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The Recognition of The Factors Effective on The Shrinkage of Parts Polyamide 6 Through Using Design of Experiments Method

Kazem Noghondarian, Ph.D
Assistant Professor, Iran University of Technology

Mani Sadraee
M.A. of Industrial Management, Islamic Azad University- Firoozkouh Branch

ABSTRACT

Paying more attention to quality, reduction of production waste, reduction of final cost of products and resisting in competitive market, fully clarifies the necessity for using the methods like "Design of Experiments". In this Method in put variable of process are defined and to achieve the determined quality Principles, the effect on response variable are studied while performing changes through input variables systematically using statistical methods. In this article, Design of Experiments has been used for accessing the rate of standard shrinkage of Parts Polyamide 6 and also reducing the waste of the products which are made of Polyamide 6 in Fardan Electric Company.

Introduction:

All the time, such those strategies will be accepted and considered that can increase the competitive specifications of the product in competitive market within the least period of time and through minimum possible cost. In a condition that the taste and demand of the customers change rapidly due to variety of products, rapid progress in production technology, full competitive markets; the producer should consider innovation and novelty through coordination, reducing waste, reducing the repetitions, reducing the final cost of the products, synchronically with the other competitors in the domain of new products. Improving the quality and time productivity can affect in a best way and that can be inseparable part of design, process development and product circle.

In the primary stages of development circle where the new product of design and the existed designed product are improved and the process of product optimized; using Design of Experiments Methods can specially be the secret of success for the product. These principles are used in many industries such as electronics and semiconductors, aerospace, automobile, medical equipments food industries, pharmaceutics and chemical industries.

Exactly using Statistical Design of Experiments Methods can facilitate the design and production processes. Also using these methods can promote levels of reliability and the improvement of the operation of the products. Design of Experiments Methods can considerably improve the design and product development and activities relevant to problem solving. In the modern world the producers inevitably modernize the used techniques in order to keep on their presence in the markets. Especially the control and quality improvement techniques are specifically important in this case. Design of Experiments Methods is also one of the quality improvement techniques which were proposed in the 1980-1990 decades as a competitive advantage in western countries and Japan, in a way that it was accepted as one of the necessities for QS 9000 Certificate.

Due to high thermal power of Polyamide 6 materials and its consistency to different environmental conditions the use of these kinds of material is very common in electric

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industries and most of the producers of the electrical goods use these kinds of primary materials in final products for making their pieces. Also, in electrical industry, like other industries one of the demanding and main domains of production is the suitable match of pieces and their desired appearance that has clearer effect on montage process, appearance of the final product and the satisfaction of the customer. It is tried in this article to recognize the input variable in plastic injection process through Design of Experiments Methods and study their effects on response variable which is the same as shrinkage percent of these kinds of pieces after plastic injection and determine an optimize compound for production with high quality and less waste. Since the molding units manufactured the molds in 1.5 percent shrinkage standard and deliver to production units, approaching to this number is very important and has determining effect in matching of pieces and their appearance and following it affects the amount of waste and repetitions during montage process of the final product.

Research performance:
First, through the cooperation of the engineers, quality control and production management team of Fardan Electric Company, the amount and type of the wastes of the company were studied through documents and records during the year 2009 existed in quality control unit and Pareto diagram was drawn for the discovered wastes –hg1.

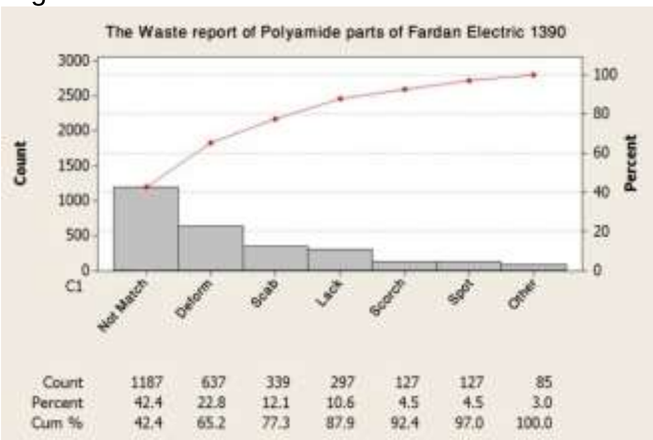

Figure1. The waste Pareto chart

After drawing Pareto diagram, the research team determined the reason of these wastes to be the inexactness during plastic inject process and after several sessions the factors that can affect plastic inject process of polyamide materials were recognized. These factors which have been shown in cause and effect diagram 2 include: type of consumed materials, injection pressure, injection descending temperature, time of injection, injection speed, time for cooling piece in the mold, operator's experience, operator's skill, the volume of piece and the size of the piece.

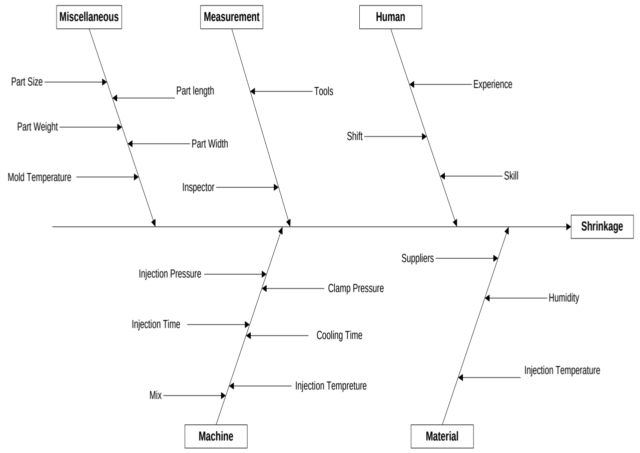

Figure2. Cause and effect Chart

After finding the mentioned reasons, through several brainstorming sessions at the presence of the mentioned teams, 4 factors were determined as the important and considerable factors in this research. The examined piece in this research is a 3-outlet socket which has a lid and a case made of polyamide materials and the researcher has performed separate defined experiments on these two pieces. The specifications of these pieces are based on the table 1.

Part Perimeter (mm)	Part Width (mm)	Part length (mm)	Part Name	Row
492	52	194	Lid 3	1
494	52.5	194.5	Case 3	2

Table1. Parts Specification

It is mentionable that after the performed studies it is specified that the study of these factors in 2 levels as the 2nd table is sufficient and can use two-level designs or 2^k of Experiments Design.

Row	Factor name	High level	Low level
A	Injection pressure (pascal)	75	70
B	Injection Tempreture (Celsius)	235	225
C	Injection time (Second)	6	4

D	Cooling time (Second)	20	10

Table2. Factors level

Regarding the 2nd table, for examining 4 two-level factors, 16 experiments were needed in a full factorial design, since the experiments were done in two pieces so 32 experiments were done on the whole. It is mentionable that two kinds of Italian and Thai materials were used in this research and as the consumed materials have more effect on the amount of shrinkage, they were considered in the form of block.
Meanwhile the following variables were specified as response variables:
Y_1: shrinkage percent of lid environment simple 3-outlet
Y_2: shrinkage percent of case environment simple 3-outlet
The shrinkage percent of the studied pieces is also calculated as follows:

$$\left(1-\frac{\text{part perimeter}}{\text{part perimeter in the mold}}\right)\times 100=\hat{Y_i}$$

The analysis of the measurement system
Regarding that dimensioning was done in data collection; first it was making sure about the Fardan Electric Company's Measurement System Operation. For this purpose, the analysis of the measurement system was done before starting the experiments.
In Fardan Electric Company there are 2 inspectors together with 2 calipers. It is mentionable that the inspectors have been trained about the necessary instructions in the case of dimensioning and methods of product control and they are competent in view point of quality control unit. Also, the calipers of this company have recently been calibrated. Regarding the table for the number and times of test repetition and regarding the number of inspectors and tools, the 10 samples in 2 times repetitions were considered in system measurement analysis. The calculation results of a tool which was done based on Minitab software has been shown in figure 3. Regarding the report of figure 3 it is concluded that the pieces have been sampled in an appropriate way from the company's production line and indicates the total statistical universe (part to part =99.8) the reproducibility and reduplication is less than 10 percent. Also, NDC (the disjunction capability of samples to different groups) is 31 that this number is more than 5 and on the whole the measurement system in suitable in the case of tool A.

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Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
part	9	0.62311	0.0692344	2010.03	0.000
oprator	1	0.00004	0.0000400	1.16	0.309
part * oprator	9	0.00031	0.0000344	0.98	0.482
Repeatability	20	0.00070	0.0000350		
Total	39	0.62416			

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
part	9	0.62311	0.0692344	1987.92	0.000
oprator	1	0.00004	0.0000400	1.15	0.293
Repeatability	29	0.00101	0.0000348		
Total	39	0.62416			

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.0000351	0.20
Repeatability	0.0000348	0.20
Reproducibility	0.0000003	0.00
oprator	0.0000003	0.00
Part-To-Part	0.0172999	99.80
Total Variation	0.0173350	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)
Total Gage R&R	0.005923	0.035540	4.50
Repeatability	0.005901	0.035409	4.48
Reproducibility	0.000509	0.003051	0.39
oprator	0.000509	0.003051	0.39
Part-To-Part	0.131529	0.789175	99.90
Total Variation	0.131662	0.789974	100.00

Number of Distinct Categories = 31

↓	C1-T	C2	C3	C4
	Subscripts	data	oprator	part
1	C1	8.10	1	1
2	C1	8.10	1	1
3	C2	7.69	1	2
4	C2	7.69	1	2
5	C3	7.68	1	3
6	C3	7.67	1	3
7	C4	7.69	1	4
8	C4	7.70	1	4
9	C5	7.70	1	5
10	C5	7.70	1	5
11	C6	7.70	1	6
12	C6	7.70	1	6
13	C7	7.69	1	7
14	C7	7.72	1	7
15	C8	7.66	1	8
16	C8	7.67	1	8
17	C9	7.68	1	9
18	C9	7.68	1	9
19	C10	7.70	1	10
20	C10	7.70	1	10
21	C1	8.10	2	1
22	C1	8.10	2	1
23	C2	7.69	2	2
24	C2	7.69	2	2
25	C3	7.67	2	3
26	C3	7.68	2	3
27	C4	7.69	2	4
28	C4	7.69	2	4
29	C5	7.70	2	5
30	C5	7.70	2	5
31	C6	7.70	2	6
32	C6	7.70	2	6
33	C7	7.72	2	7
34	C7	7.72	2	7
35	C8	7.66	2	8
36	C8	7.67	2	8
37	C9	7.68	2	9
38	C9	7.68	2	9
39	C10	7.70	2	10
40	C10	7.70	2	10

Figure3. Measurement system Analysis of Tool A

It is specified from the performed analysis in the case of tool B that the measurement system of tool B is also suitable and therefore on the whole the total measurement system of this company has been evaluated as accurate and the obtained results are reliable.

After performing system measurement analysis test and make sure about its operation, the matrix of experiment design for the two pieces, and under study 3-outlet which has been referred previously, was provided by Minitab 14 software (figure 4) that only the calculation relevant to 3-outlet has been referred in the following.

This table is a guide for performing the desired defined experiments in order to find the optimum point and the best matching of the pieces and the products using polyamide 6 materials. The experiments have been done respectively as mentioned in the figure 4 and regarding the desired levels for each factor on a special set which has standard conditions with injection volume of 250gr. For two-level designs,

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•	C1 BldOrder	C2 RunOrder	C3 CenterPt	C4 Blocks	C5 pressure	C6 Temprature	C7 time	C8 Cooling time	C9
1	1	1	1	1	75	225	4	10	
2	2	2	1	1	70	235	4	10	
3	3	3	1	1	70	225	6	10	
4	4	4	1	1	75	235	6	10	
5	5	5	1	1	70	225	4	20	
6	6	6	1	1	75	235	4	20	
7	7	7	1	1	75	225	6	20	
8	8	8	1	1	70	235	6	20	
9	9	9	1	2	70	225	4	10	
10	10	10	1	2	75	235	4	10	
11	11	11	1	2	75	225	6	10	
12	12	12	1	2	70	235	6	10	
13	13	13	1	2	75	225	4	20	
14	14	14	1	2	70	235	4	20	
15	15	15	1	2	70	225	6	20	
16	16	16	1	2	75	235	6	20	
17									

Figure4. Experiment plan matrix

The size of the required sample for finding changes in average with type 1 error□□□□□0.05 and □ = 0.05 were calculated through this formula:

Implementation = L

$1\delta < \Delta < 2\delta$

$$n = \frac{64}{L\Delta^2}$$

$\Delta = 1.1\ \delta$

$$n = \frac{64}{16 \times (1.1)^2} = 3.3 \approx 4$$

So, in each experiment 4 samples were studied and their average was used as response variable for the next analysis. After performing each experiment, the required measurement which was the measure of length and width of the produced pieces were done. Then the amount of shrinkage of the produced piece was calculated through formula for calculation of shrinkage and written in the relevant columns as shown in figure 5 for future analysis. It is mentionable that after four repetitions foe each experiment, the average of data was recorded as response variable for more examination.

•	C1 StdOrder	C2 RunOrder	C3 CenterPt	C4 Blocks	C5 A	C6 B	C7 C	C8 D	C9 Y1	C10 Y2	C11 Y3	C12 Y4	C13 Y
1	1	1	1	1	75	225	4	10	1.39	1.40	1.41	1.40	1.40
2	2	2	1	1	70	235	4	10	1.35	1.35	1.34	1.36	1.35
3	3	3	1	1	70	225	6	10	1.30	1.30	1.30	1.30	1.30
4	4	4	1	1	75	235	6	10	1.46	1.44	1.44	1.45	1.45
5	5	5	1	1	70	225	4	20	1.20	1.21	1.20	1.90	1.20
6	6	6	1	1	75	235	4	20	1.37	1.38	1.38	1.39	1.38
7	7	7	1	1	75	225	6	20	1.35	1.35	1.35	1.35	1.35
8	8	8	1	1	70	235	6	20	1.24	1.24	1.26	1.26	1.25
9	9	9	1	2	70	225	4	10	1.31	1.30	1.29	1.30	1.30
10	10	10	1	2	75	235	4	10	1.50	1.51	1.51	1.52	1.51
11	11	11	1	2	75	225	6	10	1.45	1.45	1.45	1.45	1.45
12	12	12	1	2	70	235	6	10	1.43	1.43	1.41	1.41	1.42
13	13	13	1	2	75	225	4	20	1.39	1.40	1.40	1.41	1.40
14	14	14	1	2	70	235	4	20	1.31	1.31	1.29	1.29	1.30
15	15	15	1	2	70	225	6	20	1.20	1.20	1.20	1.20	1.20
16	16	16	1	2	75	235	6	20	1.34	1.35	1.35	1.36	1.35

Figure5. Experiment data matrix

Analysis of obtained results:

Then the relevant calculations were done using Minitab 14 Software and the results of the figure 6 were concluded:

Factorial Fit: Y versus A, B, C, D

Estimated Effects and Coefficients for Y (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		1.35063	0.008353	161.70	0.000
A	0.12125	0.06062	0.008353	7.26	0.001
B	0.05125	0.02563	0.008353	3.07	0.028
C	-0.00875	-0.00437	0.008353	-0.52	0.623
D	-0.09375	-0.04687	0.008353	-5.61	0.002
A*B	-0.02875	-0.01438	0.008353	-1.72	0.146
A*C	-0.01375	-0.00687	0.008353	-0.82	0.448
A*D	0.01125	0.00563	0.008353	0.67	0.531
B*C	-0.00875	-0.00438	0.008353	-0.52	0.623
B*D	-0.01875	-0.00937	0.008353	-1.12	0.313
C*D	-0.02375	-0.01187	0.008353	-1.42	0.214

S = 0.0334103   R-Sq = 95.31%   R-Sq(adj) = 85.92%

Figure6. The Minitab reports

As it is specified through the report of Minitab for the factors A, B and D the P-value< 0.05 and this means that the effect of these factors on the plastic injection process of Polyamide 6 materials is important and it should be considered in shrinkage average prediction equation as follows:

The diagram of the main effects relevant to 3-outlet has been shown in figure 7.

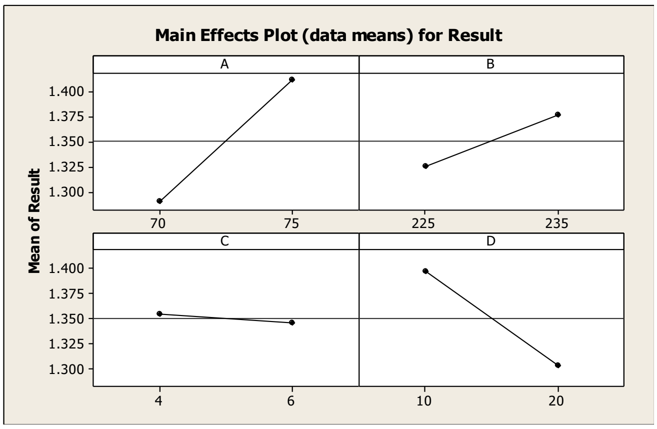

Figure7. The main effective chart

It is understood from this diagram that for obtaining 1.5 percent shrinkage the factors levels should be considered as follows:

A^+ B^+ C^- D^-

It is also done in a way similar to the calculations relevant to 3-outlet case that the final formula and determined levels of which are mentioned here.

$$\hat{Y}_i = 1.37 + 0.058A_i + 0.021B_i - 0.05D_i$$

A^+ B^+ C^- D^-

The study of the correctness of experiments results:

For examining the correctness of the presented model, through regulating factors in suggested levels, 5 samples of lid and case of another product of Fardan Electric Company was produced named 4-outlet and the shrinkage of each product was obtained. The obtained data were studied in order to achieve the 1.5 percent shrinkage average through a sample A T-student and the following result were obtained:

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	A	B	C	D	Y1	Y2	Y3	Y4	Y5	Y
1	75	235	4	10	1.49	1.49	1.5	1.5	1.49	1.494
2										

$\bar{X} = 1.494$

$S = 0.00548$

$H_0 = \mu = 1.5$

$H_1 = \mu \neq 1.5$

$\alpha = 0.05$

$T_{\text{critere}} = 0.025 , 4 = -2.776$

$$T = \frac{\bar{x} - \mu 0}{S/\sqrt{n}} = \frac{1.494 - 1.5}{0.00548 / \sqrt{5}} = -2.448 > -2.776$$

So, the zero hypotheses cannot be rejected.

The results obtained from regression equations are almost equal to the results obtained from the real experiments and indicates that the regression equations have been defined and determined correctly. Regarding the percent of the obtained shrinkages in two-pieces i.e. the case and 4-cell lid which are almost equal, it is concluded that the match of these two pieces are appropriate and exact. It is mentionable that none of the produced pieces has problem in appearance or quality and they are confirmable and usable in final product in view point of Fardan Electric Company's quality control unit.

Conclusion:

Regarding the performed calculations four important factors were recognized in plastic injection process of Polyamide 6 materials together with their appropriate levels so that the production unit produce pieces with defined shrinkage through determining the exact value of these levels and supply the montage unit with pieces and prevent the wastes and repetitions. Another important result of this research is the 60 percent reduction of the total wastes of polyamide pieces and increasing the level of certainty about plastic injection process.

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