Identifying the Critical Moulding Machine Parameters Affecting Injection Moulding Process by Basic Statistical Process Control Tools

S. Rajalingam, Awang Bono, Jumat Bin Sulaiman

***Abstract*—**In injection moulding the processing condition have critical effect on the quality of the moulded products. Since there are many process parameters involved in an injection moulding process, identification of the critical parameters are very important. Simple techniques like the “Seven Basic Quality Control Tools (7 QC Tools)” can provide a very valuable and cost effective way to meet these objectives. This paper presents a case study for identifying the critical factors and its level affecting a plastic injection moulding process of a plastic cell phone shell call Front Cover by deployed some of the 7 QC Tools. The Pareto diagram help to identify that the highest defects (30%) was contributed due to shrinkage. The shrinkage defect cause the length and width of the Front Cover below the given specification limit. The Course and Effect diagram help to decide to select the mould temperature, injection pressure and screw rotation speed as the machine input parameters (factors) and the length and width dimensions of the Front Cover as the response of the experiment. A full factorial design of experiments was conducted to study the effect of three injection moulding process parameters versus shrinkage defect. Finally, the critical process parameters and its level influencing the shrinkage were identified and the confirmation run shows that the shrinkage defect eliminated to zero percentage.

***Keywords*—**Process, Parameters, Response, Shrinkage, Dimension, Quality Control, Component, Moulding

I. INTRODUCTION

INJECTION moulding is the most commonly used manufacturing process for the fabrication of plastic parts [1]. A wide variety of products are manufactured using injection moulding, varying in their sizes and applications. The injection moulding process requires the use of an injection moulding machine (Figure 1), raw plastic material and a mould. These machine consist of two basic parts, an injection unit and a clamping unit. The plastic is melted in the injection moulding machine and then injected into the mould, where it cools and solidifies into the final part. In this process, hot molten polymer is forced into a cold empty cavity of a desired shape and is then allowed to solidify under a high holding pressure [2, 3]. The entire injection moulding cycle can be divided into three stages: filling, post-filling and mould-opening [4, 5].

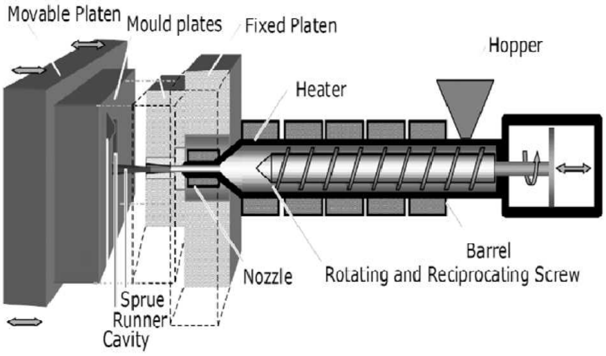

Fig. 1 Injection molding machine with reciprocating screw [6]

In the injection moulding industry, the setting of machine process parameters has crucial effects on the quality of products [7-11]. Injection moulding manufacturers have to obtain the optimal conditions for process parameters before they can produce faster, cheaper and better quality product. Unsuitable machine process parameter settings can cause production and quality problems, long cycle times and high production costs [12]. Final optimal process parameter setting is one of the most important steps in injection moulding for improving the quality of moulded products [13].In an injection moulding process development, Seven Basic Quality Control Tools (7QC Tools) [14] can be applied in identifying the critical machine process parameters that have significant influence in the injection moulding process. The easiest way to set-up the injection machine parameter is based on the machine set-up technician’s experience or trial and error method. This trial and error method is unacceptable because it is time consuming and not cost effective, thus it is not suitable for complex manufacturing process because when using a trial and error method, it is impossible to verify the actual optimal process parameter setting [15].

Injection moulding processes are affected by numerous parameters and it is not possible to identify the effects of all these parameters. Therefore it is necessary to select the parameters that have major effects on the output. Some of the potential parameters for an injection moulding process might be: material drying temperature, injection pressure, barrel temperature, injection time, pack pressure, holding pressure, cooling time, mould temperature, injection speed and others. In moulding industry, the machine set-up technician will choose the inputs of machine process parameters and the outputs will depend on the product drawing and customer requirements. In Design of Experiments (DOE), the inputs are frequently referred to as factors and the outputs are referred to as responses.

Researchers [16-18] have been using DOE Technique to study the effects of injection parameters on the quality

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characteristics of the moulded products. Selecting the correct inputs parameters and outputs requires knowledge of what need to be improved as well as strong knowledge of injection moulding technology [19]. There are three types of control factors [20]: (1) Control factors are factors that can be controlled, for example, the holding pressure. These are the factors that influence the responses. (2) A noise factor is any factor which is believed to affect the response, but either cannot be or chosen not to be controlled, for example, the room temperature and viscosity change due to resin lot or moisture content. (3) Constant factors are factors that the authors do not want to study. These are either factors whose best settings are already known or those believed to have little or no influence at all on the responses. In this study the authors want to identify the control factors which can influence the responses by using 7 QC tools.

Common quality problems or defects that come from an injection moulding process are sink mark, short-shot, flash, jetting, flow marks, weld lines, burns, warpage, shrinkage and others. The defects of injection moulding process usually arise from several sources, including the pre-processing treatment of the plastic resin before the injection moulding process, the selection of the injection moulding machine, and the setting of the injection moulding process parameters. The effects on the moulding parameters on the physical and mechanical properties of thermoplastics have been studied by researchers [4, 7-11]. The quality characteristics of plastic injection moulded products can be divided into three kinds: (1) the dimensional properties, (2) the surface properties and (3) the mechanical properties [21, 22]. These study focus on dimension properties.

7QC tools are fundamental instruments to improve the quality of products. They are used to analyze the production process, identify major problems, control fluctuations of product quality and provide solutions to avoid future defects. These tools use statistical techniques and knowledge to accumulate data and analyze them. They help organize the collected data in a way that is easy to understand. Moreover, by using 7QC tools, specific problems in a process can be identified [23]. The 7 QC tools are [24]: Check Sheets, Pareto Charts, Histograms, Scatter Diagrams, Process Flow Charts, Cause and Effect Diagram and Control Charts.

A. *Check Sheet*

Check sheet, which shows the history and pattern of variations. This tool is used at the beginning of the change process to identify the problems and collect data easily. The team using it can study observed data (a performance measure of a process) for patterns over a specified period of time.

B. *Pareto Chart*

Pareto chart is named after Wilfredo Pareto, the Italian economist who determined that wealth is not evenly distributed [25]. The chart shows the distribution of items and arranges them from the most frequent to the least frequent. The fundamental idea behind the use of Pareto diagrams for quality improvement is that the first few contributing causes to a problem usually account for the majority of the result. Therefore, targeting these "major causes" for elimination will provide very cost-effective improvement results.

C. *Cause and Effect diagram*

The Cause-and-Effect Diagrams were proposed by Kaoru Ishikawa [14] in Japan. It is a graphical technique for grouping people's ideas about the causes of a problem. Using a Cause and Effect diagram forces the team to consider the complexity of the problem and to take an objective look at all the contributing factors. It helps the team to determine both the primary and the secondary causes of a problem and is helpful for organizing the ideas generated from a brainstorming session. Common uses of the diagram are in defect prevention and to identify potential factors causing the defects. Causes are usually grouped into major categories to identify these sources of variation. The categories typically include: People, Methods, Machines, Materials, Measurements and Environment [22, 26].

D. *Histogram*

Histogram is a bar chart showing a distribution of variables. This tool helps identify the cause of problems in a process by the shape as well as the width of the distribution. It shows a bar chart of accumulated data and provides the easiest way to evaluate the distribution of data.

E. *Scatter diagram*

Scatter diagram, which shows the pattern of relationship between two variables that are thought to be related. The closer the points are to the diagonal line, the more closely there is a one-to-one relationship. The scatter diagram is a graphical tool that plots many data points and shows a pattern of correlation between two variables.

F. *Control Charts*

Control Charts are among the simplest and best techniques to analyze and display data for easy communication in a visual format. Data can be depicted graphically using control charts. Control chart is a line chart with control limits. By mathematically constructing control limits at three standard deviations above and below the average, one can determine what variation is.

In this study the authors only used Check Sheets, Pareto Charts and Cause and Effect Diagram tools in their problem solving techniques.

II. EXPERIMENTAL DETAIL

The objectives of this study is to identify the critical injection moulding parameters (factors) and its level affecting the dimensions of length and width (responses) of a plastic cell phone shell (known as Front Cover) by using 7QC tools. The current machine process setting in use caused variation below the specification limit for both responses due to shrinkage defect. The specification limit for the length and width without shrinkage are 93.49 ± 0.2 mm and 45.93 ± 0.2 mm respectively. In other word, it is desirable that the actual dimensions for the length and width to be within the limit

[93.29, 93.69] and [45.73, 46.13] respectively. Thus the experiments needed to find out the process factors and its level that could be set to maintain the dimension of length and width within the given specification limits.

Due to a non-disclosure agreement between the company and the authors, certain information relating to the company cannot be revealed. Over the years, the company was involved in production of injection moulds of engineering plastics and precision parts. The data collected for the experiment is extracted from actual production line data of the company for the period of one month. The case study was carried out at a plastic injection moulding department. One of the critical components in the cell phone assembly was the Front Cover (Figure 2) which will be the main focus in this study.

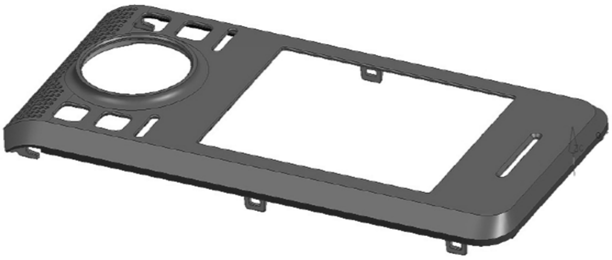

Fig. 2 Cell phone Shell - Front Cover

Since this Front Cover is a critical component in the company's latest new cell phone product, high percentage process defects of Front Cover from the injection moulding process is the company's main concern. The data collection was limited to one month only because the production of the Front Cover was just being set up and the cell phone assembly using the component had just been introduced into the market in June 2010. The material used to produce Front Cover was commercially available polycarbonate (PC) material. The material was pre-conditioned at 120 degree celcious for four hours using a dehumidifying drier before moulding. The trade name, manufacturer and melt flow index of the material are shown in Table 1.

A study group comprised of eight members from various job scopes was formed. The members were selected from the Production Engineering staff ranking from Technicians, Supervisors and Quality Engineers. A manager and a facilitator guided the team. At the beginning stage, they formed their project team, selected their team leader and drafted the milestone chart in the form of PDCA (Plan, Do, Check and Action). The project was conducted in the injection moulding department. Training was given to the production operators on how to perform the measurement, inspection, segregation and arrangement of the Front Cover.

TABLE I

MOULDING MATERIAL SPECIFICATION

Material name	Polycarbonate
Category	General purpose
Manufacturer	Mitsubishi
Trade name	Lupilon
Grade	S-2000
Melt flow index	10 g/10min

The following six steps are involved in this case study:

1) Data collection

The production output data was recorded in the check sheet based on type of defects. Data was collected over a period of a month.

2) Data analysis

Based on daily rejection output a Pareto Chart was constructed to identify the most common defects. Only the top defect was are chosen for this case study.

3) Identifying defect causes

After identifying the main defect, a brainstorming session was held to list out the possible causes of that defect in the Cause and Effect Diagram.

4) Identifying the factors and response

After identifying the possible causes of that defect, a brainstorming session was held to list out the possible machine input parameters (factors) that will be influencing the main defect and the appropriate working range (level) was selected based on initial and pilot experiment data.

5) The Experimental Design

Experiment was designed to confirm whether the combinations of factors and its levels can produce the Front Cover without the main defect. A full two level factorial experimental design was carried out in this study.

6) Verification and Validation

Confirmation runs were carried out to verify the reproductively and predictability of the result.

III. RESULT AND DISCUSSION

A. Data Collection and Data Analysis

After completing the data collection by using check sheets the team performed the data analysis. Figure 3 shows the Front Cover rejection percentage for the month of June 2010. It also shows that average 15% of rejects reported due to the Front Cover due quality problem. The Pareto Chart (Figure 4) shows the results of investigations on the types of defects that contributed to the rejection percentage of the Front Cover. Figure 5 shows the cumulative percentage reject rate based on the type of defects. The Pareto Chart (Figure 4) show that the types of defects of highest occurrence were due to shrinkage. The shrinkage defects accounted for about 30% of the total defects from the Front Cover overall rejection rate. The possible causes for shrinkage defect were due to the design of the part, gate location and also highly related to machining parameters setting.

In this case study the authors try to eliminate the shrinkage defect by machine parameter setting before look in the part and gate design which will increase the manufacturing cost and production down time.

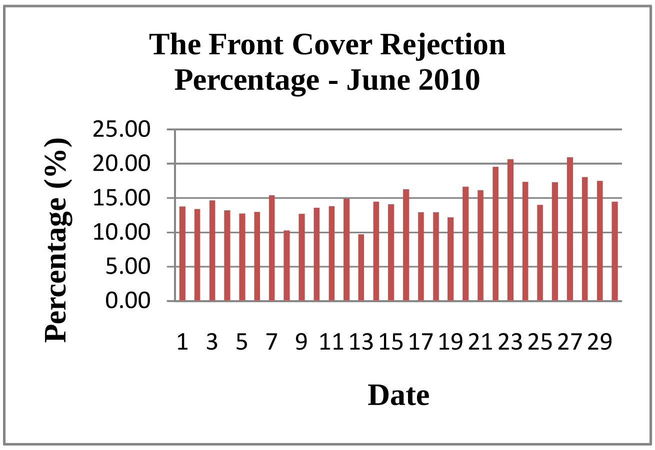

Fig. 3 The Front Cover rejection percentage for June 2010

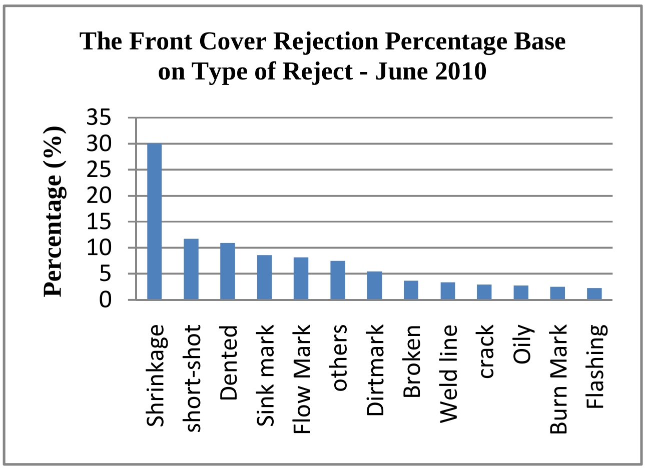

Fig. 4 The Front Cover rejection percentage base on type of defects

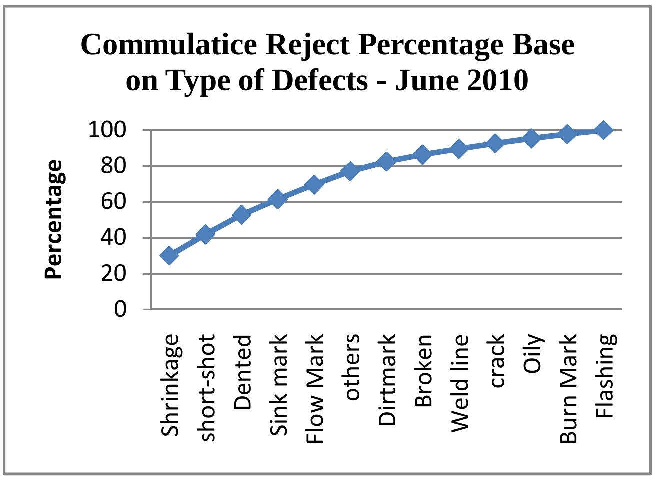

Fig. 5 The Cumulative Reject percentage base on type of reject

B. Identifying Defect Causes

The team conducted a brainstorming session to find the root cause of the shrinkage defect, and summarized the outcome in a Cause and Effect Diagram in Figure 6. Based on the four major categories (Machines, Materials, Method and Mould) the team decided to work on machine first to reduce the 30 % of shrinkage defect. Finally, from the machine perspective, the team decided that the machine process parameter setting will be the key to overcoming the shrinkage defect problem. Other parameters like materials, mould and method will be only consider if the shrinkage defect cannot be overcome by adjusting machine parameter setting. This is because working or adjusting other parameters will increase the manufacturing cost and production down time.

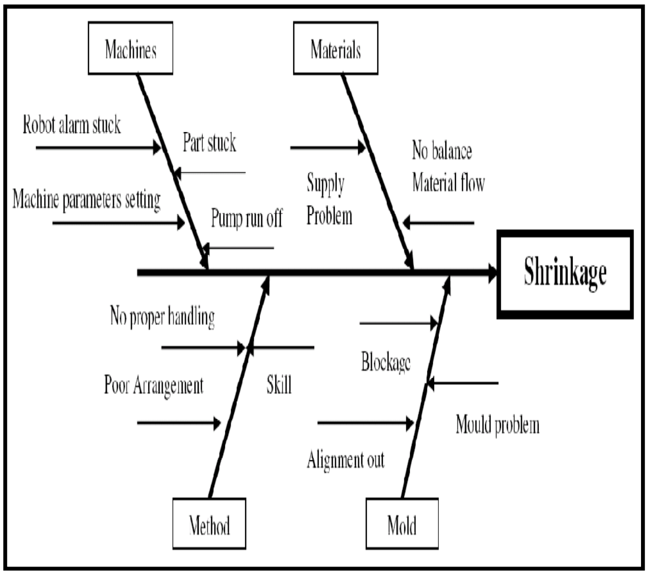

Fig. 6 Cause and Effect analysis for shrinkage defect

C. Identifying the Factors and Responses

Based on the process knowledge experience of the process engineer, moulding supervisor, QC engineer, literature review and machine supplier, the machine input parameters (factors) that will be influencing the shrinkage defect are as shown in Figure 7. Based on the advice of the company's process engineer, moulding supervisor, machine history, maintenance report, and material study, the team decided to select the mould temperature, injection pressure and screw rotation speed as moulding machine parameters (factors) and dimension of the length and width of the Front Cover as the output (responses). The appropriate working range (level) was selected based on initial and pilot experiment data. The team tested this level on the injection moulding machine before selecting the appropriate parameter levels for the experiment. The selected factors and response and its levels are shown in Table 2.

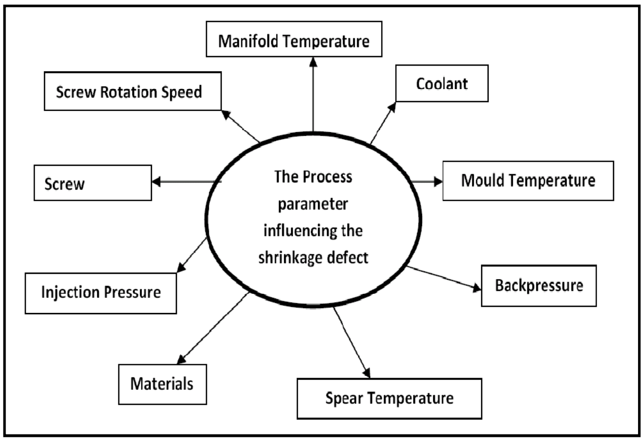

Fig. 7 The Machine process parameters influencing the shrinkage defect

D. The Experimental Design

TABLE II
FACTORS AND LEVELS OF THE EXPERIMENTS

Factor	Units	Low Level (-)	High Level (+)
A. Mould Temperature	Celsius	85	95
B. Injection Pressure	kg/cm^2	2250	2400
C. Screw Rotation Speed	mm/sec	110	140

The three experimental factors mould temperature, injection pressure and screw rotation speed (labeled as A, B and C) are to be studied at the two levels as given in Table 2. A full two level factorial experimental design was carried out to study on how the above three factors will influence the responses. The number of run (combination of machine parameter setting) needed according to full two-level factorial experimental design method for three factors was eight and each run was repeated twice.

Therefore a total 16 experimental runs were required for these study. At each combination of this machine setting, the team leader will record the dimension of the responses. The dimensions were measured by using digital smart scope machine. An experimental design matrix was constructed according to standard order rule which was given in Table 3. Experiments were executed randomly to provide protection against the extraneous factors, which could affect the measured responses. In all experimental runs, the reaction time was considered as 5 min. The resulting responses values are shown in Table 3 as well. The actual experiment was conducted in the factory with some help from the staff, taking one working day to be completed.

E. Experimental Results

The control charts (Figure 8 and 9) shows clearly the upper, lower and central specification limit for the both responses. The figures also shows that the dimension of the length and width are within the specification limit 93.49 ± 0.2 mm and 45.93 ± 0.2 mm respectively for 16 experimental runs. Therefore the team decided that the shrinkage defect for the Front Cover can be eliminated by injection moulding parameter setting and the machine parameters (factors) and its level which can eliminate the shrinkage defect are shown in Table 2.

TABLE III
EXPERIMENTAL DESIGN MATRIX AND WEIGHT RESULT

Run	Factors			Responses	
	A	B	C	Length (mm)	Width (mm)
1	95	2400	140	93.462	45.834
2	95	2250	140	93.442	45.825
3	95	2400	110	93.458	45.824
4	95	2250	140	93.446	45.815
5	85	2250	140	93.434	45.812
6	85	2400	140	93.454	45.823
7	95	2250	110	93.440	45.817
8	95	2400	110	93.468	45.825
9	85	2400	110	93.454	45.823
10	95	2250	110	93.429	45.814
11	85	2400	110	93.453	45.832
12	95	2400	140	93.470	45.822
13	85	2250	110	93.438	45.822
14	85	2250	110	93.435	45.832
15	85	2400	140	93.443	45.820
16	85	2250	140	93.436	45.822

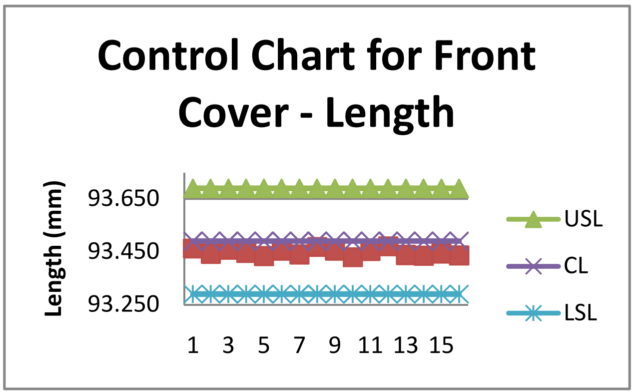

Fig. 8 The control chart for the response length

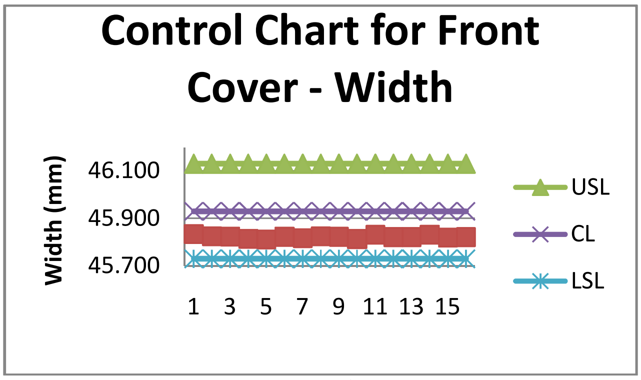

Fig. 9 The control chart for the response width

F. Verification and Validation

The team conducted the validation test based on the setting shown in Table 2 with five sample or replicate per run. The average for the responses (length and width) had shown in Figure 10 and 11. The figures also show that for 16 experimental runs the dimension for both responses (length and width) are within the specification limit 93.49 ± 0.2 mm and 45.93 ± 0.2 mm respectively. The quality engineer from the team also confirms that the Front Cover produce by 16 experimental runs were without other defect by visual inspection.

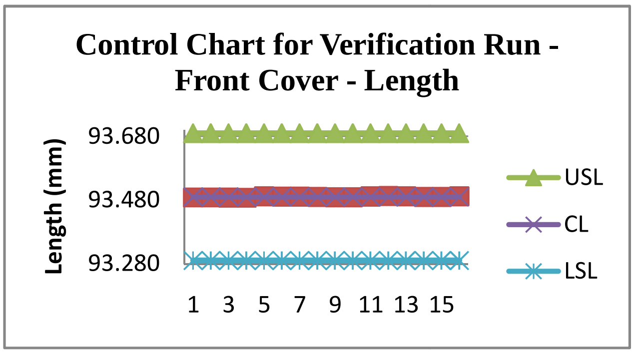

Fig. 10 The control chart for verification run - response length

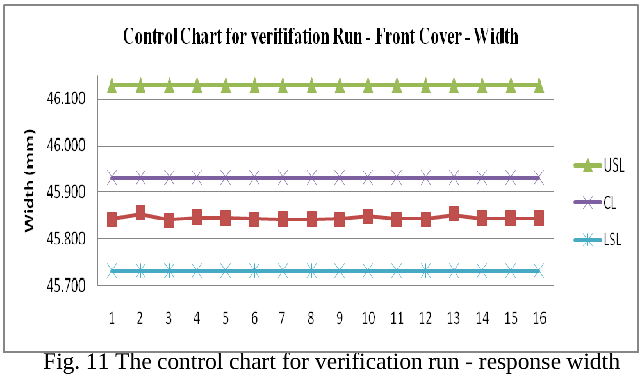

Fig. 11 The control chart for verification run - response width

IV. CONCLUSION AND RECOMMENDATION

In this study basic statistical process control tools was used to identify the critical moulding machine parameters affecting the shrinkage defect of the Front Cover of a cell phone shell. The bar chart help the team to identify that average 15% of rejects of the Front Cover was due to quality problem. Pareto Chart show that the types of defects of highest occurrence were due to shrinkage. The identification of the three critical factors and its level were confirm by conducting experiment by Design of Experiment technique where 16 combination runs shows that the length and width of Front Cover are within the specification limit. In other word the parts are now without shrinkage. Finally the team successful in eliminating shrinkage defects from 30% to 0%.

Recommendation for further study – This is an ongoing research, therefore after the identification of the critical parameters effect the shrinkage by 7QC Tools, it will be easier and faster to obtain the optimal conditions to start the mass production to produce a high volume of parts. Optimal conditions can be obtain by continuing this study by using the methodology of DOE, where the data in Table 3 have to be feed to the Design Expert software and the results will be analyze. The analysis should be includes ANOVA, residual analysis and model adequacy checking, regression analysis, interaction plots and cube plot.

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REFERENCES

[1] S.A.Brent, (2000). *Plastics materials and processing* (3rd ed.). New Jersey: Prentice Hall.

[2] J.-F. Agassant, P. Avenas, J.-Ph. Sergent, P.J. Carreau. *Polymer Processing – Principle and Modelling*, Hanser Publishers, New York 1991

[3] T.A. Osswald. *Polymer Processing – Fundamentals*. Hanser Publishers, 1998.

[4] W.C. Chen, P.H. Tai, M.W. Wang, W.J. Deng, & CT. Chen, (2008), A neural network-based approach for a dynamic quality predictor in plastic injection molding process. *Expert Systems with Applications*, 35(3), 843–849.

[5] C.M. Seaman, (1994). Multiobjective optimization of a plastic injection molding process. *IEEE Transactions on Control Systems Technology*, 2(3), 157–168.

[6] M. H. Wesselmann, Impact of moulding conditions on the properties of short fibre reinforced high performance thermoplastic parts. PhD Thesis, Ecole des Mines Albi, 1998.

[7] R.D. Chien, S.C. Chen, P.H. Lee, & J.S. Huang, (2004). Study on the molding characteristics and mechanical properties of injection-molded foaming polypropylene parts. *Journal of Reinforced Plastics and Composites*, 23(4),429–444.

[8] H. Ismail, & Suryadiansyah (2004). A comparative study of the effect of degradation on the properties of PP/NR and PP/RR blends. *Polymer–Plastics Technology and Engineering*, 43(2), 319–340.

[9] Y.H Lin, W.J. Deng, C.H. Huang, & Y.K. Yang, (2008). Optimization of injection molding process for tensile and wear properties of polypropylene components via Taguchi and design of experiments method. *Polymer–Plastics Technology and Engineering*, 47(1), 96–105.

[10] H. Oktem, T. Erzurumlu, & I.Uzman, (2007). Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part. *Materials and Design*, 28, 1271–1278.

[11] H.SadAbadi, & M. Ghasemi, (2007). Effects of some injection molding process parameters on fiber orientation tensor of short glass fiber polystyrene composites (SGF/PS). *Journal of Reinforced Plastics and Composites*, 26(17), 1729–1741.

[12] B. Ozcelik, & T.Erzurumlu, (2006). Comparison of the warpage optimization in the plastic injection molding using ANOVA, neural network model and genetic algorithm. Journal of Materials Processing Technology, 171(3), 437–445.

[13] S.L. Mok, & C.K. Kwong, (2002). Application of artificial neural network and fuzzy logic in a case-based system for initial process parameter setting of injection molding. *Journal of Intelligent Manufacturing*, 13(3), 165–176.

[14] K. Ishikawa, Guide to Quality Control, Asian Productivity Organization, Tokyo, 1982

[15] Y.C. Lam, L.Y. Zhai, K. Tai, & S.C. Fok, (2004). An evolutionary approach for cooling system optimization in plastic injection moulding. *International Journal of Production Research*, 42(10), 2047–2061.

[16] Th. Barriere, B. Liu, J.C. Gelin, “Determination of the optimal process parameters in metal injection molding from experiment and numerical modeling”, *Journal of Materials Processing Technology*, 2003, vol. 143-144, pp. 636-644.

[17] Mohd Afian Omar, “Injection molding of 316L stainless steel and NiCrSiB alloy powders using a PEG/PMMA binder”, 1999, Ph.D. Thesis University of Sheffield, UK.

[18] Muhammad Hussain Ismail, “Powder loading influence to the processing phenomena in metal injection molding”, 2002, M.Sc. Thesis National University of Malaysia.

[19] A. Robert Malloy, (1994). *Plastic Part Design for Injection Molding*. Cincinnati, OH: Hanser/Gardener Publication, Inc.

[20] Lahey, P. Jayme and Robert G.Launsby, (1998*). Experimental Design for Injection Molding*, 205pp., illus.

[21] Y. Yang, & F. Gao, (2006). Injection molding product weight: Online prediction and control based on nonlinear principal component regression model. *Polymer Engineering and Science*, 46(4), 540–548.

[22] B.H. Min, (2003). A study on quality monitoring of injection – molded parts. *Journal of Material Processing Technology*, 136 , 1-6.

[23] Nancy R. Tague, (2004). "Seven Basic Quality Tools". The Quality Toolbox. Milwaukee, Wisconsin: American Society for Quality. p.15. http://www.asq.org/learn-about-quality/seven-basic-quality-tools/overview/overview.html. Retrieved 2010-02-05.

[24] K. Ishikawa, (1985*) What is Total Quality Control*. Prentice Hall. Englewood Cliff, N.J.

[25] D.C. Montgomery, (1985). *Statistical quality control*. New York: Wiley.

[26] Dale and G. Barrie (2007). *Managing Quality* (5th ed). ISBN 978-1-4051-4279-3 OCLC 288977828.