.3.28 Mold Temperature Too Low

2.6.3.29 Jetting

2.6.3.30 Knit Lines (Weld Lines)

2.6.3.31 Nonfill (Short Shots)

2.6.3.32 Insufficient Venting

2.6.3.33 Shrinkage (Excessive)

2.6.3.34 Early Gate Opening

2.6.3.35 Sink Marks

2.6.3.36 Splay (Silver Streaking)

2.6.3.37 Warp age

2.7 Taguchi Methods

2.8 ARBUG Injection Molding

2.9 Mold Construction and Operation for Container Mould
3. METHODOLOGY

3.1 Introduction.................................................63
3.2 Taguchi Method.............................................64
3.3 Planning Experiment.......................................65
3.4 Design of Experiment......................................67
3.5 Conducting Experiment.....................................71
3.6 Experiment Procedure.....................................73
3.7 Parameter Setting..........................................75

4. RESULT AND ANALYSIS.....................................76

4.1 Conducting Experiment...................................76
   4.1.1 Experiment 1: Test for the actual parameter value from lab manual........77
   4.1.2 Experiment 2: Test for the Feed Yoke Temperature............................78
   4.1.3 Experiment 3: Test for the Cylinder Heating/ Barrel Temperature..........79
   4.1.4 Experiment 4: Test for the Nozzle Heating Temperature.....................80

4.2 Analyzing Result.........................................81
   4.2.1 Result Analysis from Experiment 1........................................81
   4.2.2 Result Analysis from Experiment 2........................................82
   4.2.3 Result Analysis from Experiment 3........................................83
   4.2.4 Result Analysis from Experiment 4........................................84
   4.2.5 Final Result Analysis.................................................86
   4.2.6 Temperature and Defect Analysis........................................87

4.3 Confirming Predicted Result..............................90
   4.3.1 Experiment 5: Confirming Predicted Result for the Feed Yoke Temperature............................90
   4.3.2 Experiment 6: Confirming Predicted Result for the Cylinder Heating/ Barrel Temperature....................91
   4.3.3 Experiment 7: Confirming Predicted Result for the Nozzle Heating/Mold Temperature............................92

4.4 Final Result................................................93
5 DISCUSSION .............................................................................................................. 94
  5.1 Result discussion ................................................................................................... 94
  5.2 Problem Occur During the Experiment ................................................................. 95
  5.3 Recommendations ............................................................................................... 96

6 CONCLUSION .............................................................................................................. 97

REFERENCES .............................................................................................................. 98

APPENDICES

A. Table 1: The features and application PP in fabrication and thermo-formed

B. Table 2: Suggested Melt Temperatures for Various Plastics

C. Table 3: Suggested Mold Temperatures for Various Plastics

D. Arbug Injection Molding Machine 420 C 800-250 Technical data

E. Figure 1: Gantt chart for PSM I

F. Figure 2: Gantt chart for PSM II
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Typical properties of polypropylene</td>
<td>15</td>
</tr>
<tr>
<td>2.2</td>
<td>The specification for Polypropylene</td>
<td>17</td>
</tr>
<tr>
<td>2.3</td>
<td>Melt index Value's Impact on Plastics Properties</td>
<td>31</td>
</tr>
<tr>
<td>2.4</td>
<td>Parameter Change versus Property Effect</td>
<td>40</td>
</tr>
<tr>
<td>3.1</td>
<td>The factor to be consider in planning experiment</td>
<td>65</td>
</tr>
<tr>
<td>3.2</td>
<td>The relationship between the parameter and the quality characteristic</td>
<td>67</td>
</tr>
<tr>
<td>3.3</td>
<td>Below shows the parameter for the 5 heating zones</td>
<td>68</td>
</tr>
<tr>
<td>3.4</td>
<td>The interaction between the temperature parameter and the defects</td>
<td>69</td>
</tr>
<tr>
<td>3.5</td>
<td>The factor assign to the experiment and interaction located</td>
<td>70</td>
</tr>
<tr>
<td>3.6</td>
<td>Data of the parameter setting</td>
<td>75</td>
</tr>
<tr>
<td>4.1</td>
<td>The result of defects for actual value from lab manual</td>
<td>77</td>
</tr>
<tr>
<td>4.2</td>
<td>The result of defects for the Feed Yoke Temperature</td>
<td>78</td>
</tr>
<tr>
<td>4.3</td>
<td>The result of defects for the Cylinder Heating/Barrel Temperature</td>
<td>79</td>
</tr>
<tr>
<td>4.4</td>
<td>The result of defects for the Nozzle Heating Temperature</td>
<td>80</td>
</tr>
<tr>
<td>4.5</td>
<td>Defects from the actual parameter value from lab manual</td>
<td>81</td>
</tr>
<tr>
<td>4.6</td>
<td>Result analysis for Feed Yoke Temperature</td>
<td>82</td>
</tr>
<tr>
<td>4.7</td>
<td>Result analysis for Cylinder Heating Temperature</td>
<td>83</td>
</tr>
<tr>
<td>4.8</td>
<td>Result analysis for Nozzle- Heating Temperature</td>
<td>84</td>
</tr>
<tr>
<td>4.9</td>
<td>Defect Occur with Cause and Remedies</td>
<td>87</td>
</tr>
<tr>
<td>4.10</td>
<td>The Confirming Predicted Result for the Feed Yoke Temperature</td>
<td>90</td>
</tr>
<tr>
<td>4.11</td>
<td>The Confirming Predicted Result for the Cylinder Heating/Barrel</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>4.12</td>
<td>The Confirming Predicted Result for the Nozzle Heating Temperature</td>
<td>92</td>
</tr>
<tr>
<td>4.13</td>
<td>The Optimize Parameter for Temperature</td>
<td>93</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Outline of the study</td>
<td>4</td>
</tr>
<tr>
<td>2.1</td>
<td>The injection molding machine</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>Fabricated metal components of product</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Plastic molding with integrated component</td>
<td>10</td>
</tr>
<tr>
<td>2.4</td>
<td>The injection molding process</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>A single screw injection molding machine for thermoplastics</td>
<td>18</td>
</tr>
<tr>
<td>2.6</td>
<td>A single screw injection molding machine for thermoplastics</td>
<td>19</td>
</tr>
<tr>
<td>2.7</td>
<td>A reciprocating screw</td>
<td>20</td>
</tr>
<tr>
<td>2.8</td>
<td>(a) Nozzle with barrel in processing position</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>(b) Nozzle with barrel backed out for purging</td>
<td>21</td>
</tr>
<tr>
<td>2.9</td>
<td>A typical (three-plate) molding system</td>
<td>22</td>
</tr>
<tr>
<td>2.10</td>
<td>(Left) A two-plate mold. (Right) A three-plate mold</td>
<td>23</td>
</tr>
<tr>
<td>2.11</td>
<td>The molded system includes a delivery system and molded parts</td>
<td>24</td>
</tr>
<tr>
<td>2.12</td>
<td>Categories of parameters</td>
<td>26</td>
</tr>
<tr>
<td>2.13</td>
<td>Measuring plastic temperature</td>
<td>27</td>
</tr>
<tr>
<td>2.14</td>
<td>Controlling temperature of mold</td>
<td>28</td>
</tr>
<tr>
<td>2.15</td>
<td>Melt index rheometer</td>
<td>30</td>
</tr>
<tr>
<td>2.16</td>
<td>Mold – closing distance</td>
<td>35</td>
</tr>
<tr>
<td>2.17</td>
<td>Injection and hold distance</td>
<td>36</td>
</tr>
<tr>
<td>2.18</td>
<td>Cushion</td>
<td>37</td>
</tr>
<tr>
<td>2.19</td>
<td>Ejection of finished part</td>
<td>39</td>
</tr>
<tr>
<td>2.20</td>
<td>Distribution of defect causes</td>
<td>42</td>
</tr>
<tr>
<td>2.21</td>
<td>ARBUG Injection Molding Machine</td>
<td>59</td>
</tr>
<tr>
<td>2.22</td>
<td>(a): The injection mold for container mould (side view)</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>(b): The injection mold for container mould (front view)</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>(c): The injection mold for container mould (rear view)</td>
<td>62</td>
</tr>
</tbody>
</table>
3.1 Design of Experiments approach by Taguchi
3.2 The planning of the experiment
3.3 The 5 heating zones for injection unit
3.4 The Process Flow for Conducting Experiment
3.5 The machine standard cycle

4.1 The types of defects occur from actual temperature value
4.2 The Feed Yoke temperature defects
4.3 Cylinder Heating Temperature defect
4.4 Nozzle Heating Temperature defect
4.5 The number of experiment and the defect occur
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>Propylene</td>
</tr>
<tr>
<td>ABS</td>
<td>Acrylonitrile butadiene styrene</td>
</tr>
<tr>
<td>PE</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low density polyethylene</td>
</tr>
<tr>
<td>HDPE</td>
<td>High density polyethylene</td>
</tr>
<tr>
<td>MFI</td>
<td>Melt Flow Index</td>
</tr>
<tr>
<td>MI</td>
<td>Melt index</td>
</tr>
<tr>
<td>Temp</td>
<td>Temperature</td>
</tr>
<tr>
<td>No</td>
<td>Number</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.1 Background

Injection molding technology is a method of processing predominantly used for thermoplastic polymers. It consist of heating thermoplastic material until it melts, then forcing this melted plastic into a steel mold, where it cools and solidifies. The increasingly sophisticated use of injection molding is one of the principal tools in the battle to produce elegant product structures with reduced parts counts.

In order to exploit the versatility of injection molding technology for economical manufacture, it is necessary to understand the basic mechanisms of the process and the related aspects of the molding equipments and materials used. Also, since the injection molding is a process that utilizes expensive tooling and equipment, it is vital to be able to obtain part and tooling cost estimates at the earliest stages of design. Only in this way can the design team be sure that the choice of the process is correct and that economic advantage will be obtained from the process. (Geoffrey Boothroyd, 2002)

For these reason, this we will present a literature review of plastic injection molding, injection molding machine, injection molding materials, injection molding process, mold design construction, parameters involves and defects from the process.
1.2 Problem Statement

Base to this project (Projek Sarjana Muda 1&2) we are focusing on how to get optimum value for parameters setting of injection molding machine to produce the best result or product. The product that we had chosen to investigate is the plastic container mould.

Regarding to the project, we will going to solve a problem base to the existing product that we had choose to investigate and to optimize the plastic injection molding parameters besides to suit the procedure or method of the process that will be learn soon. Besides that, we will going to build—up and do some experimental in order to find in terms of surface texture, shrinkage, overall quality, product defects and any problems during processing and the parameters involved in this process. This step were planning to be taken soon as to investigate on how to get optimize parameters until become the finest and quality product.

Base to the product that we had chosen, plastic container mould, we find there was a lot of parameter to be considered such temperature, time, force, pressure and etc. But for this project, we only focus to the temperature parameter to be experimental. Besides of that, we need to choose the best material in the process for our product. Selection material is also important in order to reduce the defect and as to achieve the quality product. We also have to analyze all the problem occurred due to unit operation. Lastly, we run the confirming parameters that we get from the analyzing result.

1.3 Objectives

- To study the plastic injection molding process
- To produce the quality of plastic container product with no defect
- To get the optimum value for parameter setting of plastic injection molding process (container mould)
1.4 Scope of Study

- Study the procedure/method to set up the mold in injection molding machine
- Study the parameters of plastic injection molding process
- Material Selection
- Study the types of defects occurs to the plastic container product
- The method for DOE
- The procedure for experiment
- Result analysis

1.5 Importance of Study

Injection molding is one of the most common methods of processing plastics. Part quality depends on a large number of process variables, many of which interact one another. In this research will gain familiarity with the injection molding process. Pay particular attention to the process variables and how they influence the results.

1.6 Outline of Study

This research will be divided into six chapters. The first chapter is mainly about the introduction of the research, problem statement. Objectives, scope of study, importance of study and lastly about the study outlines.

The next chapter is the literature review. Based on the reference gathered (journals, books, websites etc.), this chapter will discuss the definition and introduction to plastic injections molding. It will also discuss the method on how the research will be done based on the past researcher.
Chapter three will be discussing about the review of the research methodology. This will include the design and framework of study. This chapter are also discussing about the advantage and disadvantage of the methods chosen, and the selection of the best method.

In the next chapter, the results will be discussed briefly. This will include the setup for the parameters, the working procedure and the findings during the research will be discussed in details and in the last chapter and the conclusion will be reviewed.

Figure 1.1: Outline of the study
CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Injection moulding (United States Injection Molding) is a manufacturing technique for making parts from thermoplastic material. Molten plastic is injected at high pressure into a mold, which is the inverse of the desired shape. The mold is made by a moldmaker (or toolmaker) from metal, usually either steel or aluminium, and precision-machined to form the features of the desired part. Injection moulding is very widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars. It is the most common method of production, with some commonly made items including bottle caps and outdoor furniture.

The most commonly used thermoplastic materials are polystyrene (low-cost, lacking the strength and longevity of other materials), ABS or acrylonitrile butadiene styrene (a co-polymer or mixture of compounds used for everything from Lego parts to electronics housings), nylon (chemically resistant, heat-resistant, tough and flexible - used for combs), polypropylene (tough and flexible - used for containers), polyethylene, and polyvinyl chloride or PVC (more common in extrusions as used for pipes, window frames, or as the insulation on wiring where it is rendered flexible by the inclusion of a high proportion of plasticiser). (From Wikipedia, the free encyclopedia, 2006)

The plastic injection molding process is a well-established technique widely used in the polymerization industry. Such a process usually consists of an extruder, one (or
two) powerful screw(s) controlled by electric or hydraulic actuators, a molding mechanism controlled by electric or hydraulic actuators, and the peripheral control elements. The extruder typically consists of a large barrel divided into several constant temperature zones, with a hopper at one end and a die at the other. Polymer is fed into the barrel in raw and solid particle form from the hopper and is pushed forward by a powerful screw. While passing through the temperature zones with gradually increasing temperature, the raw polymer is gradually heated. The heat produced by the heaters in the barrel, together with the heat released from the friction between the raw polymer and the surfaces of the barrel and screw, causes the melting of the feed polymer, which is then pushed by the screw into the molding mechanism from the die. Generally speaking, the quality of the extrudate depends upon the uniformity of temperature distribution, magnitude of the temperature in the barrel, back pressure, and the homogeneity of the physical mixing. (Ching-Chih Tsai, Member, IEEE, and Chi-Huang Lu, 1998)

In this chapter, we were present a detailed of plastic injection molding, injection molding machine, injection molding materials, injection molding process, mold design construction, parameters involves and defects from the process.

2.2 Plastic Injection Molding

2.2.1 Evolution of the Process

In 1968, a gentleman by the name of John Wesley Hyatt developed plastic material called celluloid and entered it in a contest created by a billiard ball manufacturer. The purpose of the contest was to find a substitute for ivory, which was becoming expensive and difficult to obtain. Celluloid was actually invented in 1851 by Alexander Parkers, but Hyatt perfected it to where it could be processed into a finished form. He used it to replace the billiard ball ivory and won the contest’s grand prize of $10,000, a rich sum in those days. Unfortunately, after the prize was won, some of the celluloid billiard balls exploded on impact during a demonstration (due to the instability
and high flammability of the material) and further refinement was required to use it in commercial ventures. Nonetheless, the plastics industry was born, and it would begin to flourish when John Wesley Hyatt and his brother Isaiah patented the first injection molding machine in 1872. They used this machine to injection mold celluloid plastic. Over the next 40 to 50 years others began to investigate this new process and expand its application to manufacturing such item as collar stays, buttons, and hair combs. By 1920, the injection molding industry was well entrenched, and it has been booming ever since.

During the 1940s the industry exploded with a bang (not because of the instability of celluloid) as the World War II created a demand for inexpensive, mass-produced products. New materials were invented for the process on a regular basis, and technical advances resulted in more successful applications. (Douglas M. Bryce, 1997)

### 2.2.2 Three Critical Measurement on Injection Molding Process

The key to implementing control of the injection molding process is to utilize a strategy through which we understand the molding process from a plastics point of view. It is extremely important to understand the plastic as it flows through the barrel of the machine and into the mold, as well as understanding how the various variables of the process acting on the plastic material determine the characteristics of the finished plastic part.

These plastic variables are important in injection molding because during the molding process, long-chained molecules become aligned ill the direction of the flow of the plastic material. As plastics molecules become aligned due to faster flow rates, the viscosity of the plastics material decreases. This is a phenomenon called non-Newtonian behavior and is unique to plastics materials.
Statistically, relationships between finished plastic part properties and injection molding conditions have been to be very poorly correlated. Yet almost all variations in plastic part properties are directly affected by four plastics processing variables.

To achieve the maximum degree of process control and have positive effects on the finished plastic product being molded, it is important to measure and control these plastics variables. These four plastics variables in injection molding are: (1) the plastics pressure in the mold (cavity pressure), (2) plastics flow rate, (3) plastics melt temperature (stock temperature), and (4) plastics cooling rate. All molding machine settings and environmental factors can be directly or indirectly translated into these plastics variables.

One major problem exists in measuring and controlling these plastics variables however, injection molding machines do not have controls marked "plastics temperature", "cooling rate", and "plastics moisture content". The molding machines and auxiliary equipment only have controls that indirectly influence these plastics variables. Because of the interrelationship of these plastics variables, the basic injection molding process is extremely capricious. Any attempt to control these plastics variables must seek to isolate them from each other as much as possible. Then, changing one control will not cause multiple effects in key parameters. (Mr. Jeffrey Dinninger, 2002).

2.2.3 The Injection Molding Concept

In its simplest form, the injection molding process is like the operation of hypodermic needle. A barrel contains heated plastic that is injected (by use of a plunger or auger device) into a closed mold that contains a machined, reverse image of the desired product, as shown in figure 2.1. This image is called cavity image.

The injected plastic is allowed to cool and solidify in the cavity. Then, the mold is opened and the product is ejected. While this may seem simple, the process actually