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QUALITY IMPROVEMENT USING TAGUCHI METHOD IN A MANUFACTURING COMPANY

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ABSTRACT

Quality improvement is crucial for manufacturing companies to survive in today's marketplace. The main purpose of this study was to improve the quality of one selected product produced by a manufacturing company using the Taguchi Method. The product, a plastic injection moulding is studied as it showed the highest reject quantity. The type of defects found in the product includes bubble, short mould, scratches and over pack. However due to company's request and limitations, only two defects, short mould and over pack, were further investigated. Experimentation using Taguchi method was decided as the approach to reduce the occurrence of the defects. To that end, four main factors affecting the surface defects were identified. They are injection pressure (A), injection speed (B), melting temperature (C) and holding pressure (D). Taguchi method was chosen since it provides fast and lower costs for conducting the experiments as well as in determining optimum parameter. Qualitek-4 software was used to facilitate the signal-to-noise (S/N) ratio analysis in the Taguchi Method and to predict the results at optimal parameters setting. The results from the two levels of experiments (L8) suggest that all parameters and 2-factor interactions investigated were significant for short mould and all the factors should be set at high level to achieve optimum condition. In the case of the over pack problem, two significant factors and one significant interaction factor which are injection speed (B), melting temperature (C) and interaction AB (injection pressure and melting temperature) were found to be significant and should be set at low level. Confirmation run was conducted for over pack problem and the recommended optimal settings are injection pressure at high level, injection speed at low level, melting temperature at low level and holding pressure at high level ($A_2B_1C_1D_2$)*. Future studies could look at introducing others factors that may be involved in the process and to possibly use conventional design of experiment method.*

Keywords: *Quality improvement, injection moulding, Taguchi Method*

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1.0 INTRODUCTION

The word quality has been and is being used by many people in their daily life and business to illustrate their satisfaction level. “What is quality?” has always been a difficult question especially in engineering and manufacturing professions. Numerous definitions have been given by the quality gurus. They include meeting the needs of customers fit for purpose and conformance to requirements. People need to accurately define quality, at each stage, for any organization undertaking the continual improvement journey. They need to use the common terminology of each business and to link to its business planning cycle, to effectively communicate with management. Many different techniques and concepts in quality engineering have been developed to improve product or service quality, including Statistical Process Control, Zero Defects, Six Sigma, Malcolm Baldrige National Quality Award, quality circles, TQM, Theory of Constraints (TOC),Quality Management Systems (ISO 9000 and others) and continuous improvement. The meaning for the term quality has developed over time. Besterfield refers quality to an excellent product or services that fulfills or exceeds user expectations. These expectations are based on the intended use and the selling price. Thus, it is somewhat of an intangible concept based on perception [1].

The need for continuously understand and improve quality problems require the application of quality tools and techniques, and Taguchi being one of the advanced technique. The objective of this project is to determine best process parameters setting for a selected product based on the identified quality problems using Taguchi Method. This method was applied on a plastic injection moulding process and the selection of the optimum conditions is done based on the result of S/N ratio analysis.

In the study, the production processes were observed, and formal discussions made with related company personnel. This was followed by data collection and to look at the company’s documents in order to identify the major problems. Suitable quality engineering tools were employed in carrying out a detailed study in order to identify the problems. The Taguchi method has been applied to investigate two quality problems of a microelectronic chips moulded with plastic. The problems are short mould and over pack. These two quality characteristics were chosen because they are the most serious quality problems which are of company concern, although the over pack defect is not the most critical found in Pareto analysis.

2.0 COMPANY BACKGROUND

This manufacturing company is focused to aggressively increase their revenue by involving in the assembly modules, polymer optics, premoulded package, optoelectronics modules and metal keypad industry. The nature of products produced has resulted in the manufacturing of plastic injection moulds and insert to exist as the main business activities of the company. The core competency discovered is the fabrication of precision mould with single and multiple cavities specifically for vertical rotational lead frame mould. It have grown to a stage where their clients have chosen them to be their fabrication partner-of-choice in the area of plastic injection tool development and build, plastic injection moulding and process development, plastic secondary processes, mechanical sub-assembly and plastic plating.

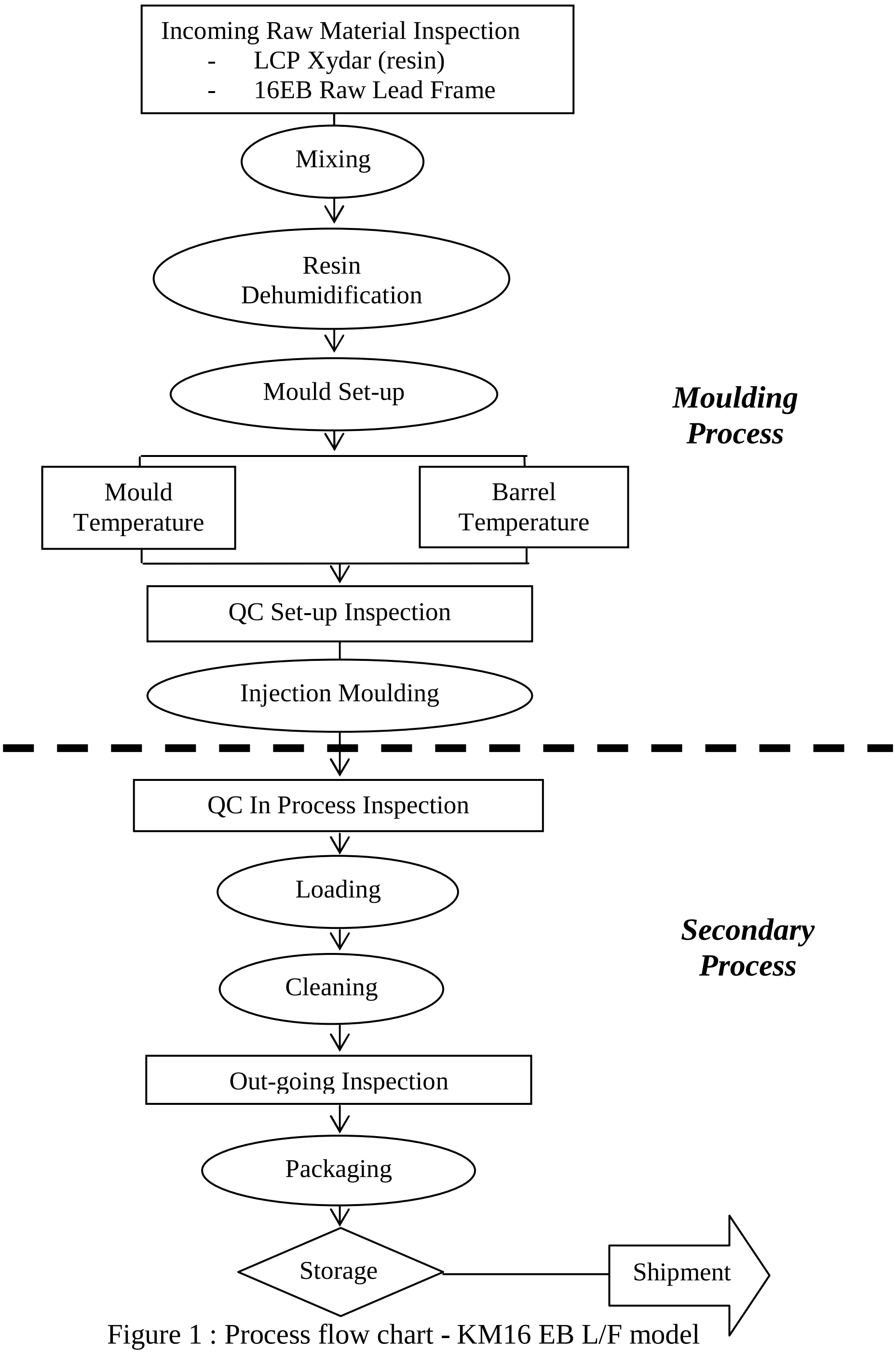


Figure 1 : Process flow chart - KM16 EB L/F model

The major problem in the company is in the high rejection rate when the products are shipped to its' customers. Therefore, the product to be studied must be based on high volume produced and high demand of the model as requested by customer. High volume criteria and high demand criteria will make the product expose to high chances of defect rate. Having gone through the documents, such as Quality Assurance monthly report, and through numerous discussions with the production manager and quality assurance engineer, KM 16 EB lead frame was selected as the product to be studied further. This product functions as a system controller in a typical mouse used in a computer.

The activities for the fabrication process of KM EB 16 lead frame model consist of incoming raw materials inspection, resin dehumidification, moulding process, secondary process, out-going inspection and packing. The flow of the activities is shown in Figure 1.

3.0 EXPERIMENTATION

Several methods were used in determining the possible controllable factors, uncontrollable factors and interaction based on Taguchi Methods [9]. Based on the brainstorming with experimental team, cause and effect diagram and literature study on the plastic injection moulding process, the possible main factors (controllable factors) and its interaction affecting the surface defects were determined. These are given in Table 1.

Table 1 : The possible main factors affecting surface defects

Factors			Level 1	Level 2	Units
Main Factor	A	Injection Pressure	65	80	Kg/cm^2
	B	Injection Speed	45	75	%
	C	Barrel Temperature (Nozzle zone & first zone)	Low (320, 290)	High (340, 320)	°C
	D	Holding Pressure	20	30	Kg/cm^2
Interaction	AB	Injection Pressure X Injection Speed	Dummy		
	AC	Injection Pressure X Barrel Temperature			
	BC	Injection Speed X Barrel Temperature			

Basically, a minimum of two levels experiment is required to evaluate the effect of selected factors on quality characteristics determined earlier [3]. There are four main factors, which are injection speed, injection pressure, barrel temperature, and holding pressure. All factors are set at two levels; a low and a high level. From the Orthogonal Array design, it is expected that there is interaction between injection pressure with injection speed, injection pressure with barrel temperature and injection speed with barrel temperature.

In addition, uncontrollable factors have also been identified, which are suspected to adversely affect the injection moulding process. Figure 2 shows the uncontrollable factors which have been identified, but not included in the experiment since it is very difficult and expensive to control.

The minimum required number of degree of freedom in the experiment refers to the sum of all the factors and interactions in the experiment [3]. Table 2 shows the degree of freedom for each factor and interaction and how it was calculated. From the table, it is noticed that the total degree of freedom of the array is 7. This will then lead to selection of appropriate orthogonal array used to design the experiment structure later.

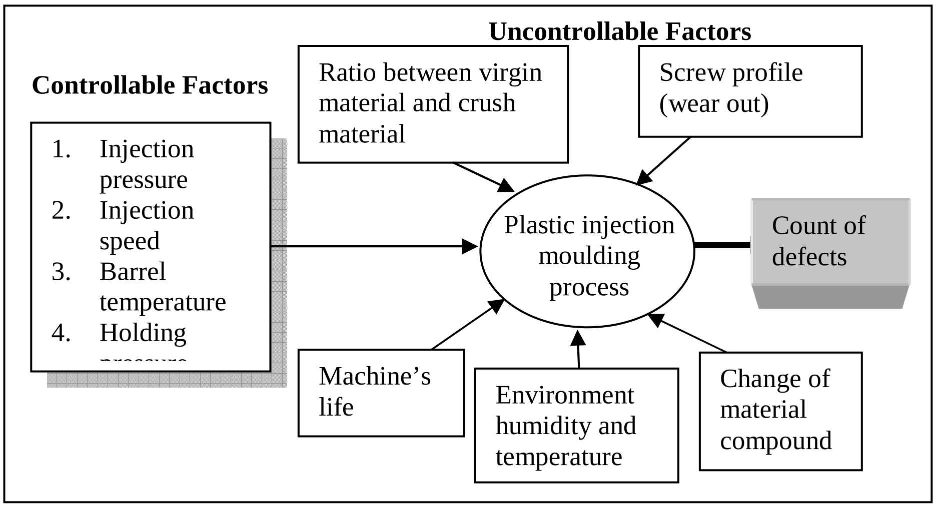


Figure 2 : Controllable and uncontrollable factors

There are four degrees of freedom due to main factors and three degrees of freedom due to two-way interaction which gives the total number of degrees of freedom of seven as shown in Table 2. Thus, the two level L_8 (2^7) orthogonal array is selected because it is able to cover the total of seven degrees of freedom as required from the calculation. There are three replications for each run; giving a total number of runs to be twenty four. Location of the controllable factors is assigned to the array as shown in Table 3. The main factors are located in Columns 1, 2, 4 and 7 and the three interactions are assigned in Columns 3, 5 and 6.

Table 2 : Degrees of freedom

Factor	Degree of freedom
A	(2-1)=1
B	(2-1)=1
C	(2-1)=1
D	(2-1)=1
AB	(1x1)
AC	(1x1)
BC	(1x1)
Total DOFs	7

Table 3 : Orthogonal array for controllable factors

Column	1	2	3	4	5	6	7
Run	A	B	AB	C	AC	BC	D
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

As the factor D is assigned to the column of interaction between factors AxBxC, there exists confounding effects between factor D and this interaction. Since factors D and this interaction are confounded with each other, the effects of the factors are indistinguishable.

4.0 RESULTS AND DISCUSSION

Table 4 shows the experimental matrix with a total of 24 experiment units (8 rows x 3 replications) for short mould and over pack. From the data collected, it was found that the high level setting for all main factors will cause increase in over pack on the lead frame. Since over pack results in scrap and will increase internal failure cost, the setting is discontinued from the initial plan of the experiment sheet. In order to complete the results analysis, the data for run 8 is assumed to be equivalent to 20 defects to indicate high over pack occurrence in the experiments.

Since the sample size of each run is different (where it is based on the equivalent time allocated in every run), the output recorded (count of defect) was converted in the form of percentage (%) to gain accurate analysis. The results which in percentage (%) and average response of short mould and over pack for each run together with calculated $\sum y^2$ and S/N ratio shown in Table 5.

Table 4 : The result data (in count of defect) of short mould and over pack

Run	**Column**							**Result**					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Short Mould**			**Over Pack**		
	A	**B**	**AB**	**C**	**AC**	**BC**	**D**	**1**	**2**	**3**	**1**	**2**	**3**
1	1	1	1	1	1	1	1	4	13	5	0	0	0
2	1	1	1	2	2	2	2	4	9	10	0	0	1
3	1	2	2	1	1	2	2	9	5	7	1	1	0
4	1	2	2	2	2	1	1	4	9	4	2	2	0
5	2	1	2	1	2	1	2	5	5	7	0	0	0
6	2	1	2	2	1	2	1	5	8	11	0	0	1
7	2	2	1	1	2	2	1	12	2	5	0	0	2
8	2	2	1	2	1	1	2	2	1	1	20	20	20

RUN	**Short Mould**				$\sum y^2$	**S/N Ratio**	**Over Pack**				$\sum y^2$	**S/N Ratio**
	1	**2**	**3**	**Avg**			**1**	**2**	**3**	**Avg**		
1	3.81	11.61	4.31	6.58	167.8843	-17.48	0	0	0	0	0	70
2	3.85	8.41	9.25	7.17	171.1131	-17.56	0	0	0.93	0.31	0.8649	5.40
3	8.26	4.39	5.83	6.16	121.4886	-16.07	0.92	0.88	0	0.6	1.6208	2.67
4	3.70	8.11	3.54	5.12	91.9937	-14.87	1.85	1.80	0	1.22	6.6625	-3.47
5	4.31	4.31	6.03	4.88	73.5131	-13.89	0	0	0	0	0	70
6	4.67	7.27	9.48	7.14	164.5322	-17.39	0	0	0.86	0.29	0.7396	6.08
7	10.08	1.77	4.72	5.52	127.0177	-16.27	0	0	1.89	0.63	3.5721	-0.76
8	1.82	0.80	0.89	1.17	4.7445	-1.99	18.18	16.00	17.86	17.35	905.492	-24.80

Table 5 : The result data (%) and the average response of short mould and over pack

4.1 Analysis on effects of main factors for short mould

The main interest in the Taguchi method is in the signal to noise ratio responses. For that purpose the data collected was analyzed using Qualitek-4 in the form of signal to noise ratio instead of average value [5]. The average responses are considered as marginal interest only and not reported here.

The average S/N ratio for each control factor level is calculated and average S/N ratio table is constructed as shown Table 6. This is performed by selecting values of S/N ratio at each factor level, taking the sum and dividing by the number of values at each level. Column response in Table 6 indicates the difference in the average level effects and corresponds to the influence of the factors to the variability.

Table 6 : Main effect calculation for short mould (calculated manually)

AVERAGE							
Control factor	A	B	AB	C	AC	BC	D
Average of Level 1	6.2575	6.4425	5.11	5.785	5.2625	4.4375	6.09
Average of Level 2	4.6775	4.4925	5.825	5.15	5.6725	6.4975	4.845
Response (2-1)	-1.58	-1.95	0.715	-0.635	0.41	2.06	-1.245
SIGNAL TO NOISE RATIOS							
Average of Level 1	-16.495	-16.58	-13.325	-15.928	-13.233	-12.058	-16.503
Average of Level 2	-12.385	-12.3	-15.555	-12.953	-15.648	-16.823	-12.377
Response (2-1)	4.11	4.28	-2.23	2.975	-2.415	-4.765	4.125

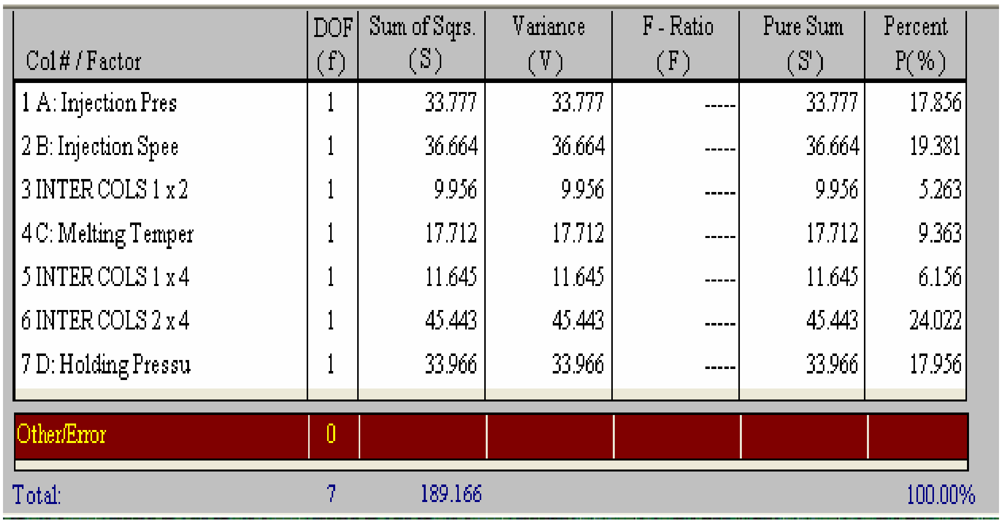
The same calculation is used for the other factors and interactions, shown in Table 6. The S/N ratio obtained then can be used to plot the S/N ratio graphs which are generally referred to as the main effect plots. The effects of each factor level can visually be identified through the S/N response graph. It shows the trend of influence of the factor by observing the slope of the line for each factor.

The S/N response graph can be used to determine the significance of the factor. Since the higher S/N ratio means the greater robustness and less variability, therefore, the level with largest value will be chosen. However, it is not adequate to justify the level setting of factor in the experiment by just viewing the factors relationship through S/N ratio response graph. Statistical analysis is needed to verify and identify the significant factors in the experiment whereby ANOVA can be performed to prove the confidence level of initial significant factors generated.

The main objective of ANOVA is to extract from the results how much variation each factor (or interaction assigned to the column) causes relative to the total variation observed in the result [6]. Important information such as sum of squares, variance, F-ratio, pure sum and the percentage of contribution to the experiment variation for each factor are provided in the ANOVA table as shown in Table 7.

The Table 7 shows the significant factors and their relative influence to the variation of results. The value in the right column of the table (percentage of influence) represents the breakdown of the total influence (100%) to the results. The sums of squares column shows the relative contribution of each factor to the total variance of the 7 factors [7]. Meanwhile, the F ratio shows the effect of each factor relative to the error [7]. Degree of Freedom (DOF) is the indication of the amount of information contained in a data set [7].

Table 7 : ANOVA table for short mould



Col# / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 A: Injection Pres	1	33.777	33.777	-----	33.777	17.856
2 B: Injection Spee	1	36.664	36.664	-----	36.664	19.381
3 INTER COLS 1 x 2	1	9.956	9.956	-----	9.956	5.263
4 C: Melting Temper	1	17.712	17.712	-----	17.712	9.363
5 INTER COLS 1 x 4	1	11.645	11.645	-----	11.645	6.156
6 INTER COLS 2 x 4	1	45.443	45.443	-----	45.443	24.022
7 D: Holding Pressu	1	33.966	33.966	-----	33.966	17.956
Other/Error	0					
Total:	7	189.166				100.00%

Since error for DOF was zero, the test for significance is not possible, therefore, pooling is accomplished. As a rule, a few factors that have least influence or with the smallest percentage of influence (P %) should be pooled (compare S value). In this case, the percentages of all the factors are approximately close with each other. If pooling is applied, it will result in high error in the experiment. Thus, each factor will be considered for further investigation.

From the table, the interaction between BC (interaction between factor injection speed and melting temperature) is the most significant factor as it contributes to the highest percentage of total variation, which is 24.0%. Then, the other significant factors are factor B (injection speed – 19.4%), factor D (holding pressure – 18.0%) and factor A (injection pressure – 17.9%).

As for factor C (melting temperature), the interaction between factor A (injection pressure) and factor C (melting temperature) and interaction between factor A (injection pressure) and factor B (injection speed), are found to have little contribution to the total variation in the experiment. The percentages of contribution for these significant factors are 9.4%, 6.2% and 5.3%.

In short, interaction between factor injection speed and melting temperature (interaction BC) is the most significant factor, followed by injection speed (factor B), holding pressure (factor D) and injection pressure (factor A). These factors contributed to about 79.2% of the total variation. Thus, in order to minimize the variation, these four factors must be given high priority and controlled during the process. Other factors seem to have no significant influence to the variation.

4.2 Analysis on effects of main factors for over pack

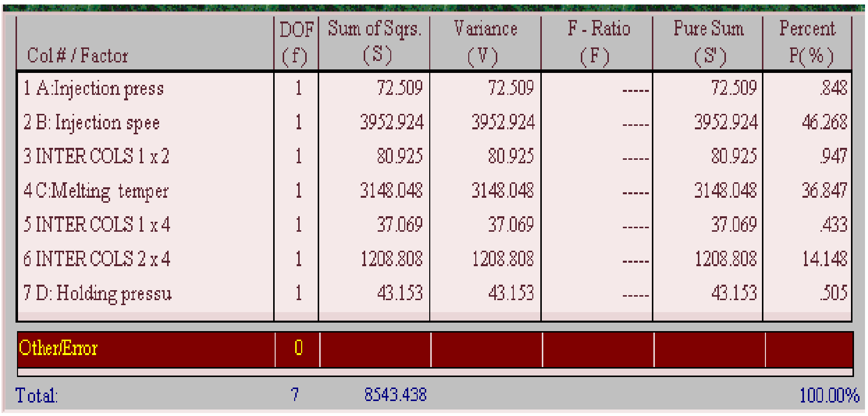
The average effect and S/N ratio for each control factor level is calculated and shown in Table 8. The significant factors of the experiment for over pack defect was found using the S/N ratio response graph. The results were also statistically analyzed using ANOVA in Qualitek-4 to verify the actual significant factor and its level.

Table 8 : Main effect calculation for over pack (calculated manually)

AVERAGE							
Control factor	A	B	AB	C	AC	BC	D
Average of Level 1	0.685	0.15	4.53	0.3075	4.5175	4.7525	0.6875
Average of Level 2	4.525	5.06	0.68	4.9025	0.6925	0.4575	4.5225
Response (2-1)	3.84	4.91	-3.85	4.595	-3.825	-4.295	3.835
SIGNAL TO NOISE RATIOS							
Average of Level 1	18.65	37.87	12.46	35.4775	13.4875	27.9325	17.9625
Average of Level 2	12.63	-6.59	18.82	-4.1975	17.7925	3.3475	13.3175
Response (2-1)	-6.02	-44.46	6.36	-39.675	4.305	-24.585	-4.645

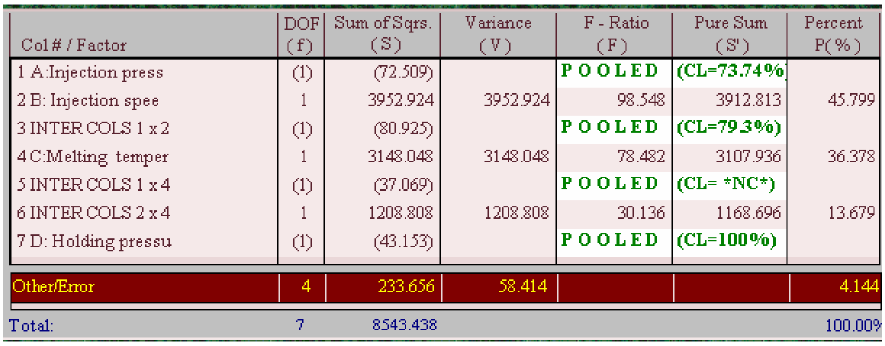
The ANOVA analysis for the over pack is carried out with a confidence level of 90% as given in Table 9. The pooling process was carried out since there are a few factors with the smallest percentage of influence (P %) having less than 1%. Taguchi recommends pooling factors until the error percentage is more than 2% [8]. Interaction AC is pooled as it has the smallest percentage of influence and followed by factor D (holding pressure), factor A (injection pressure) and interaction AB. These factors are not significant and were thus pooled as factor B (injection speed) is the most significant factor in this experiment since it contributes to the highest percentage of variation of 45.8%. This is followed by factor C (melting temperature) and interaction BC, which contribute 36.4% and 13.7% respectively. Since these factors contribute to the variation, Qualitek-4 is used in choosing optimum parameters setting. The remaining 4.1% of the variation refers to experimental error either due to control or uncontrollable factors not included in the study.

Table 9 : ANOVA table for over pack



Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 A:Injection press	1	72.509	72.509	-----	72.509	.848
2 B: Injection spee	1	3952.924	3952.924	-----	3952.924	46.268
3 INTER COLS 1 x 2	1	80.925	80.925	-----	80.925	.947
4 C:Melting temper	1	3148.048	3148.048	-----	3148.048	36.847
5 INTER COLS 1 x 4	1	37.069	37.069	-----	37.069	.433
6 INTER COLS 2 x 4	1	1208.808	1208.808	-----	1208.808	14.148
7 D: Holding pressu	1	43.153	43.153	-----	43.153	.505
Other/Error	0					
Total:	7	8543.438				100.00%

(i) Before pooling



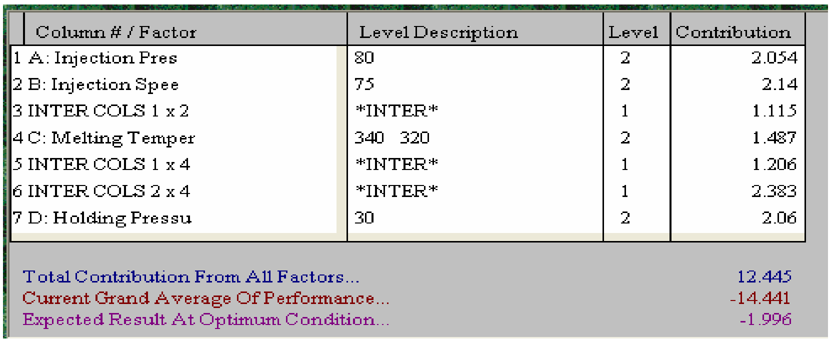
Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 A:Injection press	(1)	(72.509)		POOLED	(CL=73.74%	
2 B: Injection spee	1	3952.924	3952.924	98.548	3912.813	45.799
3 INTER COLS 1 x 2	(1)	(80.925)		POOLED	(CL=79.3%)	
4 C:Melting temper	1	3148.048	3148.048	78.482	3107.936	36.378
5 INTER COLS 1 x 4	(1)	(37.069)		POOLED	(CL= *NC*)	
6 INTER COLS 2 x 4	1	1208.808	1208.808	30.136	1168.696	13.679
7 D: Holding pressu	(1)	(43.153)		POOLED	(CL=100%)	
Other/Error	4	233.656	58.414			4.144
Total:	7	8543.438				100.00

(ii) After pooling

4.3 Optimum Setting

From the analysis, the optimum level of the control factors for machine parameter in both short mould and over pack problems have been determined and shown in Tables 10 and 11.

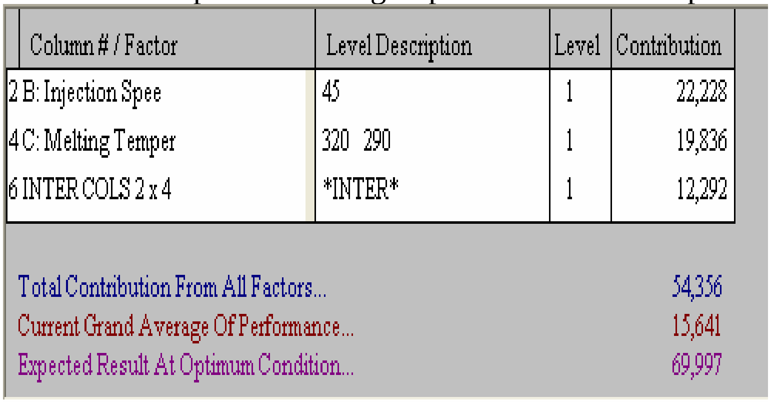
Table 10 : Optimum setting of parameters for short mould



Column # / Factor	Level Description	Level	Contribution
1 A: Injection Pres	80	2	2.054
2 B: Injection Spee	75	2	2.14
3 INTER COLS 1 x 2	*INTER*	1	1.115
4 C: Melting Temper	340 320	2	1.487
5 INTER COLS 1 x 4	*INTER*	1	1.206
6 INTER COLS 2 x 4	*INTER*	1	2.383
7 D: Holding Pressu	30	2	2.06

Total Contribution From All Factors... 12.445
Current Grand Average Of Performance... -14.441
Expected Result At Optimum Condition... -1.996

Table 11 : Optimum setting of parameters for over pack



Column # / Factor	Level Description	Level	Contribution
2 B: Injection Spee	45	1	22,228
4 C: Melting Temper	320 290	1	19,836
6 INTER COLS 2 x 4	*INTER*	1	12,292

Total Contribution From All Factors... 54,356
Current Grand Average Of Performance... 15,641
Expected Result At Optimum Condition... 69,997

As can be seen earlier from the above tables and ANOVA, the optimum process parameter setting for short mould and over pack are in opposite levels. However, setting for factor A and factor D in over pack can be set at level 2 since both factors are pooled factors which means the factors level are free to be set based on information such as cost and time consumption other than that recommended by the optimum condition.

The company has given certain restrictions of not allowing all process parameter settings at the low level. This is to avoid production being affected because they know that high level of all factors will bring to high percentage of over pack defect and low level of setting of all factors will cause high percentage of short mould defect. From Table 10 and in the ANOVA analysis, all the factors actually influenced the total variation of the experiment, so confirmation run for short mould was not allowed by the company. Furthermore, the company considers short mould as a type of rework defect. They consider that rework cost is lower than scrap. However, for scrap defect, the company is unable to do anything on the product. Thus, the concern of this company is to solve the over pack problem. Since factor A and factor D are pooled factors, the optimum process parameter setting for over pack would be as following :

Injection pressure	–	80 kg/cm^2 (high)
Injection speed	–	45% (low)
Melting temperature	–	320°C, 290°C (low)
Holding pressure	–	30 kg/cm^2 (high)

In Table 11, the current grand average of the S/N ratio is 15.641. Based on recommendation provided by Qualitek-4, the optimum S/N ratio should be 69.997. This value will be checked after the confirmation run is conducted.

A confirmation run was carried out to verify the optimum setting obtained from the analysis. Four replications of confirmation run were conducted. Table 12 shows the results of confirmation run and Table 13 shows the S/N ratios.

The percentage of error is calculated using the S/N ratio of expected result at optimum condition and the S/N ratio obtained from the confirmation run. The formula below is used to calculate the percentage error :

$$\%\text{ error}_{\text{over pack}} = \left| \frac{Expected\ result - Actual\ confirmation\ run\ result}{Expected\ result} \right| \text{x}100\%$$

$$= \left| \frac{(69.997) - (70)}{69.997} \right| \text{ x } 100\%$$

$$= 0\ \%$$

Table 12 : Total defects during confirmation run

Factor				**Sample**	**Count of Defects**	**Total Inspected**
A	B	C	D	1	0	191
				2	0	178
2	1	1	2	3	0	170
				4	0	181

Table 13 : The S/N ratios for confirmation run

Sample 1 (%)	**Sample 2 (%)**	**Sample 3 (%)**	**Sample 4 (%)**	**Average (%)**	**S/N Ratio**
0	0	0	0	0	70

5.0 CONCLUSIONS

Taguchi method is applied in the design of the experiment to investigate the quality problems in injection moulding process. For this experiment, four factors were studied to determine the optimal level parameter setting of injection moulding machine. Analysis using S/N ratio was carried out using Qualitek-4 on control factors and the interaction of the control factors. From the analysis, it has been determined that the optimal conditions for the control factors in the case of over pack problem are injection pressure of 80 kg/cm^2, injection speed of 45%, melting temperature of 320°C, 290°C and holding pressure of 30 kg/cm^2. These levels give the best setting with the smallest response due to noise or uncontrollable factors. When the confirmation run was conducted at this optimal condition, it achieved an S/N ratio of 70. The percentage of error of this experiment is approximately 0%.

From the results, it was suggested to the company that when setting the plastic injection moulding process, two significant factors to be considered are injection speed and melting temperature. They should be set at these optimal levels to reduce the over pack defects. Even though it shows zero percent of reject in the experiment, this does not mean there is no defect at all in the experiment. As there is no previous case study using Taguchi method in this company, it can be further reviewed by conducting additional studies in the future, including using conventional design of experiment methods.

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