CHAPTER IV

DESIGN OF EXPERIMENT (DOE)

This chapter will discuss about the selection of the type of design, factors, and levels to be studied. The result of the experiment will be analyzed by ANOVA, main effect plot and interaction plot for defining significant factors and their levels. These factor levels will be applied to the production process to confirm the result. The rework cost of each response will be calculated to see the improvement after implementation the new factor levels.

4.1 Design Selection

4.1.1 Factors and Levels

The following table is the list of the factors and levels that will be used in the experiment.

Table 4.1: Experimental Factors

Factors	Level	
	- 1	1
A = Pouring Height	10 cm	20 cm
B = No. of gates	1	3
C = Snow powder quantity	1	10
D = Solidification time	3 minutes	10 minutes
E = Aluminum Combination	(18,2)	(14,6)
F = Gate Size	2x4.5 cm	2x7 cm

4.1.2 Type of Design

This experiment has six factors and three responses. The experiment focuses on two products' part, which are chair's front leg and chair's back leg. Since this experiment has 6 factors, 64 full factorial runs are required to conduct the experiment. However the team has designed to run the experiment one-half fraction (2^{6-1} design) with 4 samples size of 4 legs for each run because the cost to conduct the experiment and time consumption is high *Table 4.2* shows the factor levels in each run for calculating the responses.

Table 4.2: Factors level for Calculating Responses

Standard No.	Run No.	A	B	C	D	E	F = ABCDE
1	12	-	-	-	-	-	-
2	16	+	-	-	-	-	+
3	7	-	+	-	-	-	+
4	5	+	+	-	-	-	-
5	8	-	-	+	-	-	+
6	13	+	-	+	-	-	-
7	11	-	+	+	-	-	-
8	3	+	+	+	-	-	+
9	4	-	-	-	+	-	+
10	10	+	-	-	+	-	-
11	1	-	+	-	+	-	-
12	9	+	+	-	+	-	+
13	15	-	-	+	+	-	-
14	6	+	-	+	+	-	+

(continued)

Standard No.	Run No.	A	B	C	D	E	F = ABCDE
15	14	-	+	+	+	-	+
16	2	+	+	+	+	-	-
17	17	-	-	-	-	+	+
18	25	+	-	-	-	+	-
19	21	-	+	-	-	+	-
20	32	+	+	-	-	+	+
21	19	-	-	+	-	+	-
22	22	+	-	+	-	+	+
23	24	-	+	+	-	+	+
24	18	+	+	+	-	+	-
25	28	-	-	-	+	+	-
26	20	+	-	-	+	+	+
27	26	-	+	-	+	+	+
28	23	+	+	-	+	+	-
29	27	-	-	+	+	+	+
30	29	+	-	+	+	+	-
31	31	-	+	+	+	+	-
32	30	+	+	+	+	+	+

4.2.1.1 Confounding pattern

Since this experiment has been designed to be one-half fraction or 2^{6-1} design, the generator of this fraction is **F = ABCDE**, therefore the defining relation is **I = ABCDEF**. Each main effect is aliased with a single 5-factor interaction, and each 2-factor interaction is aliased with a single 4-factor interaction as shown in *Table 4.3.* The design is of resolution VI

Table 4.3: Alias structure for the 2^{6-1}_{VI} ***Design with I = ABCDEF***

i	Effects	*i*	Effects	*i*	Effects	*i*	Effects
A	A = BCDEF	AB	AB = CDEF	BC	BC = ADEF	CE	CE = ABDF
B	B = ACDEF	AC	AC = BDEF	BD	BD = ACEF	CF	CF = ABDE
C	C = ABDEF	AD	AD = BCEF	BE	BE = ACDF	DE	DE = ABCF
D	D = ABCEF	AE	AE = BCDF	BF	BF = ACDE	DF	DF = ABCF
E	E = ABCDF	AF	AF = BCDE	CD	CD = ABEF	EF	EF = ABCD
F	F = ABCDE						

4.2 Results

The following *Table 4.4 and Table 4.5* are shown the number of defects found in each of the four sampled pieces of Front leg and Back leg.

Table 4.4 Responses of the Experiment on Front Leg

Standard No.	Run No.	A	B	C	D	E	F = ABCDE	Metallic projection					Cavities					Defective Surface				
								1	2	3	4	Sum	1	2	3	4	Sum	1	2	3	4	Sum
1	12	-	-	-	-	-	-	0	1	0	0	1	3	2	2	1	8	2	2	2	2	8
2	16	+	-	-	-	-	+	0	2	1	0	3	0	2	5	3	10	1	3	2	2	8
3	7	-	+	-	-	-	+	0	0	1	0	1	3	2	2	4	11	1	3	1	3	8
4	5	+	+	-	-	-	-	0	0	1	0	1	0	1	0	3	4	3	3	2	3	11
5	8	-	-	+	-	-	+	0	0	1	1	2	0	0	2	2	4	2	2	2	3	9
6	13	+	-	+	-	-	-	0	0	0	0	0	0	0	0	0	0	4	4	4	4	16
7	11	-	+	+	-	-	-	0	0	0	0	0	0	0	1	2	3	4	4	4	4	16
8	3	+	+	+	-	-	+	0	1	0	0	1	2	1	2	2	7	4	4	4	4	16
9	4	-	-	-	+	-	+	0	1	0	1	2	2	1	2	2	7	2	2	1	1	6
10	10	+	-	-	+	-	-	0	0	0	1	1	2	1	2	2	7	1	1	1	2	5
11	1	-	+	-	+	-	-	0	1	0	0	1	3	4	4	1	12	3	2	2	2	9
12	9	+	+	-	+	-	+	0	0	0	0	0	2	1	0	2	5	3	3	2	2	10
13	15	-	-	+	+	-	-	0	3	0	0	3	0	0	1	1	2	3	4	3	3	13
14	6	+	-	+	+	-	+	0	1	0	1	2	3	4	2	3	12	3	3	3	3	12
15	14	-	+	+	+	-	+	0	0	1	2	3	0	1	2	1	4	3	3	3	3	12
16	2	+	+	+	+	-	-	0	0	0	0	0	4	0	1	2	7	4	3	4	4	15
17	17	-	-	-	-	+	+	2	1	1	0	4	4	5	4	2	15	4	3	4	4	15
18	25	+	-	-	-	+	-	2	1	1	0	4	1	2	0	2	5	4	4	4	4	16
19	21	-	+	-	-	+	-	2	0	0	0	2	2	2	1	2	7	4	3	3	4	14
20	32	+	+	-	-	+	+	1	0	2	0	3	3	4	1	3	11	2	3	3	3	11
21	19	-	-	+	-	+	-	0	1	2	0	3	1	3	4	2	10	4	4	4	3	15
22	22	+	-	+	-	+	+	0	1	1	1	3	2	2	5	7	16	3	3	4	4	14
23	24	-	+	+	-	+	+	0	0	0	0	0	0	3	2	0	5	4	3	4	3	14
24	18	+	+	+	-	+	-	2	1	1	2	6	6	8	4	3	21	4	4	4	4	16
25	28	-	-	-	+	+	-	1	2	0	1	4	2	3	2	2	9	3	3	3	4	13
26	20	+	-	-	+	+	+	1	0	1	1	3	1	4	2	2	9	3	3	3	3	12
27	26	-	+	-	+	+	+	1	0	1	1	3	2	3	3	2	10	3	4	4	4	15
28	23	+	+	-	+	+	-	2	2	0	2	6	2	3	4	3	12	3	4	3	3	13
29	27	-	-	+	+	+	+	1	0	1	2	4	0	0	2	2	4	4	4	4	2	14
30	29	+	-	+	+	+	-	2	1	0	1	4	3	3	4	0	10	4	4	3	3	14
31	31	-	+	+	+	+	-	1	1	2	1	5	3	5	1	2	11	3	3	3	2	11
32	30	+	+	+	+	+	+	1	1	0	2	4	4	2	2	4	12	2	3	3	2	10

Remark: A = Pouring Height, B = No. of Gates, C = Snow powder quantity, D = Solidification time, E = Aluminum Combination, and F = Gate size

Table 4.5 Responses of the Experiment on Back Leg

Standard No.	Run No.	A	B	C	D	E	F = ABCDE	Metallic projection					Cavities					Defective Surface				
								1	2	3	4	Sum	1	2	3	4	Sum	1	2	3	4	Sum
1	12	-	-	-	-	-	-	0	0	1	0	1	0	2	4	0	6	2	2	2	2	8
2	16	+	-	-	-	-	+	2	1	0	0	3	0	0	1	1	2	1	3	2	2	8
3	7	-	+	-	-	-	+	0	0	1	0	1	1	2	0	3	6	1	3	1	3	8
4	5	+	+	-	-	-	-	0	0	0	1	1	0	0	1	3	4	2	3	2	3	10
5	8	-	-	+	-	-	+	0	1	1	1	3	1	1	1	1	4	2	2	3	2	9
6	13	+	-	+	-	-	-	0	0	0	1	1	0	0	0	0	0	4	4	4	4	16
7	11	-	+	+	-	-	-	0	2	1	0	3	1	2	0	0	3	4	4	4	4	16
8	3	+	+	+	-	-	+	1	2	1	0	4	6	1	4	1	12	4	4	4	4	16
9	4	-	-	-	+	-	+	0	0	1	0	1	1	2	1	2	6	1	1	1	1	4
10	10	+	-	-	+	-	-	0	0	0	0	0	1	1	1	1	4	1	1	1	2	5
11	1	-	+	-	+	-	-	1	0	1	0	2	2	1	0	4	7	3	2	2	3	10
12	9	+	+	-	+	-	+	1	1	0	0	2	0	0	0	2	2	2	3	2	2	9
13	15	-	-	+	+	-	-	0	0	0	0	0	2	1	3	1	7	3	4	3	3	13
14	6	+	-	+	+	-	+	1	0	1	0	2	1	1	3	3	8	3	3	3	3	12
15	14	-	+	+	+	-	+	0	0	1	2	3	2	1	2	3	8	2	3	3	3	11
16	2	+	+	+	+	-	-	0	0	0	0	0	0	2	2	0	4	4	3	4	4	15
17	17	-	-	-	-	+	+	1	0	0	1	2	2	0	2	1	5	4	3	4	3	14
18	25	+	-	-	-	+	-	0	0	0	0	0	0	1	2	5	8	4	4	4	4	16
19	21	-	+	-	-	+	-	1	0	1	0	2	2	3	2	5	12	4	3	3	3	13
20	32	+	+	-	-	+	+	2	0	2	1	5	2	8	3	8	21	3	3	3	3	12
21	19	-	-	+	-	+	-	0	1	0	2	3	2	2	3	2	9	4	3	4	3	14
22	22	+	-	+	-	+	+	1	0	0	0	1	0	0	1	2	3	4	3	3	3	13
23	24	-	+	+	-	+	+	0	0	1	1	2	2	0	2	3	7	4	3	3	3	13
24	18	+	+	+	-	+	-	2	2	1	1	6	5	4	5	4	18	4	4	4	4	16
25	28	-	-	-	+	+	-	0	1	2	0	3	2	1	2	4	9	3	4	3	4	14
26	20	+	-	-	+	+	+	0	1	0	1	2	2	1	0	3	6	3	3	3	3	12
27	26	-	+	-	+	+	+	2	0	0	1	3	0	5	2	1	8	3	3	3	3	12
28	23	+	+	-	+	+	-	1	2	2	0	5	5	4	8	3	20	3	4	4	3	14
29	27	-	-	+	+	+	+	1	0	1	1	3	0	3	1	2	6	4	4	3	4	15
30	29	+	-	+	+	+	-	2	0	1	0	3	5	2	8	1	16	4	4	4	4	16
31	31	-	+	+	+	+	-	2	0	2	0	4	3	2	4	2	11	3	3	3	2	11
32	30	+	+	+	+	+	+	0	1	0	1	2	2	2	3	1	8	2	3	3	2	10

Remark: A = Pouring Height, B = No. of Gates, C = Snow powder quantity, D = Solidification time, E = Aluminum Combination, and F = Gate size

4.3 Analysis of results

4.3.1 Analysis methodology

There are three steps to analyze the experiment. The first step is using ANOVA to test the significant factors. The second step is using Main effect plot and Interaction plot to tell which level of factor will reduce the response. Lastly, Test assumption of ANOVA by Residual Analysis, before making a conclusion. Three assumptions are

1) Errors are normally distributed.
2) Errors have a constant variance (σ_e^2)
3) Errors are statistically independent.

A check of the normality assumption could be made by plotting a histogram of the residuals. If the assumption on the errors is satisfied, the plot should appear straight.

The second assumption can be easily checked by the plot the Residuals Versus the Fitted Values. If the plot does not reveal any obvious pattern or structureless, the assumption is satisfied.

The last assumption can be checked by the plot the Residuals Versus the Order of the Data. If the structure of the plot is structureless or does not reveal any obvious pattern, the errors are independent.

Before starting the experiment Metallic projection and Cavities the data are needed to be transferred by using Square-root transformation since the data nature has Poisson distribution.

4.3.2 Response Analysis

4.3.2.1 Response: Metallic Projection

According to the data analyzed by MiniTab, there is one main effect that significantly affect on both legs as shown in *Table 4.6, Table 4.7, Figure 4.1, Figure 4.2, Figure 4.3, and Figure 4.4.*. The P-value for Factor E (Aluminum Combination) on both legs less than a significance level of 0.05. Refer to *Figure 4.5* and *Figure 4.6*, the effect of aluminum combination (E) at Level -1 reduce the response in front leg by 2.31 defects per 4 pieces and it reduce the response for back leg by 1.19 defects per 4 pieces.

There is one interaction effect for response metallic projection, which is interaction between E (Aluminum Combination) and F (gate size) of front leg since it has P-value less than significance level of 0.05 as shown in *Table 4.5*. The combination of a gate size of 2x4.5 cm and an Aluminum combination of (18,2) yields the lowest defect rate.

Therefore, in order to reduce the Metallic Projection in chair's leg the aluminum combination is solid 18 bars and resilient 2 bars and the gate size is 2x4.5 cm.

Table 4.6: Metallic Projection's ANOVA for Front Leg

Factorial Fit: Metallic Projection versus A, B, C, D, E, F

Estimated Effects and Coefficients for Metallic Projection (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		2.4688	0.1921	12.85	0.000
A	0.1875	0.0938	0.1921	0.49	0.636
B	-0.4375	-0.2187	0.1921	-1.14	0.281
C	0.0625	0.0312	0.1921	0.16	0.874
D	0.6875	0.3437	0.1921	1.79	0.104
E	2.3125	1.1563	0.1921	6.02	0.000
F	-0.1875	-0.0938	0.1921	-0.49	0.636
A*B	0.5625	0.2813	0.1921	1.46	0.174
A*C	-0.1875	-0.0937	0.1921	-0.49	0.636
A*D	-0.8125	-0.4062	0.1921	-2.11	0.061
A*E	0.8125	0.4063	0.1921	2.11	0.061
A*F	-0.1875	-0.0938	0.1921	-0.49	0.636
B*C	0.1875	0.0938	0.1921	0.49	0.636
B*D	0.3125	0.1563	0.1921	0.81	0.435
B*E	0.4375	0.2188	0.1921	1.14	0.281
B*F	-0.5625	-0.2812	0.1921	-1.46	0.174
C*D	0.5625	0.2813	0.1921	1.46	0.174
C*E	-0.0625	-0.0312	0.1921	-0.16	0.874
C*F	-0.0625	-0.0313	0.1921	-0.16	0.874
D*E	0.3125	0.1563	0.1921	0.81	0.435
D*F	-0.1875	-0.0938	0.1921	-0.49	0.636
E*F	-1.0625	-0.5313	0.1921	-2.77	0.020

S = 1.08685 R-Sq = 87.16% R-Sq(adj) = 60.18%

Analysis of Variance for Metallic Projection (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	48.69	48.69	8.115	6.87	0.004
2-Way Interactions	15	31.47	31.47	2.098	1.78	0.181
Residual Error	10	11.81	11.81	1.181		
Total	31	91.97				

Table 4.7: Metallic Projection's ANOVA for Back Leg

Factorial Fit: Metallic Projection versus A, B, C, D, E, F

Estimated Effects and Coefficients for Metallic Projection (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		2.2813	0.2596	8.79	0.000
A	0.0625	0.0312	0.2596	0.12	0.907
B	1.0625	0.5312	0.2596	2.05	0.068
C	0.4375	0.2188	0.2596	0.84	0.419
D	-0.1875	-0.0937	0.2596	-0.36	0.725
E	1.1875	0.5938	0.2596	2.29	0.045
F	0.3125	0.1563	0.2596	0.60	0.561
A*B	0.5625	0.2813	0.2596	1.08	0.304
A*C	-0.3125	-0.1562	0.2596	-0.60	0.561
A*D	-0.4375	-0.2187	0.2596	-0.84	0.419
A*E	0.1875	0.0938	0.2596	0.36	0.725
A*F	0.3125	0.1563	0.2596	0.60	0.561
B*C	-0.0625	-0.0313	0.2596	-0.12	0.907
B*D	-0.1875	-0.0937	0.2596	-0.36	0.725
B*E	0.4375	0.2188	0.2596	0.84	0.419
B*F	-0.4375	-0.2187	0.2596	-0.84	0.419
C*D	-0.5625	-0.2812	0.2596	-1.08	0.304
C*E	-0.1875	-0.0938	0.2596	-0.36	0.725
C*F	-0.3125	-0.1563	0.2596	-0.60	0.561
D*E	0.6875	0.3437	0.2596	1.32	0.215
D*F	-0.1875	-0.0938	0.2596	-0.36	0.725
E*F	-1.0625	-0.5313	0.2596	-2.05	0.068

S = 1.46842 R-Sq = 69.40% R-Sq(adj) = 5.14%

Analysis of Variance for Metallic Projection (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	22.94	22.94	3.823	1.77	0.202
2-Way Interactions	15	25.97	25.97	1.731	0.80	0.661
Residual Error	10	21.56	21.56	2.156		
Total	31	70.47				

The analysis is confirmed by Normal Probability plot of the standardized effects and Pareto Chart.

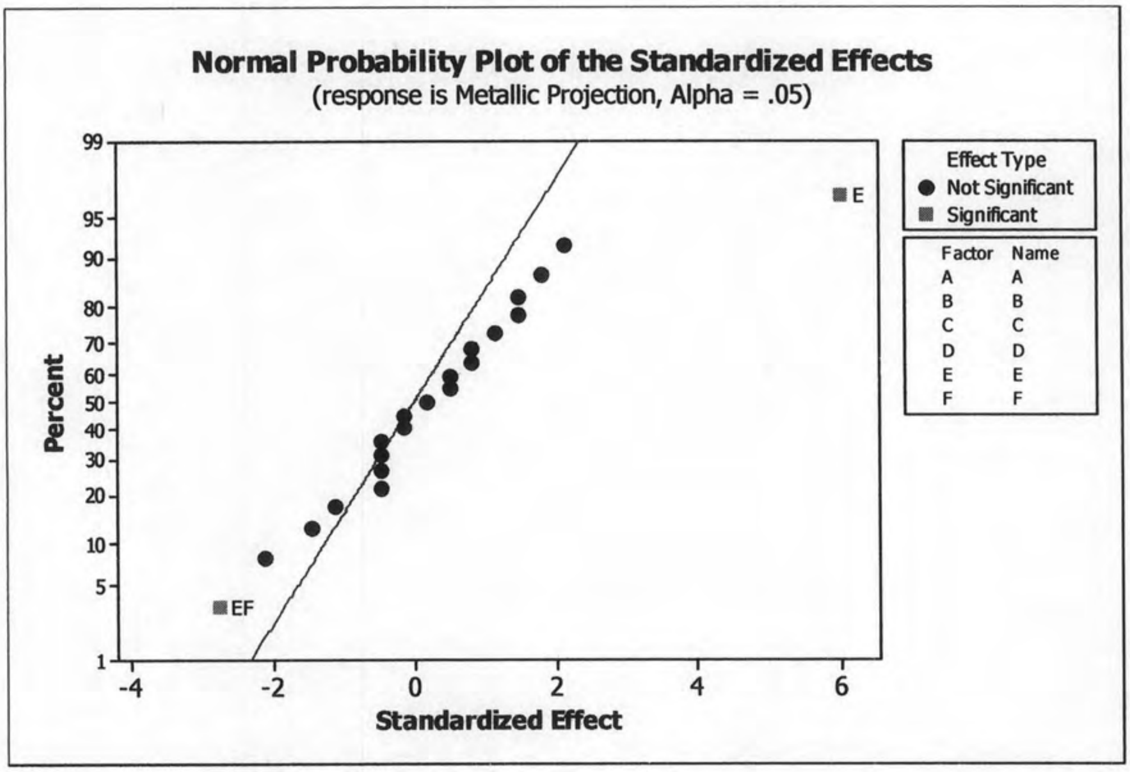

Figure 4.1: Metallic Projection's Normal Probability Plot for Front Leg

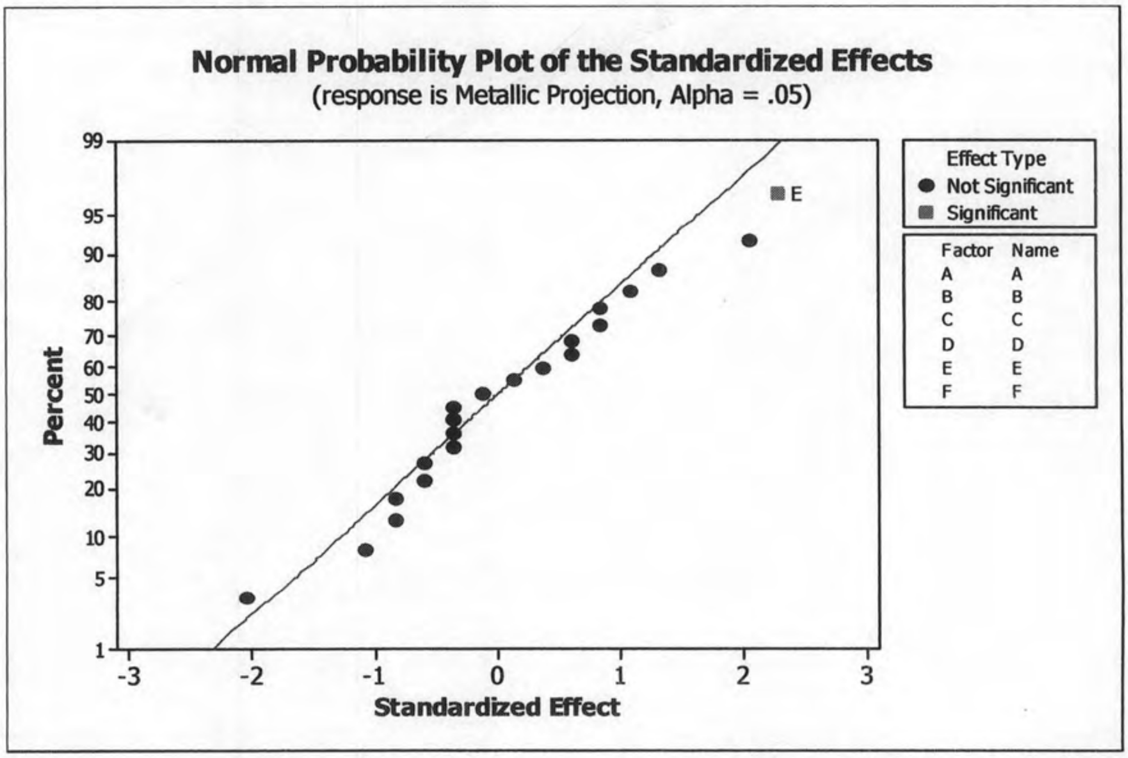

Figure 4.2: Metallic Projection's Normal Probability Plot For Back Leg

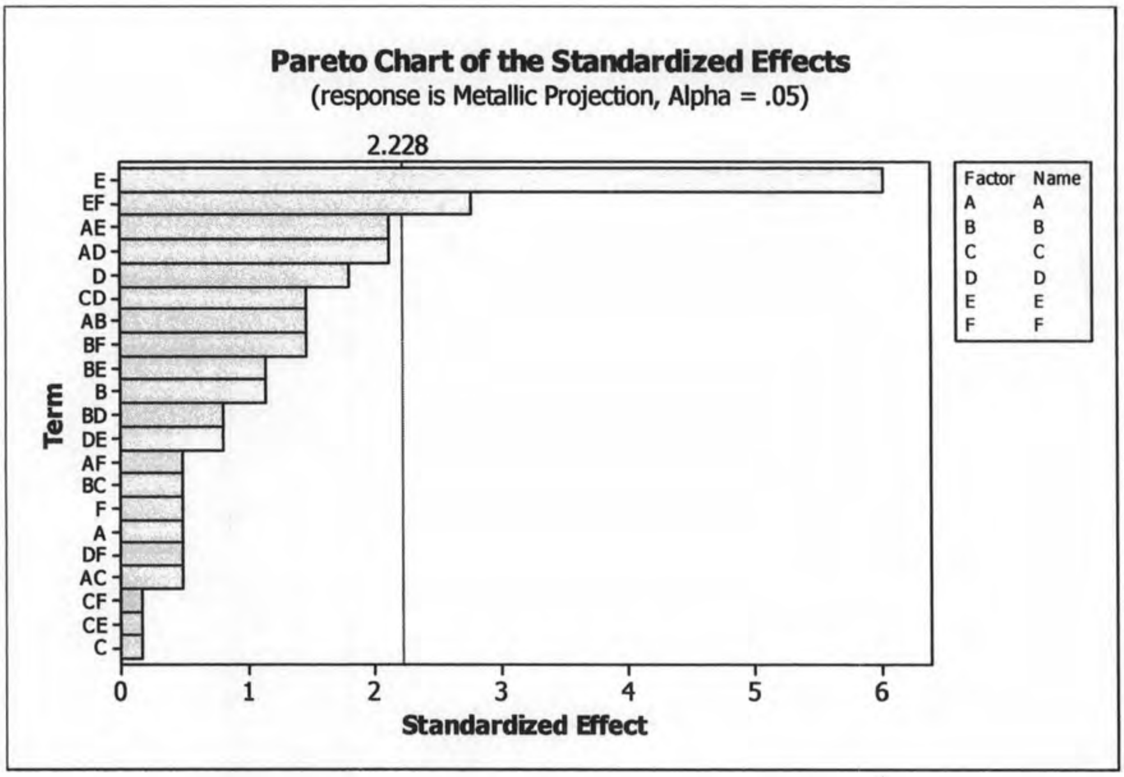

Figure 4.3: Metallic Projection's Pareto Chart for Front Leg

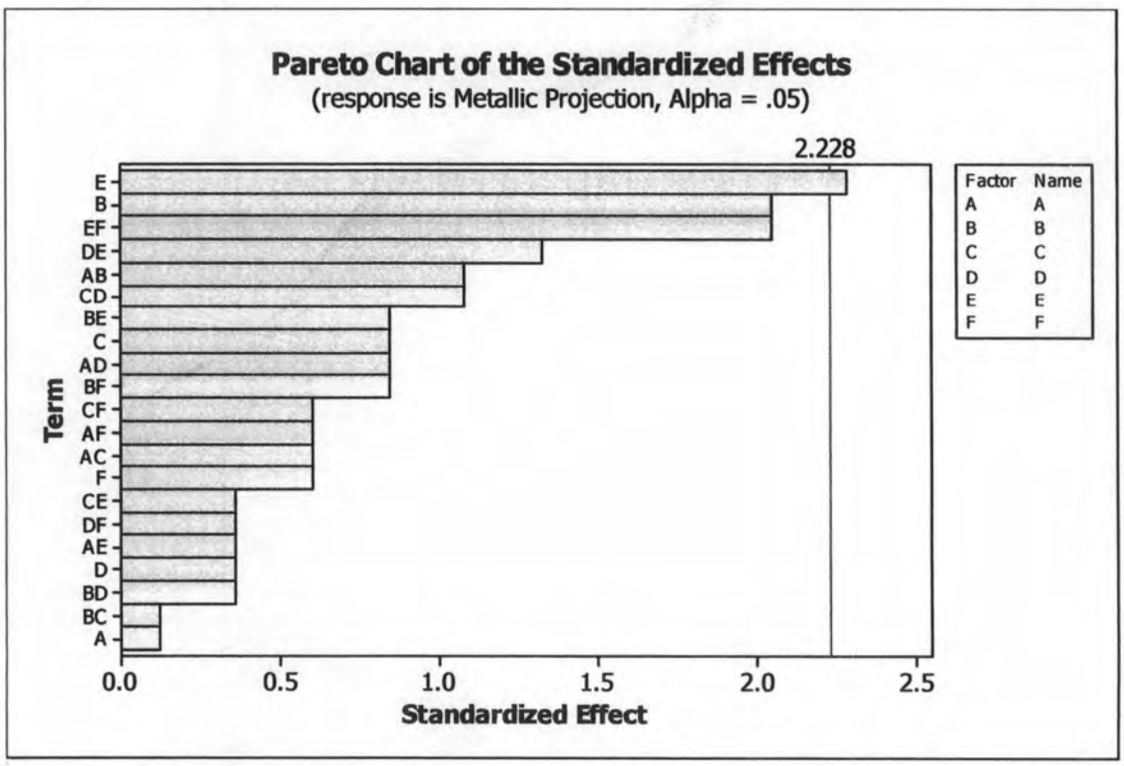

Figure 4.4: Metallic Projection's Pareto Chart for Back Leg

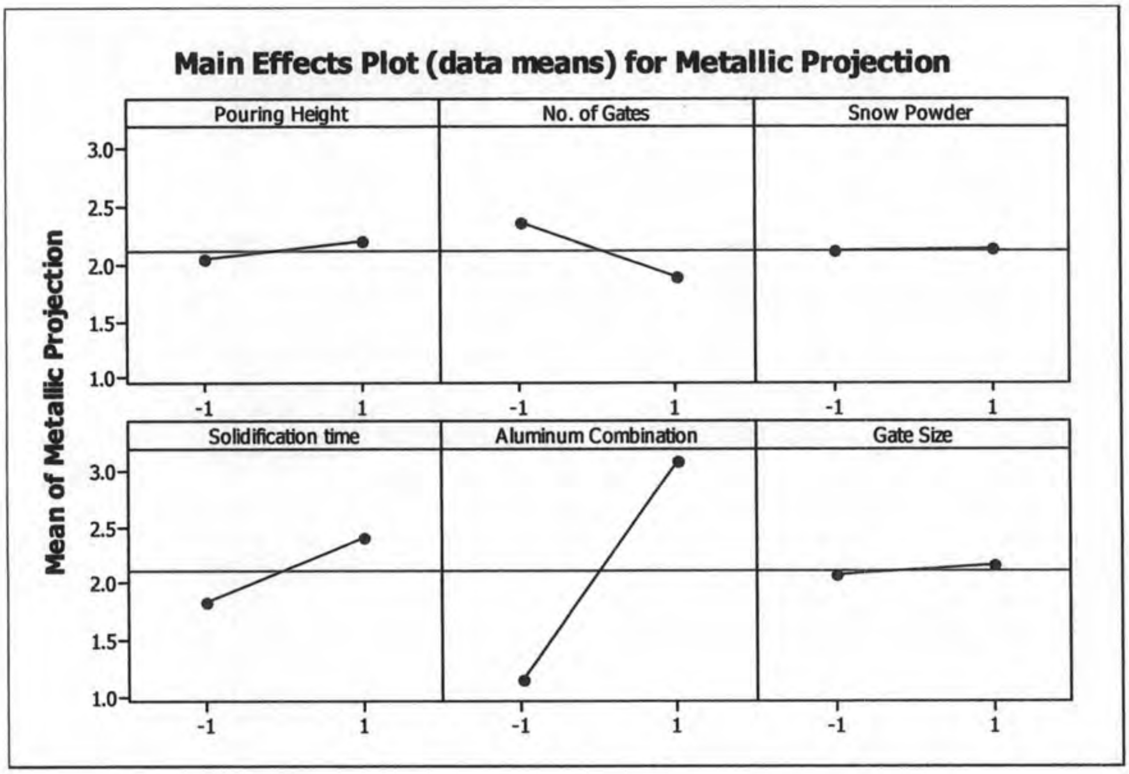

Figure 4.5: Metallic Projection's Main Effects Plot for Front Leg

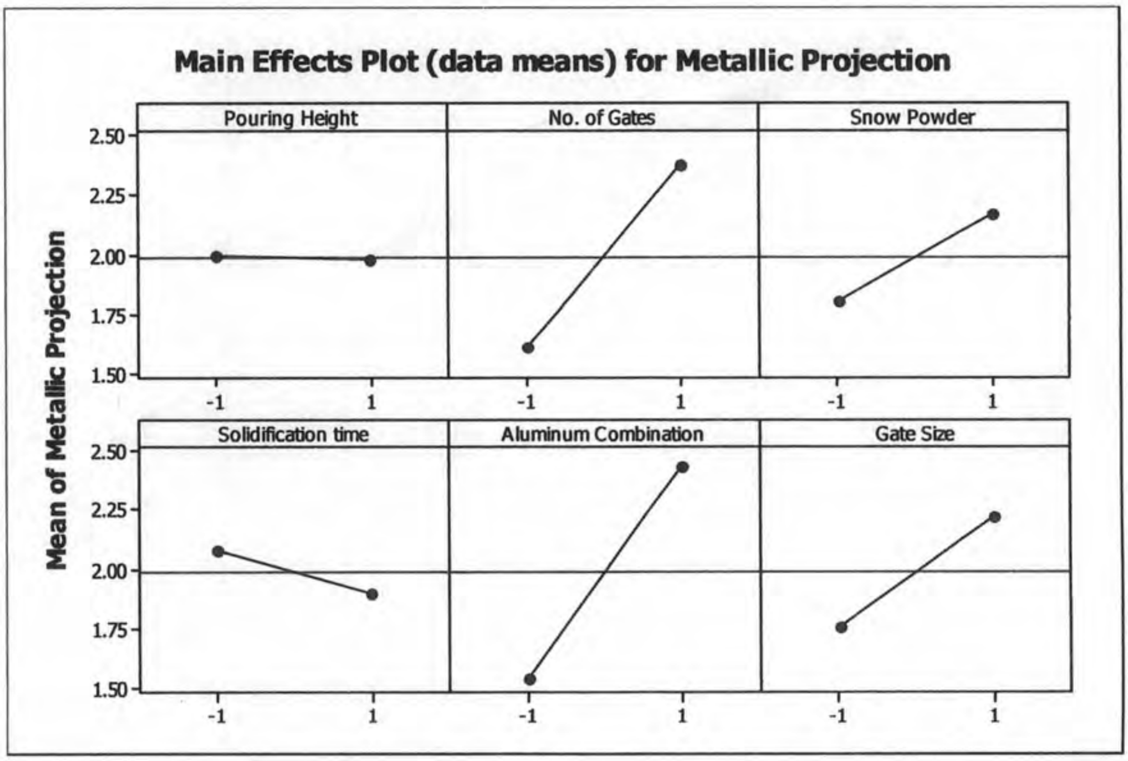

Figure 4.6: Metallic Projection's Main Effects Plot for Back Leg

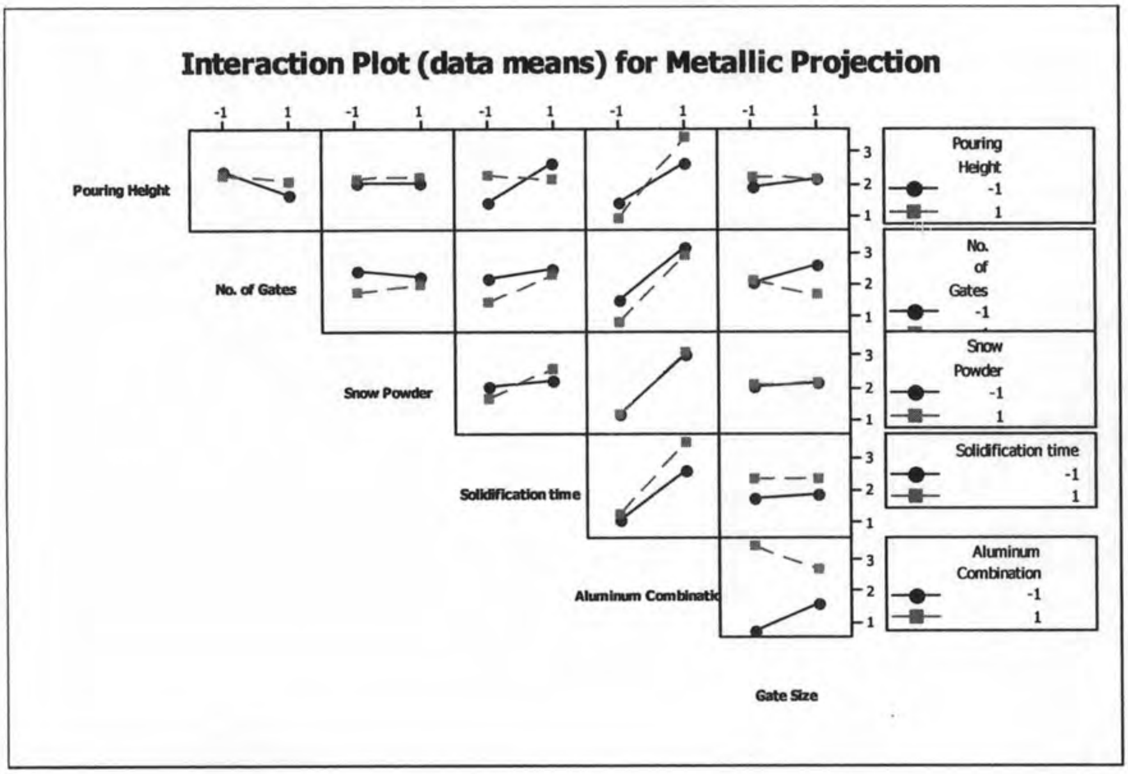

Figure 4.7: Metallic Projection's Interaction Plot for Front Leg

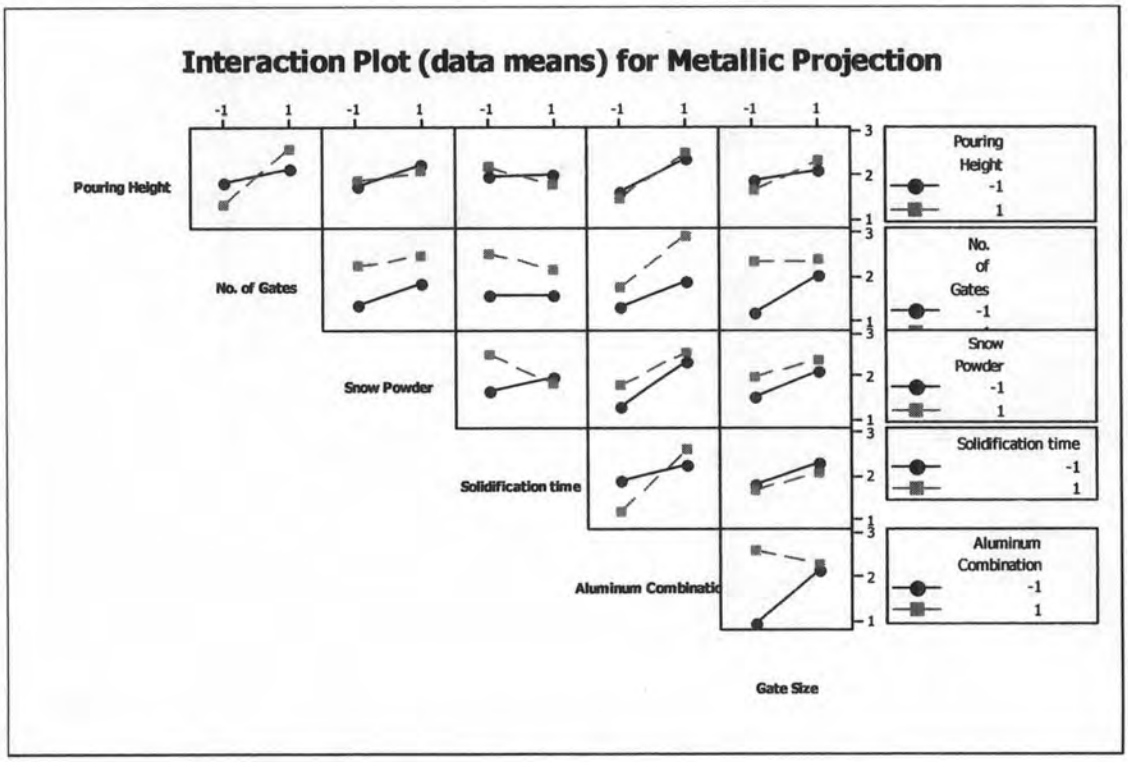

Figure 4.8: Metallic Projection's Interaction Plot for Back Leg

Residual Analysis

The normal probability plot of Metallic projection for front leg and back leg (*Figure 4.9 and 4.10*) do not reveal anything particularly troublesome; since the normal probability plots for both legs are formed resemble a straight line as shown in *Figure 4.9 and 4.10*.

The Residuals Versus the Fitted Values Plot for front leg and back leg shown in *Figure 4.9 and 4.10* respectively. The patterns of both plots are structureless, so it means the errors have a constant variance.

The Residuals Versus the Order of the Data plot of Metallic projection for front leg back leg shown in *Figure 4.9 and 4.10* respectively. Both Plots do not show obvious pattern, therefore the error are statistically independent.

In conclusion, this ANOVA has satisfied all the assumptions, therefore this model is adequate.

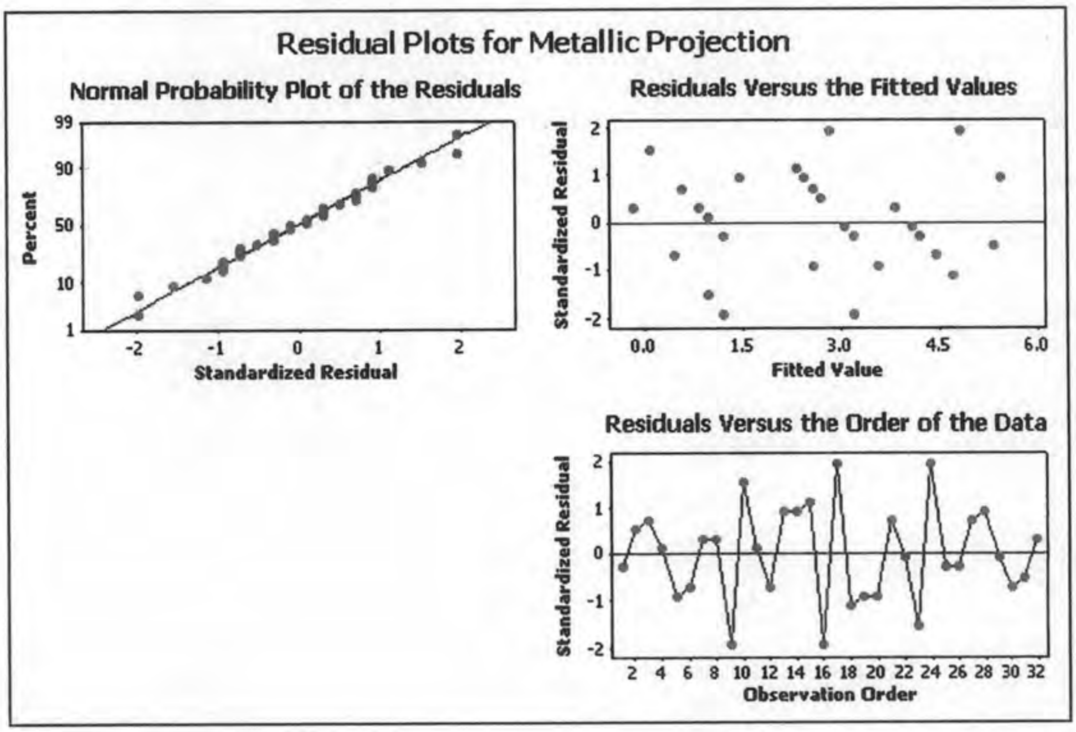

Figure 4.9: Metallic Projection's Residual Plots for Front leg

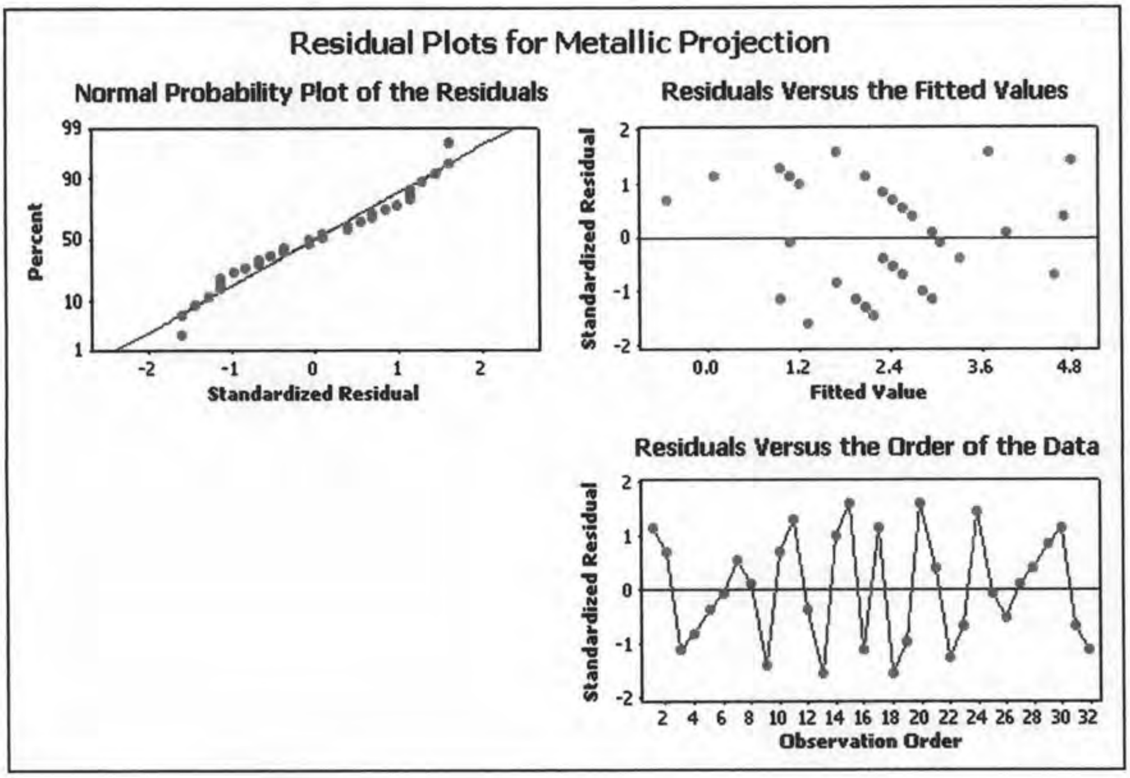

Figure 4.10: Metallic Projection's Residual Plots for Back leg

4.3.2.2 Response: Cavities

In the case of Cavities, there are two main factors effects and two interaction effects that significantly influence the response as shown in *Table 4.8, Table 4.9, Figure 4.11, Figure 4.12, Figure 4.13, and Figure 4.14,* the P-value for No. of Gates (B), Aluminum Combination (E), Interaction between Pouring Height (A) and Snow powder quantity (C), and Interaction between E and F (gate size) less than a significance level of 0.05.

Refer to *Figure 4.15*, the main effect of aluminum combination (E) at level -1 reduces the cavities in front leg by 4 defects per 4 pieces (according from *Table 4.7*). The effect of number of gates (B) at level -1 reduces the cavities in back leg by 3.25 defects per 4 pieces (according from *Table 4.8*)

According from *Figure 4.17,* the Effect of Pouring Height (A) and Snow powder quantity (C) at -1 level and -1 level respectively will reduce the cavities in front leg. Refer to *Figure 4.18*, the Effect of Aluminum Combination (E) and Gate Size (F) at level -1 and level -1 respectively reduce the cavities in back leg.

Therefore, in order to reduce the cavities in chair's leg the pouring height (A) should be 10 cm, number of gate (B) in the mold is 1, the snow powder quantity (C) that spatters in the mold is about 10 grams, the aluminum combination (E) is solid 18 bars and resilient 2 bars, and gate size (F) is 2x4.5 cm.

Table 4.8: Cavities' ANOVA for Front Leg

Factorial Fit: Cavities versus A, B, C, D, E, F

Estimated Effects and Coefficients for Cavities (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		8.438	0.6824	12.37	0.000
A	1.625	0.813	0.6824	1.19	0.261
B	0.875	0.438	0.6824	0.64	0.536
C	-0.875	-0.437	0.6824	-0.64	0.536
D	-0.250	-0.125	0.6824	-0.18	0.858
E	4.000	2.000	0.6824	2.93	0.015
F	0.875	0.438	0.6824	0.64	0.536
A*B	0.375	0.187	0.6824	0.27	0.789
A*C	3.625	1.813	0.6824	2.66	0.024
A*D	0.250	0.125	0.6824	0.18	0.858
A*E	1.500	0.750	0.6824	1.10	0.297
A*F	1.125	0.563	0.6824	0.82	0.429
B*C	0.625	0.313	0.6824	0.46	0.657
B*D	0.750	0.375	0.6824	0.55	0.595
B*E	0.500	0.250	0.6824	0.37	0.722
B*F	-2.375	-1.187	0.6824	-1.74	0.112
C*D	-0.250	-0.125	0.6824	-0.18	0.858
C*E	2.250	1.125	0.6824	1.65	0.130
C*F	-0.875	-0.438	0.6824	-0.64	0.536
D*E	-1.375	-0.688	0.6824	-1.01	0.337
D*F	-1.750	-0.875	0.6824	-1.28	0.229
E*F	-1.250	-0.625	0.6824	-0.92	0.381

S = 3.86005   R-Sq = 75.41%   R-Sq(adj) = 23.76%

Analysis of Variance for Cavities (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	168.0	168.0	28.00	1.88	0.180
2-Way Interactions	15	288.9	288.9	19.26	1.29	0.347
Residual Error	10	149.0	149.0	14.90		
Total	31	605.9				

Table 4.9: Cavities' ANOVA for Back Leg

Factorial Fit: Cavities versus A, B, C, D, E, F

Estimated Effects and Coefficients for Cavities (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		7.813	0.6483	12.05	0.000
A	1.375	0.688	0.6483	1.06	0.314
B	3.250	1.625	0.6483	2.51	0.031
C	-0.125	-0.062	0.6483	-0.10	0.925
D	0.625	0.312	0.6483	0.48	0.640
E	5.250	2.625	0.6483	4.05	0.002
F	-1.625	-0.812	0.6483	-1.25	0.239
A*B	2.000	1.000	0.6483	1.54	0.154
A*C	0.375	0.187	0.6483	0.29	0.778
A*D	-0.625	-0.312	0.6483	-0.48	0.640
A*E	2.750	1.375	0.6483	2.12	0.060
A*F	0.125	0.063	0.6483	0.10	0.925
B*C	-1.000	-0.500	0.6483	-0.77	0.458
B*D	-2.500	-1.250	0.6483	-1.93	0.083
B*E	2.125	1.063	0.6483	1.64	0.132
B*F	0.750	0.375	0.6483	0.58	0.576
C*D	0.875	0.438	0.6483	0.67	0.515
C*E	-1.250	-0.625	0.6483	-0.96	0.358
C*F	0.125	0.062	0.6483	0.10	0.925
D*E	-0.500	-0.250	0.6483	-0.39	0.708
D*F	-1.625	-0.813	0.6483	-1.25	0.239
E*F	-3.250	-1.625	0.6483	-2.51	0.031

S = 3.66742   R-Sq = 83.21%   R-Sq(adj) = 47.94%

Analysis of Variance for Cavities (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	344.5	344.5	57.42	4.27	0.022
2-Way Interactions	15	321.9	321.9	21.46	1.60	0.230
Residual Error	10	134.5	134.5	13.45		
Total	31	800.9				

The analysis is confirmed by Normal Probability plot of the standardized effects and Pareto Chart.

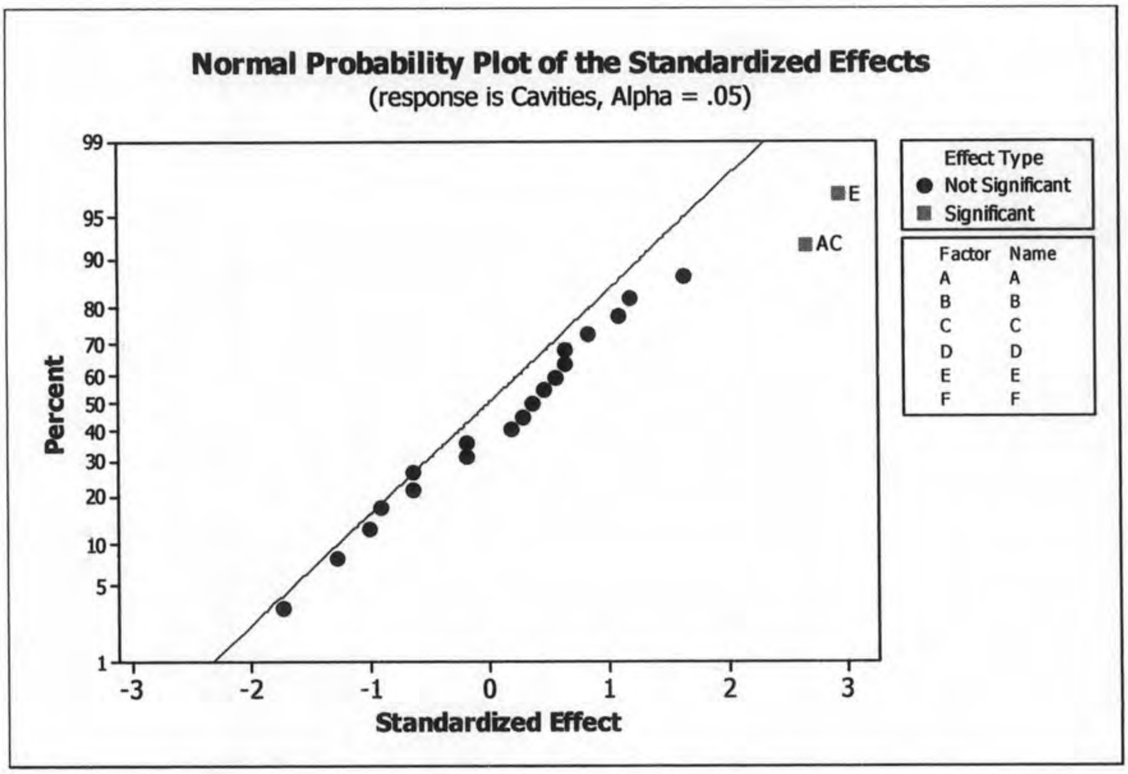

Figure 4.11: Cavities' Normal Probability Plot for Front Leg

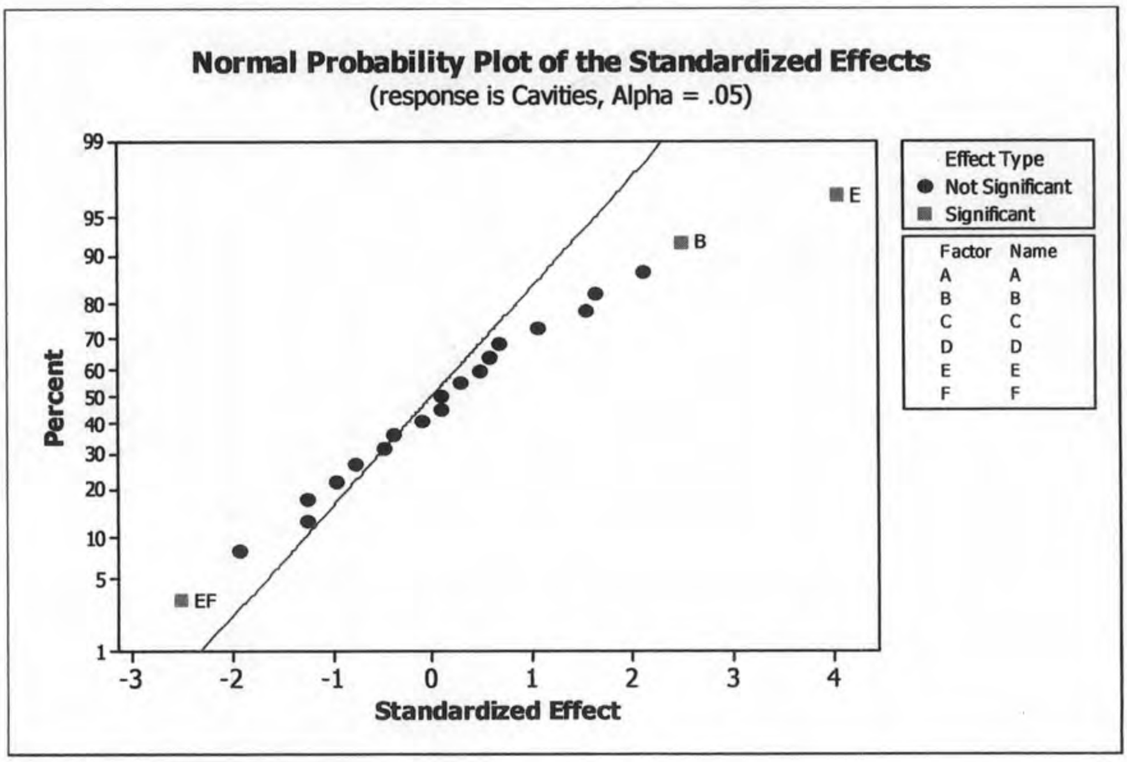

Figure 4.12: Cavities' Normal Probability Plot for Back Leg

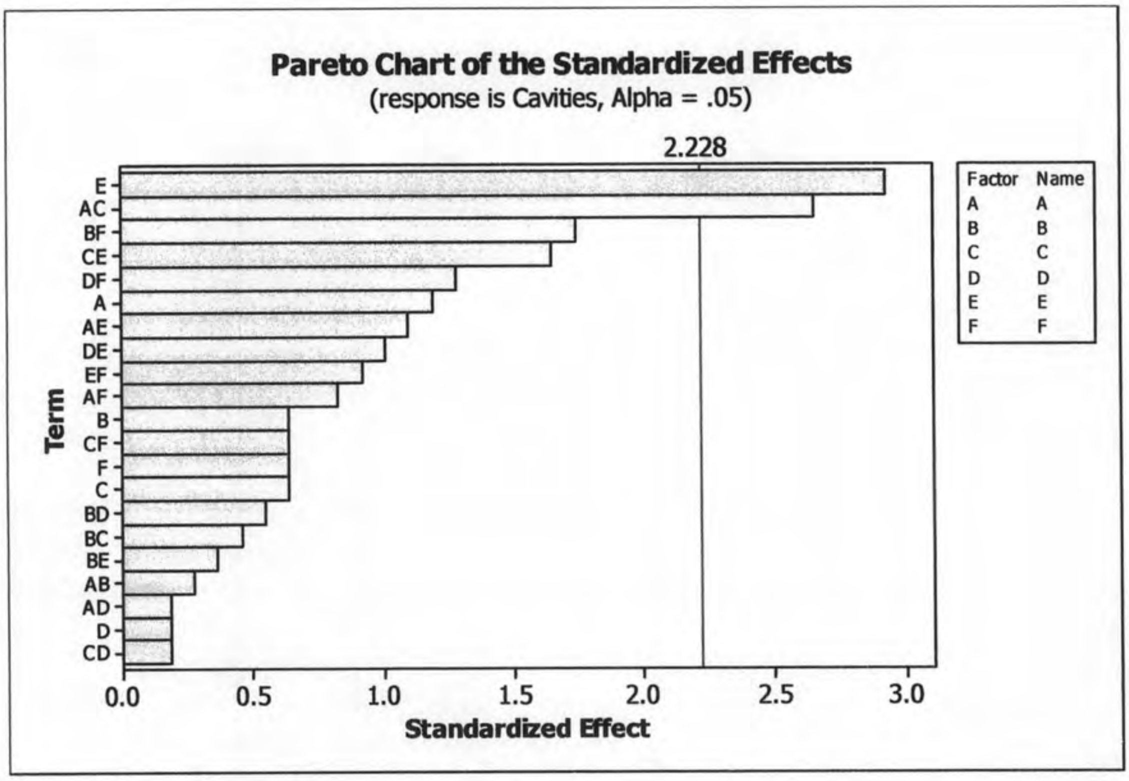

Figure 4.13: Cavities' Pareto Chart for Front Leg

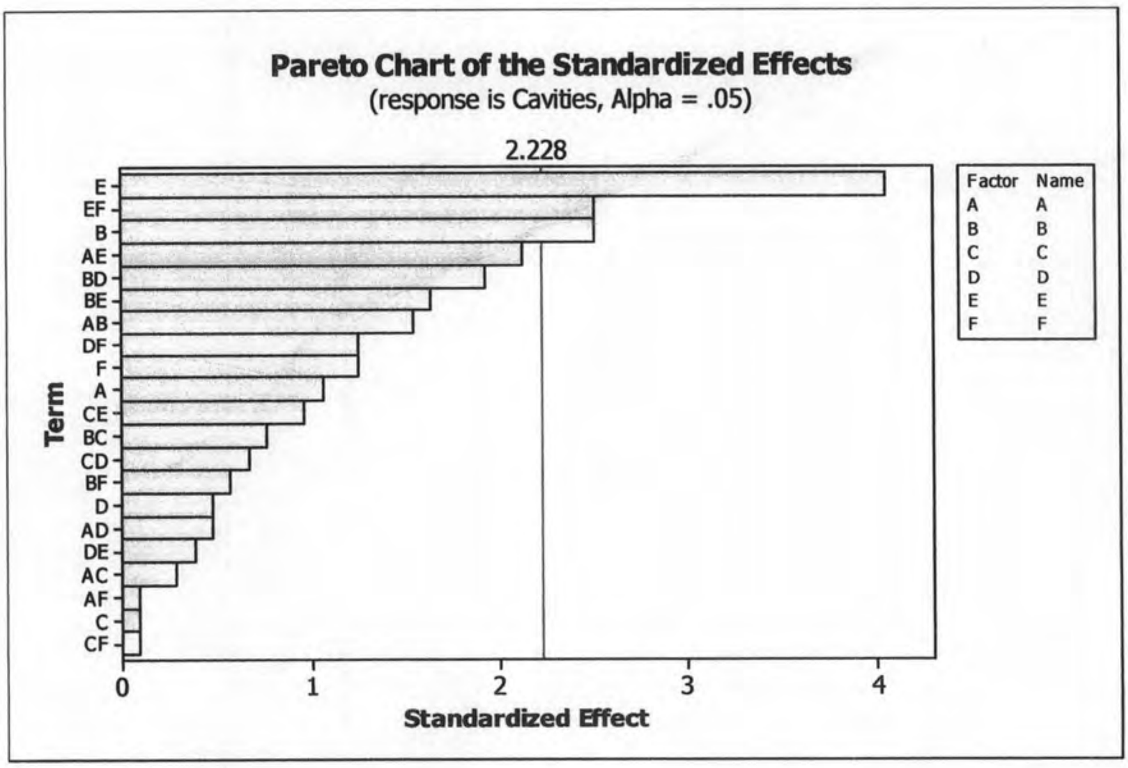

Figure 4.14: Cavities' Pareto Chart for Back Leg

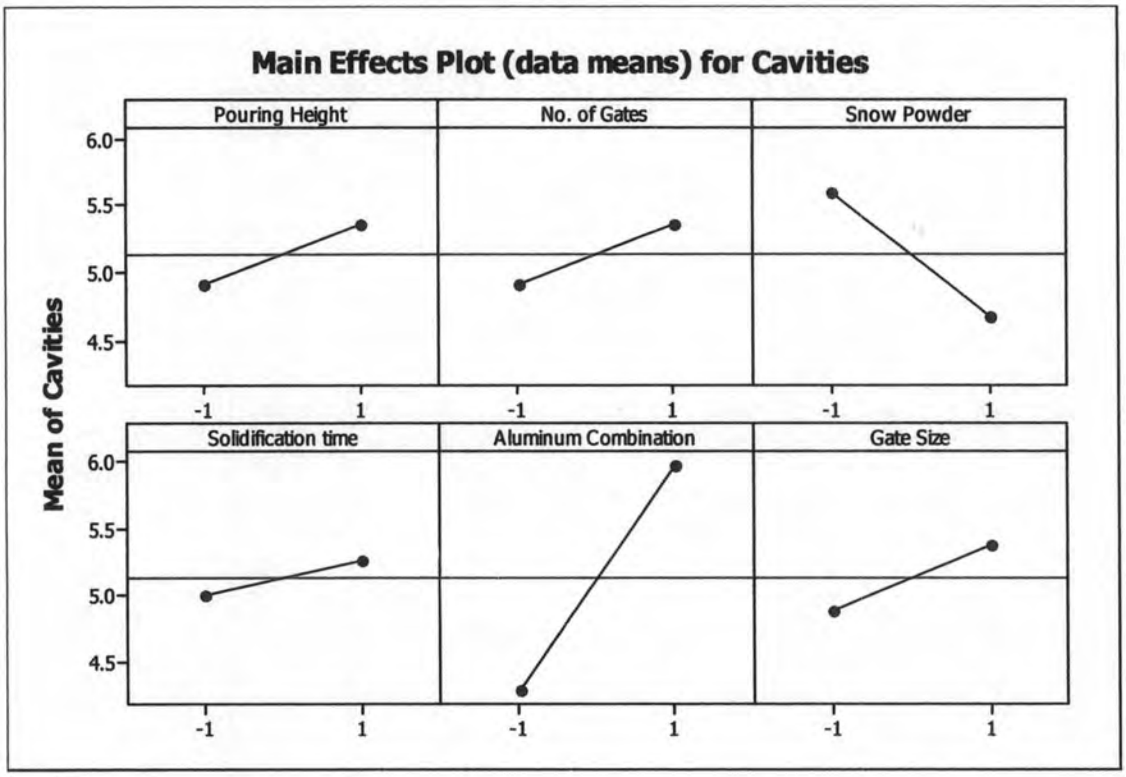

Figure 4.15: Cavities' Main Effects Plot for Front Leg

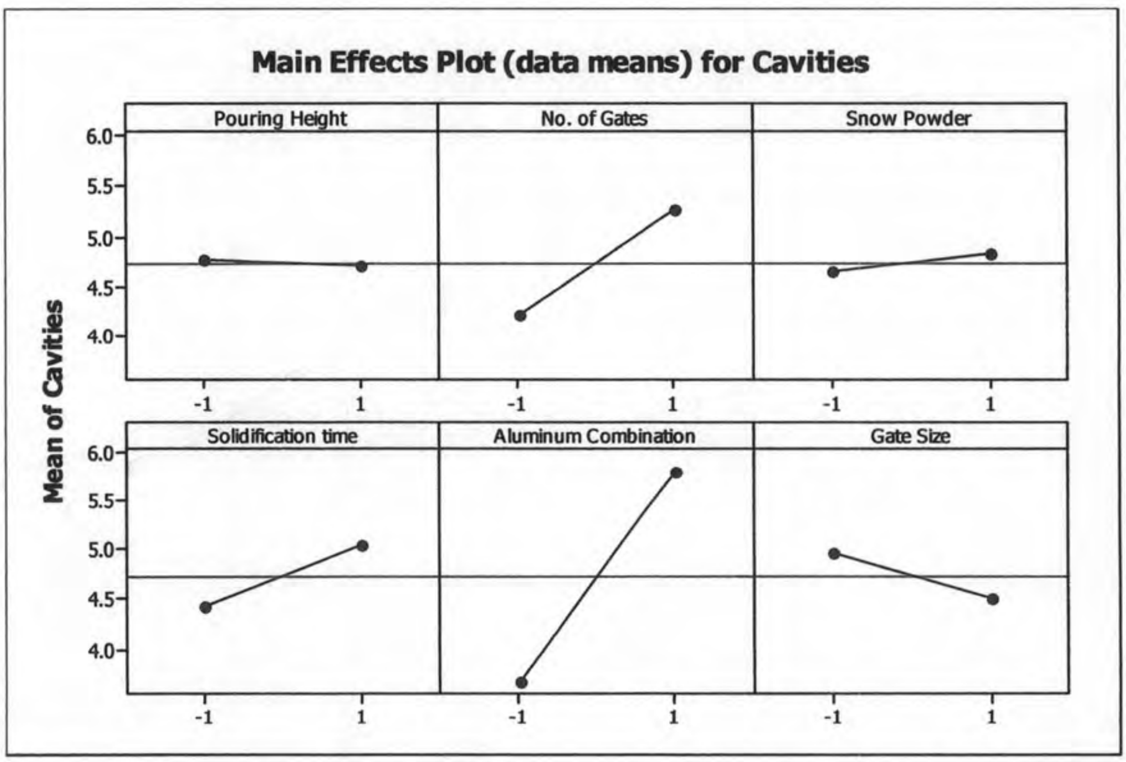

Figure 4.16: Cavities' Main Effects Plot for Back Leg

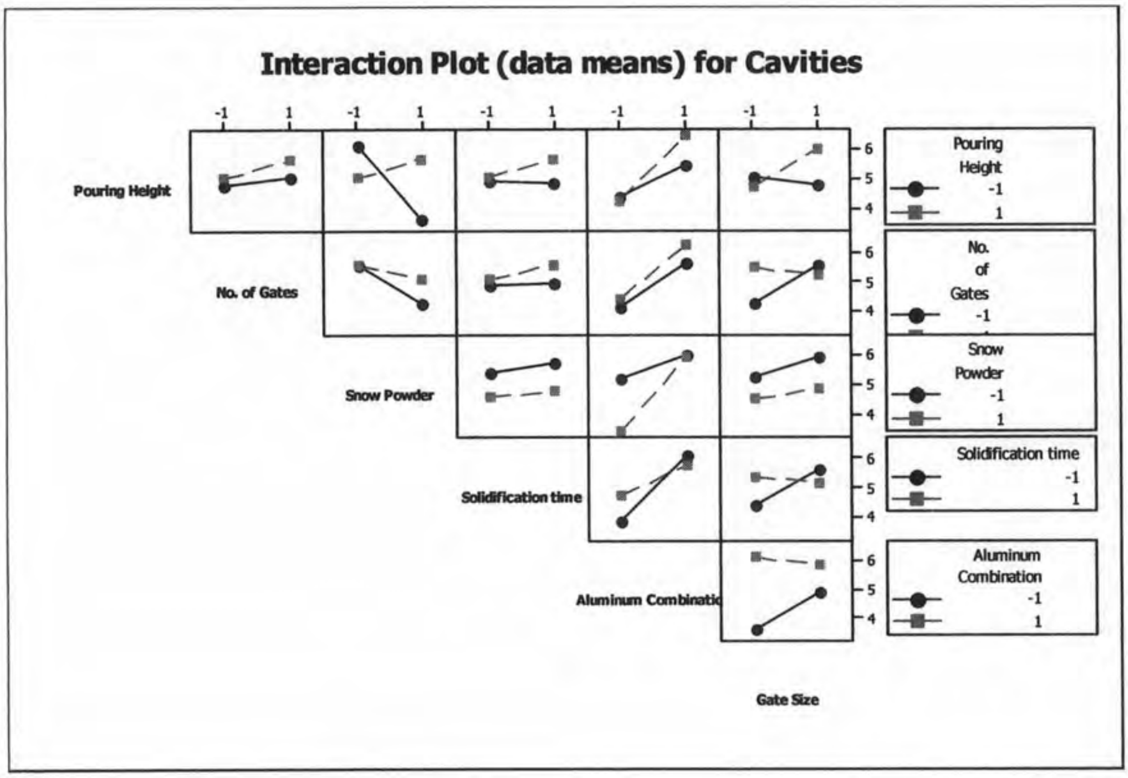

Figure 4.17: Cavities' Interaction Plot for Front Leg

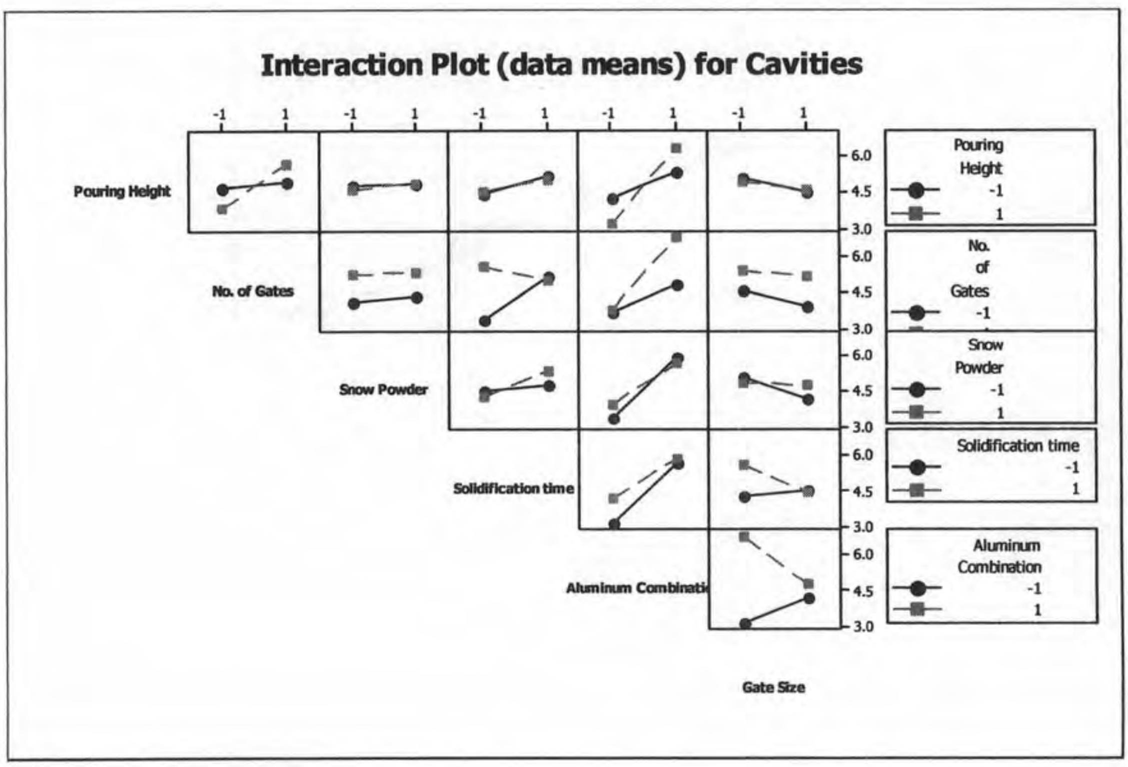

Figure 4.18: Cavities' Interaction Plot for Back Leg

Residual Analysis

The normal probability plots of Cavities for front leg and back leg are formed in a straight line as shown in *Figure 4.19 and 4.20* respectively. Therefore the error distributions for both legs are normally distributed.

The Residuals Versus the Fitted Values Plot for front leg and back leg are structureless as shown in *Figure 4.19 and 4.20*. Therefore the errors have a constant standard deviation.

The Residuals Versus the Order of the Data for both legs are structure less as shown in *Figure 4.19 and 4.20*. As a result, the errors are independently distributed.

In conclusion, all the assumptions are valid; therefore this analysis can rely on the analysis of variance.

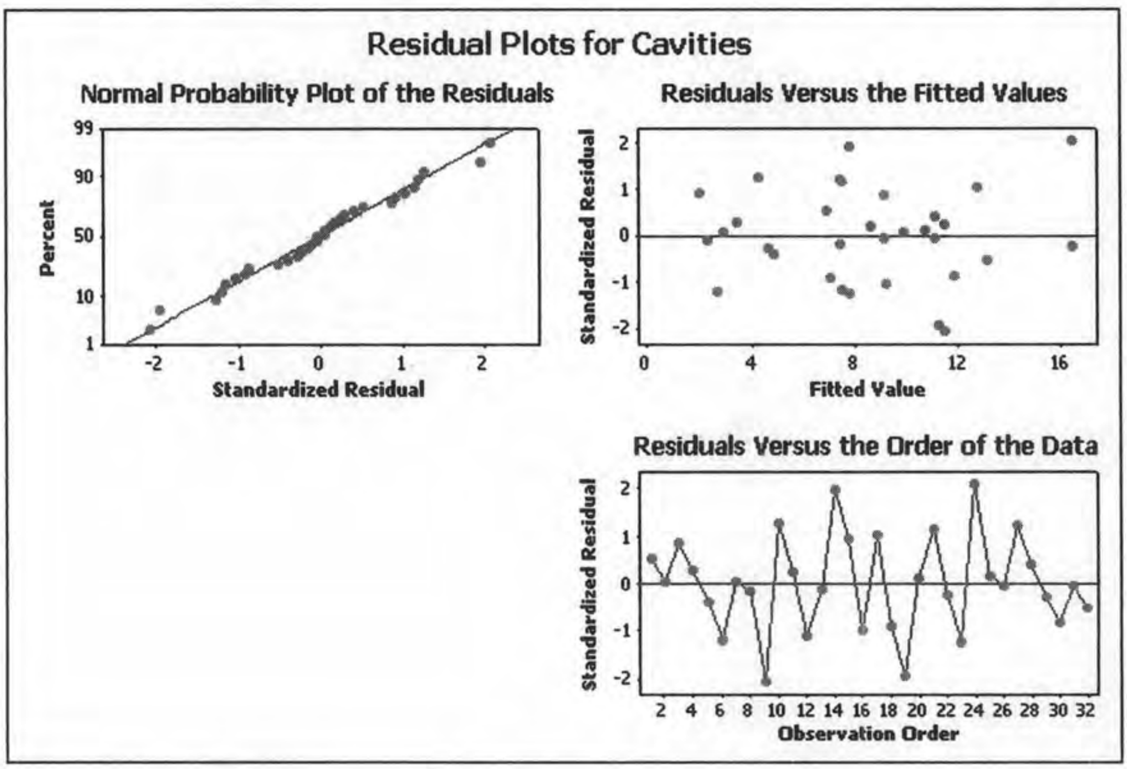

Figure 4.19: Cavities' Residual Plots for Front leg

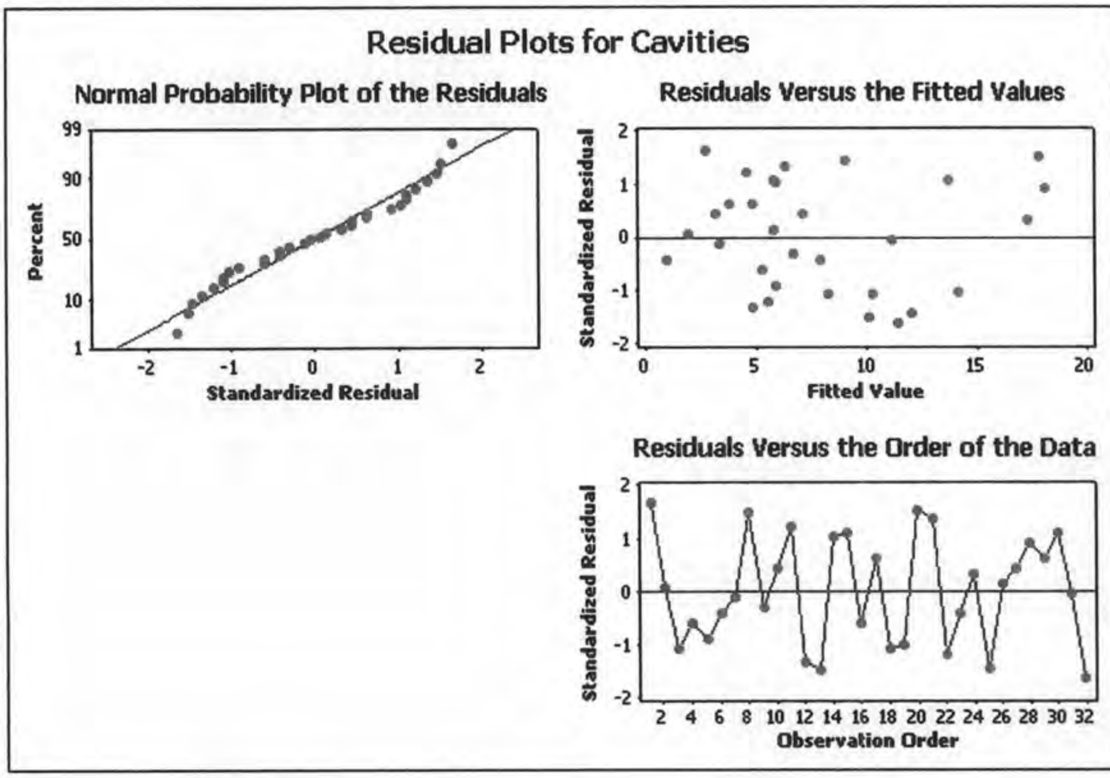

Figure 4.20: Cavities' Residual Plots for Back leg

4.3.2.3 Response: Defective Surface

In the case of Defective Surface, there are four main factors effects and two interaction effects that significantly affect the response as it shown in *Table 4.10, 4.11, Figure 4.21, 4.22, 4.23, and 4.24,* the P-value for Snow Powder Quantity (C), Solidification time (D), Aluminum Combination (E), and Gate size (F), Interaction between Number of Gates (B) and Aluminum Combination (E), and interaction between Snow Powder quantity (C) and Aluminum Combination (E) less than 0.05.

According from *Figure 4.25*, the effect of Solidification time (D) at 1 level is to reduce the defective surface in front leg by about 1.44 (according from *Table 4.9*). The effect of Gate Size (F) at level 1 reduces the defective surface in back leg by about 1.81 (according from *Table 4.10*).

According from *Figure 4.27 and 4.28*, the interaction Effect between Number of Gate (B) and Aluminum Combination (E) at level -1 and level -1 respectively reduce the defective surface in front leg and back leg. The interaction effect of Snow powder Quantity (C) and Aluminum Combination (E) at level -1 and level -1 respectively reduces the defective surface in front leg and back leg.

Therefore, in order to reduce the defective surface in chair's leg the number of gate in the mold should equal to one, the snow powder quantity that spatters in the mold is about 10 grams, the solidification time is 10 minutes, the aluminum combination is solid 18 bars and resilient 2 bars, and the gate size is 2x7cm.

Table 4.10: Defective Surface's ANOVA for Front Leg

Factorial Fit: Defective Surface versus A, B, C, D, E, F

Estimated Effects and Coefficients for Defective Surface (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		12.219	0.3001	40.72	0.000
A	0.437	0.219	0.3001	0.73	0.483
B	0.687	0.344	0.3001	1.15	0.279
C	2.688	1.344	0.3001	4.48	0.001
D	-1.437	-0.719	0.3001	-2.40	0.038
E	2.688	1.344	0.3001	4.48	0.001
F	-1.188	-0.594	0.3001	-1.98	0.076
A*B	-0.062	-0.031	0.3001	-0.10	0.919
A*C	0.687	0.344	0.3001	1.15	0.279
A*D	-0.687	-0.344	0.3001	-1.15	0.279
A*E	-1.062	-0.531	0.3001	-1.77	0.107
A*F	-0.438	-0.219	0.3001	-0.73	0.483
B*C	-0.313	-0.156	0.3001	-0.52	0.614
B*D	0.063	0.031	0.3001	0.10	0.919
B*E	-1.812	-0.906	0.3001	-3.02	0.013
B*F	0.062	0.031	0.3001	0.10	0.919
C*D	-0.438	-0.219	0.3001	-0.73	0.483
C*E	-2.813	-1.406	0.3001	-4.69	0.001
C*F	-0.688	-0.344	0.3001	-1.15	0.279
D*E	-0.188	-0.094	0.3001	-0.31	0.761
D*F	0.938	0.469	0.3001	1.56	0.149
E*F	0.313	0.156	0.3001	0.52	0.614

S = 1.69742   R-Sq = 90.38%   R-Sq(adj) = 70.17%

Analysis of Variance for Defective Surface (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	148.69	148.69	24.781	8.60	0.002
2-Way Interactions	15	121.97	121.97	8.131	2.82	0.051
Residual Error	10	28.81	28.81	2.881		
Total	31	299.47				

Table 4.11: Defective Surface's ANOVA for Back Leg

Factorial Fit: Defective Surface versus A, B, C, D, E, F

Estimated Effects and Coefficients for Defective Surface (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		12.031	0.3449	34.88	0.000
A	0.937	0.469	0.3449	1.36	0.204
B	0.438	0.219	0.3449	0.63	0.540
C	2.938	1.469	0.3449	4.26	0.002
D	-1.187	-0.594	0.3449	-1.72	0.116
E	2.813	1.406	0.3449	4.08	0.002
F	-1.813	-0.906	0.3449	-2.63	0.025
A*B	0.063	0.031	0.3449	0.09	0.930
A*C	0.562	0.281	0.3449	0.82	0.434
A*D	-0.563	-0.281	0.3449	-0.82	0.434
A*E	-0.563	-0.281	0.3449	-0.82	0.434
A*F	-0.188	-0.094	0.3449	-0.27	0.791
B*C	-0.438	-0.219	0.3449	-0.63	0.540
B*D	-0.313	-0.156	0.3449	-0.45	0.660
B*E	-2.063	-1.031	0.3449	-2.99	0.014
B*F	0.062	0.031	0.3449	0.09	0.930
C*D	-0.062	-0.031	0.3449	-0.09	0.930
C*E	-2.813	-1.406	0.3449	-4.08	0.002
C*F	-0.438	-0.219	0.3449	-0.63	0.540
D*E	0.312	0.156	0.3449	0.45	0.660
D*F	0.187	0.094	0.3449	0.27	0.791
E*F	0.187	0.094	0.3449	0.27	0.791

S = 1.95096   R-Sq = 88.36%   R-Sq(adj) = 63.91%

Analysis of Variance for Defective Surface (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	6	178.44	178.44	29.740	7.81	0.003
2-Way Interactions	15	110.47	110.47	7.365	1.93	0.147
Residual Error	10	38.06	38.06	3.806		
Total	31	326.97				

The analysis is confirmed by Normal Probability plot of the standardized effects and Pareto Chart.

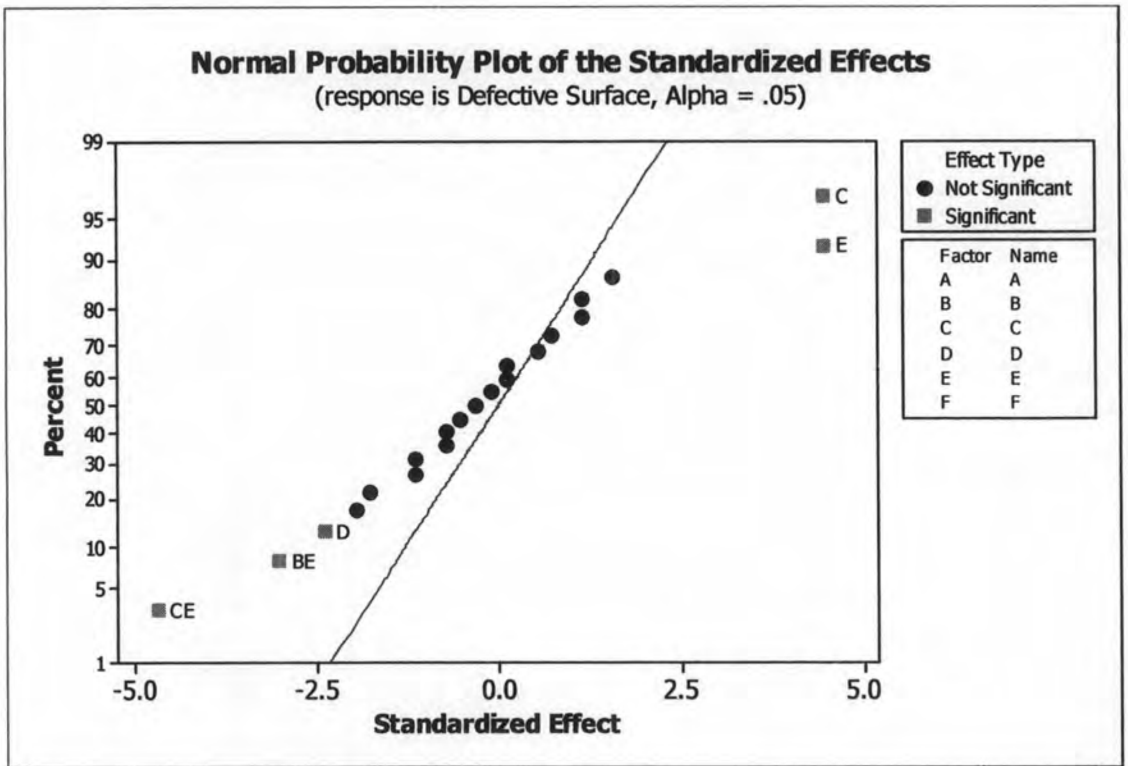

Figure 4.21: Defective Surface's Normal Probability Plot for Front Leg

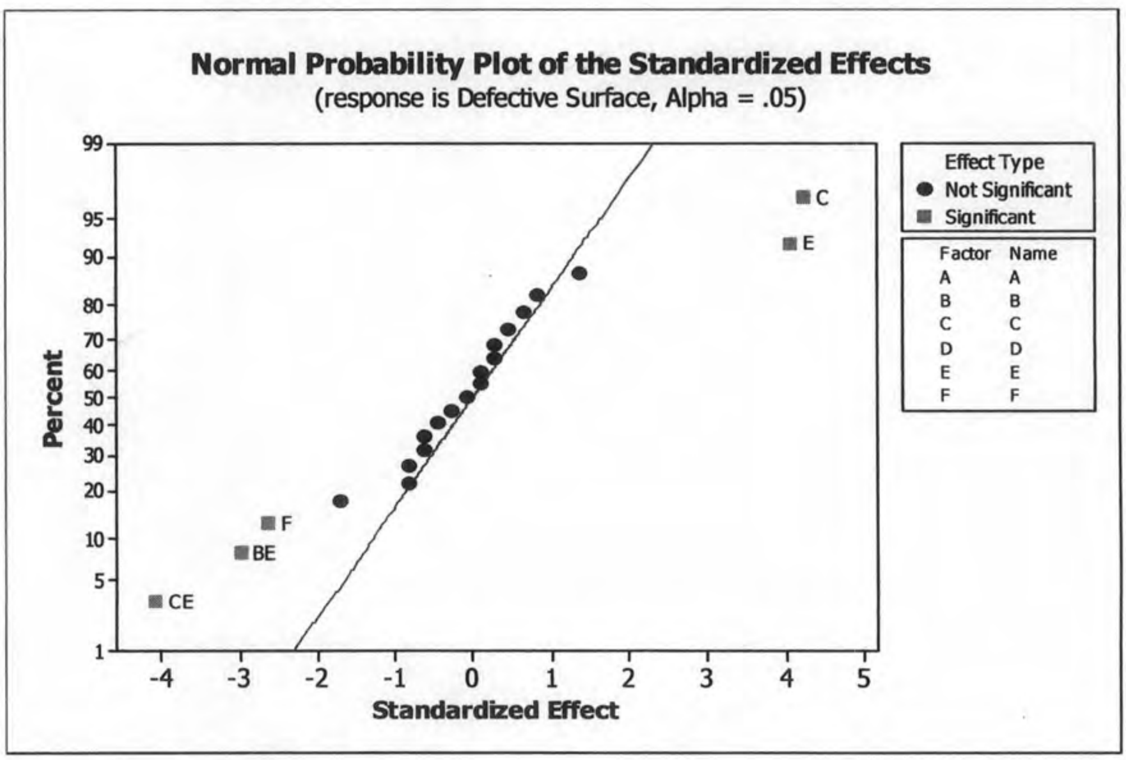

Figure 4.22: Defective Surface's Normal Probability Plot for Back Leg

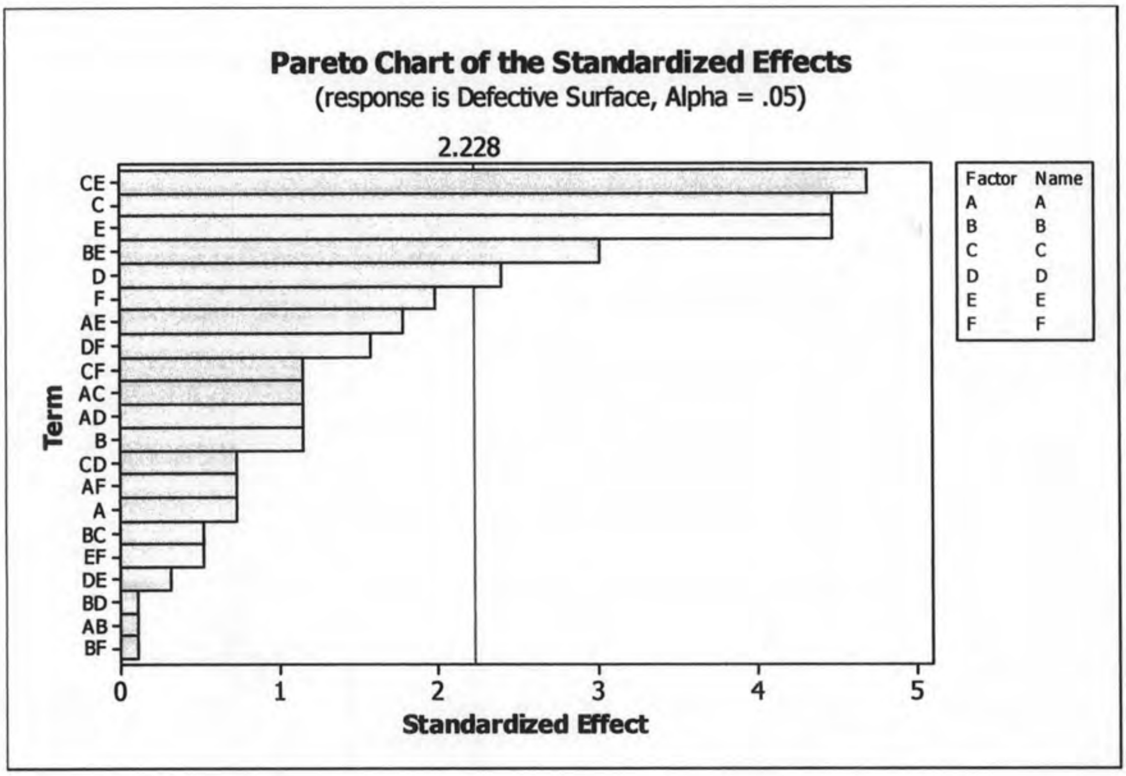

Figure 4.23: Defective Surface's Pareto Chart for Front Leg

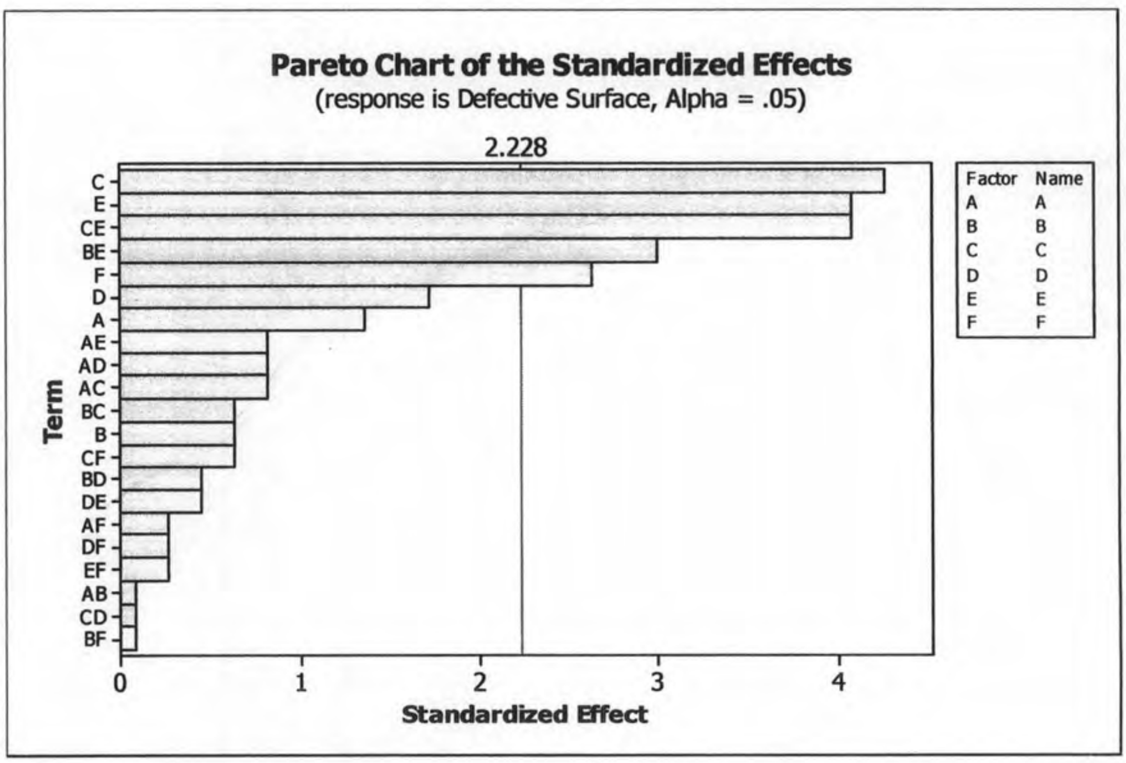

Figure 4.24: Defective Surface's Pareto Chart for Back Leg

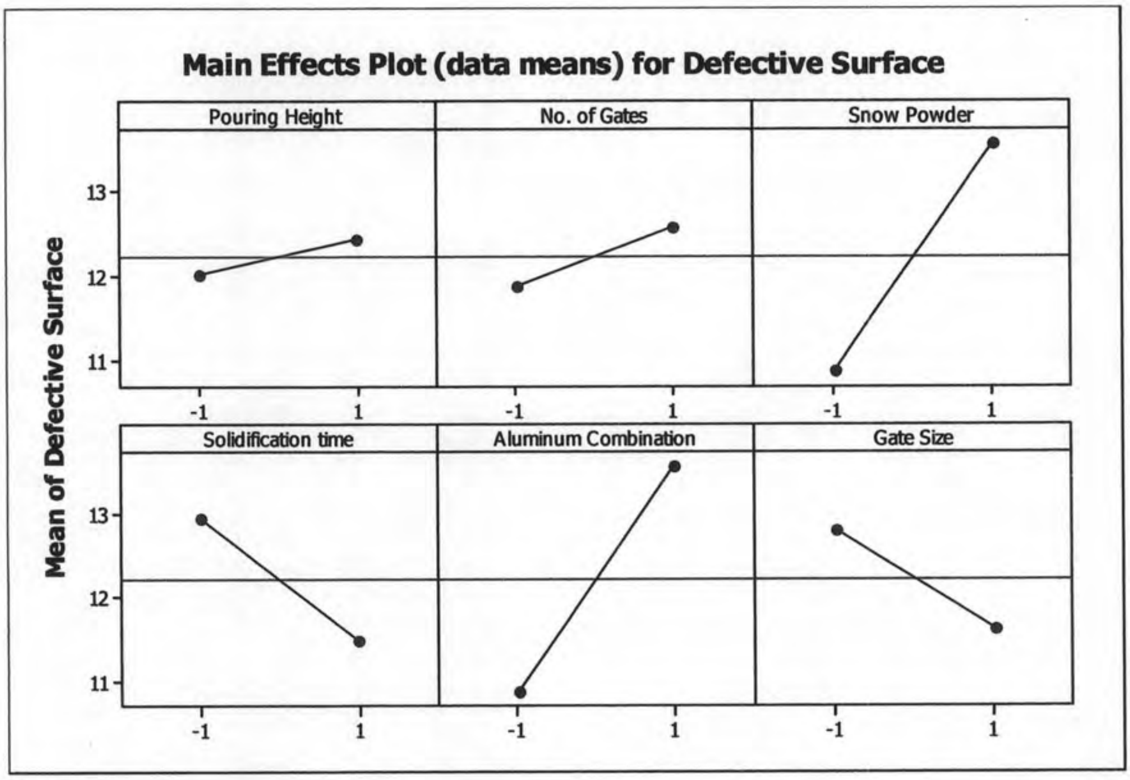

Figure 4.25: Defective Surface's Main Effects Plot for Front Leg

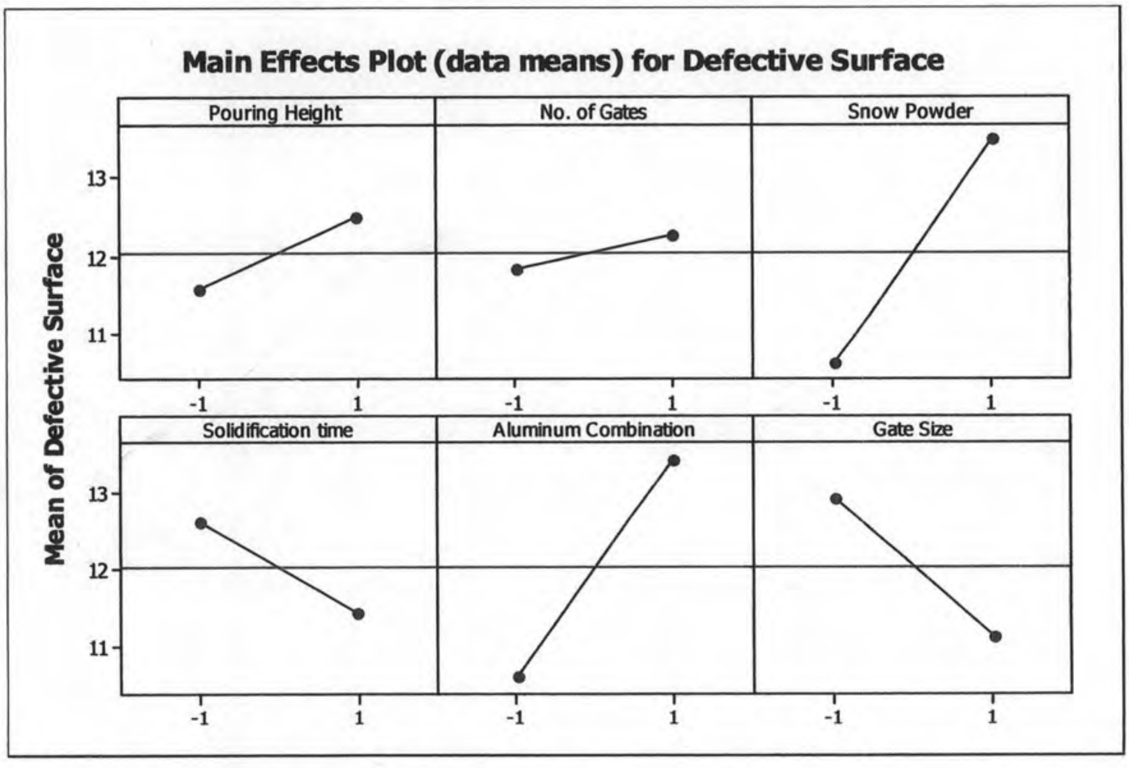

Figure 4.26: Defective Surface's Main Effects Plot for Back Leg

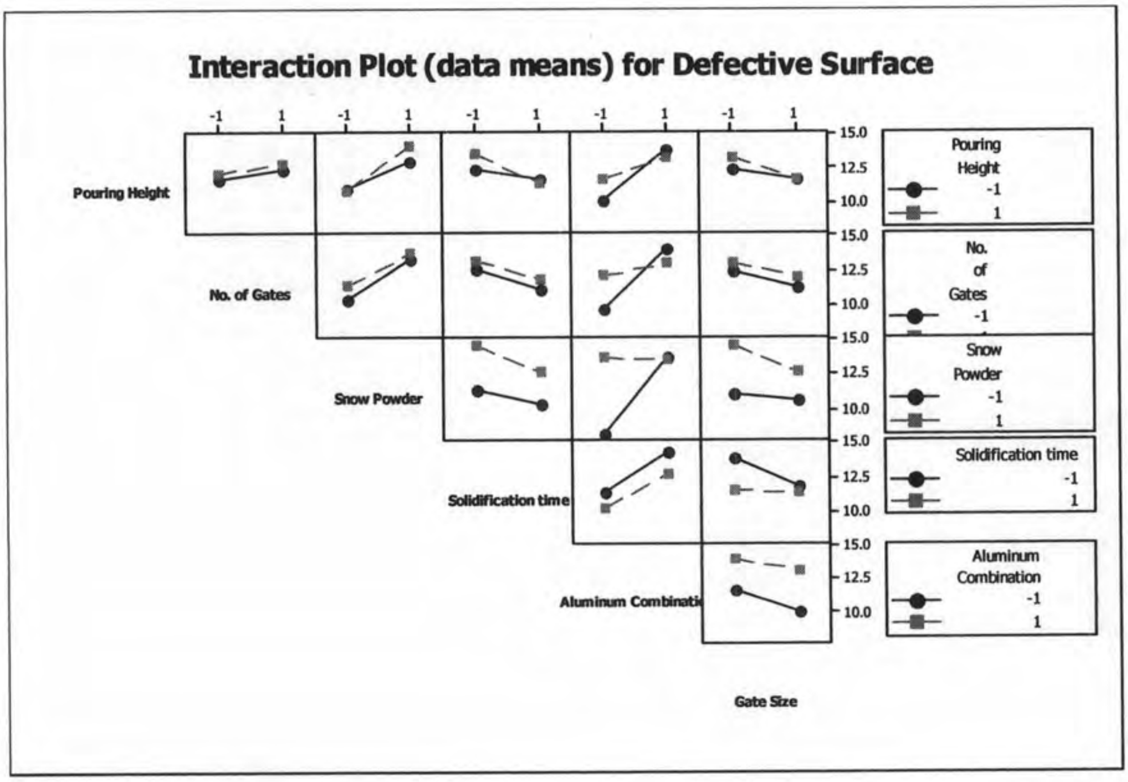

Figure 4.27: Defective Surface's Interaction Plot for Front Leg

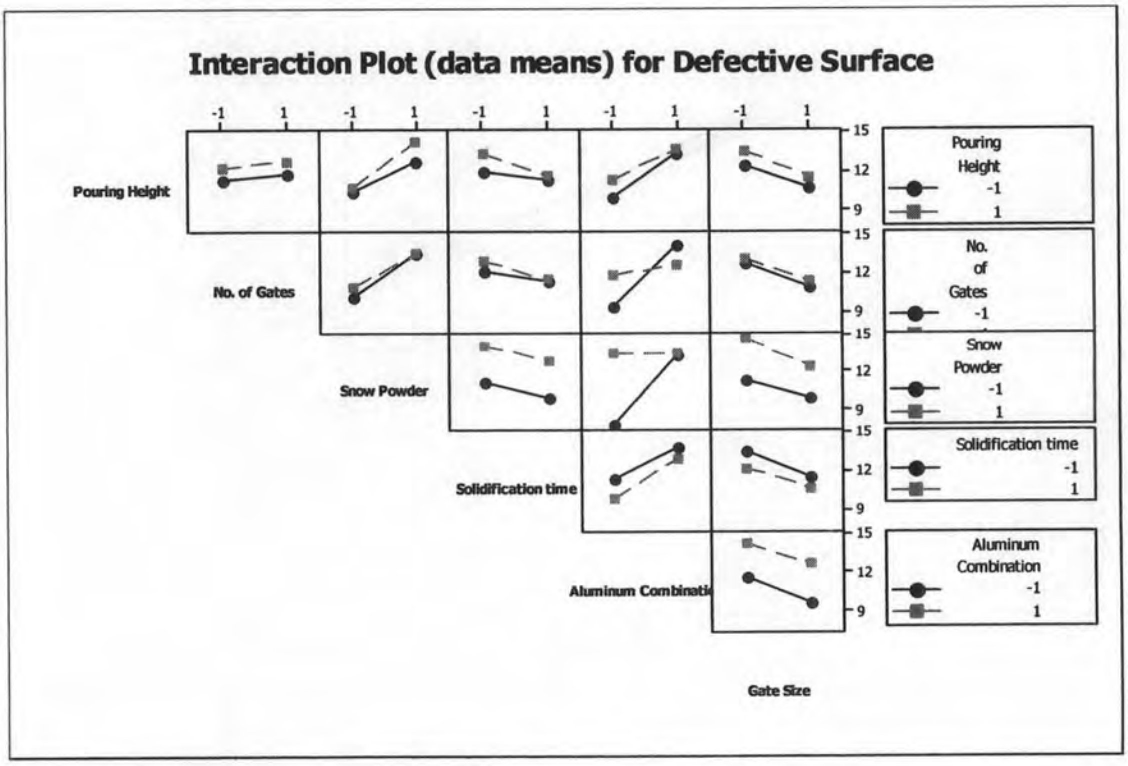

Figure 4.28: Defective Surface's Interaction Plot for Back Leg

Residual Analysis

The normal probability plots of Defective Surface for front leg and back leg are formed in a straight line as shown in *Figure 4.29 and 4.30* respectively. Therefore the error distributions for both legs are normally distributed.

The Residuals versus the Fitted Values Plot for front leg and back leg are structureless as shown in *Figure 4.29 and 4.30*. Therefore the errors have a constant standard deviation.

The Residuals versus the Order of the Data for both legs contain no obvious pattern as shown in *Figure 4.29 and 4.30*. As a result, the errors are independently distributed.

In conclusion, all the assumptions are valid; therefore this analysis can rely on the analysis of variance.

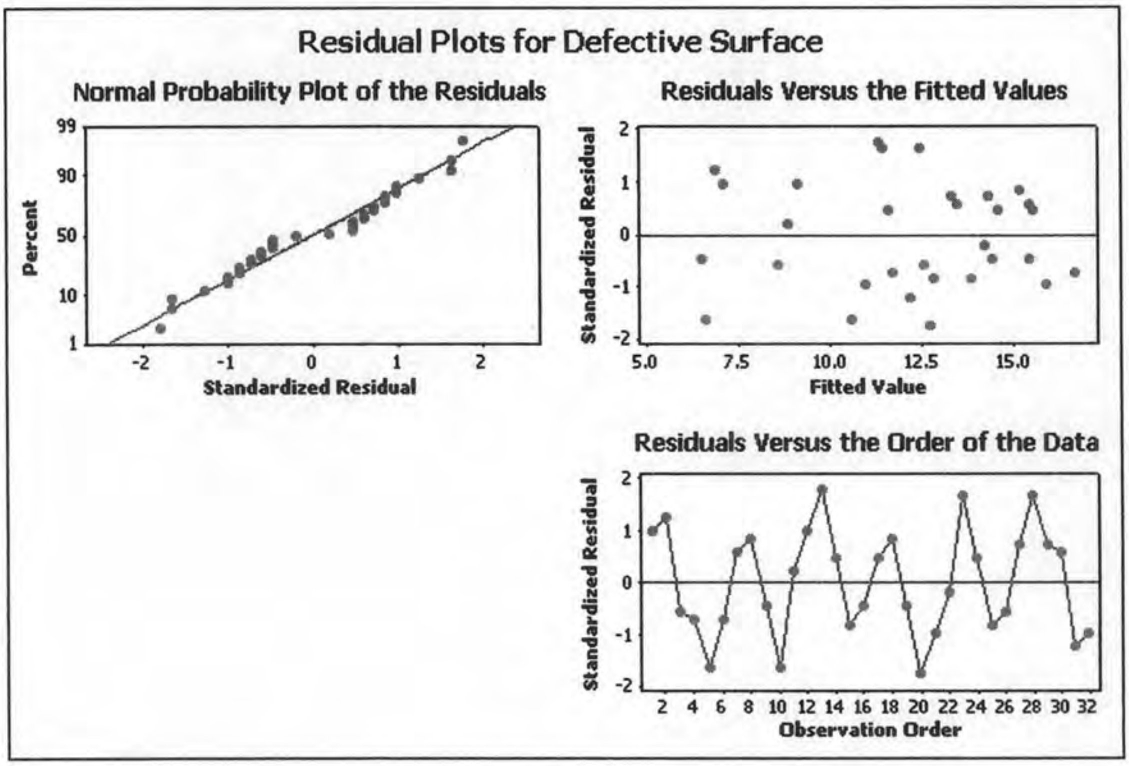

Figure 4.29: Defective Surface's Residual Plots for Front leg

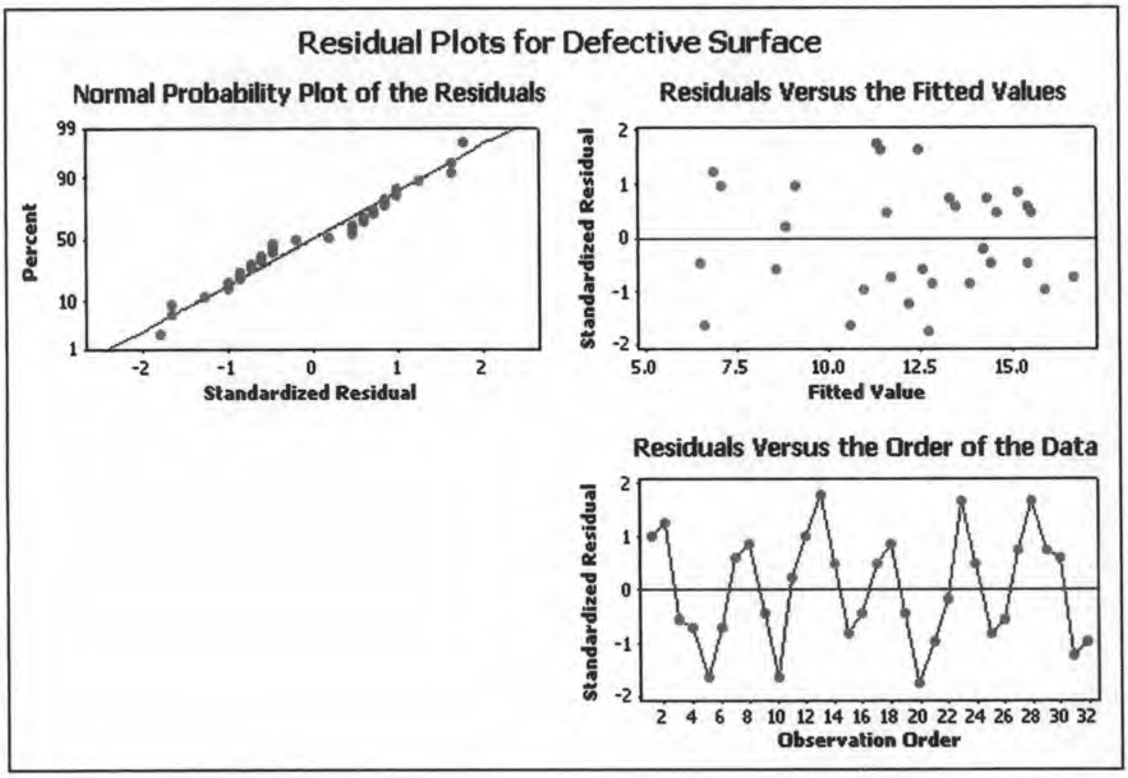

Figure 4.30: Defective Surface's Residual Plots for Back leg

4.3.2.4 Summary

As the result of ANOVA, the significant factors for Metallic projection are Aluminum combination (E) and interaction between Aluminum combination (E) and gate size (F).

The significant factors for Cavities are Number of gates (B), Aluminum combination (E), interaction between Pouring Height (A) and Snow powder quantity (C), and interaction Aluminum combination (E) and gate size (F).

The significant factors for defective surfaces are snow powder quantity (C), Solidification time (D), Aluminum combination (E), Gate size (F), number of gate (B) and aluminum combination (E) interaction, and Snow powder quantity (C) and aluminum combination (E) interaction.

However there is a conflict occurred in Gate size (F) because Gate size (F) at level + reduces the defect rate of Defective Surface, but on the other hand Gate size (F) at level - reduces the defect rate of Metallic Projection and Cavities. To solve this conflict, the total rework cost of these responses (the cost to repair product's defects) is introduced. Total Rework cost of these responses will identify which level of F Factor gives the less rework cost, which is the sum. Therefore the following section will show the calculation of the rework cost for each response.

In the *Table 4.12* shows the levels of significant factors of the experiment that reduce the defect rate.

Table 4.12: Significant Factors

	Front Leg			Back Leg		
	Metallic Projection	**Cavities**	**Defective Surface**	**Metallic Projection**	**Cavities**	**Defective Surface**
Significant Factors					B = -1	
			C = -1			C = -1
			D = 1			
	E = -1	E = -1	E = -1	E = -1	E = -1	E = -1
						F = 1
		AC A = -1 C = -1				
			BE B = -1 E = -1			BE B = -1 E = -1
			CE C = -1 E = -1			CE C = -1 E = -1
	EF E = -1 **F = -1**				EF E = -1 **F = -1**	

4.4 Factor Level Selection

4.4.1 Selection Criteria

Due to the conflict occur in gate size (F), at level -1 of gate size reduces Metallic Projection and Cavities, but for level 1 of gate size reduces Defective surface. The total cost of rework is used as the decision criteria for factor level selection. The rework cost will tell how much of each level of gate size has to be spent on rework cost. The level that yields the less rework will be selected.

4.4.2 Rework Method

There are three steps to correct the defects in metallic projection and defective surface. The three steps are grinding, painting filling, and sanding. There are two numbers of sanding papers that will be used in rework are number 80 and 150. For cavities, it only used two steps of reworking, which are painting filling and sanding (for cavities it only used sanding paper number150).

Rework for metallic projection starts with grinding. The grinding machine will grind the projection out of the product surface. Then the grinded surface will be daubed with painting filling. After the part is coated, use sanding paper number 80 is used to smooth up the surface then use number 180 to finish the work.

Rework for cavities, it starts with painting filling. Painting filling will fill up the cavities. Then sand the surface with sanding number 180 for finishing.

Rework for Defective surface, the rework starts with grinding. The grinding machine will grind where the defective surface located. Then daub painting filling to the grinded surface. After the part is filled, use sanding paper number 80 is used to smooth up the surface then use number 180 to finish the work.

4.4.3 Calculation for Rework Cost

This section will explain how to calculate the cost of rework. The rework cost of metallic projection and defective surface are the total cost of grinding cost, painting filling cost, and sanding cost. For cavities the rework cost is the total of painting filling cost and sanding cost.

Grinding cost

$$\text{cost of one defect} = \frac{\text{cost of one grinding disc cost}}{\text{number of defects per one grinding disc}} + (\text{Wage rate} \times \text{time for correcting})$$

Painting Filling

$$\text{cost of one defect} = \frac{\text{cost of one tank of painting Filling}}{\text{number of defects per one tank}} + (\text{Wage rate} \times \text{time for correcting})$$

Sanding cost

$$\text{cost of one defect} = \frac{\text{cost of one sanding paper}}{\text{number of defects per one sanding paper}} + (\text{Wage rate} \times \text{time for correcting})$$

Remark: number of defects per one grinding disc, one tank, and one sanding paper refer to the number of defects that each grinding disc, tank, and sanding paper can rework.

Table 4.13: Rework cost for Metallic Projection

	Material for Rework			Wage for rework			
	Unit cost	no. Projection/unit	Cost/projection	Wage rate (28800 second)	time/projection (second)	Wage for work	total cost
Grinding	11.77	20	0.59	180.00	22.00	0.14	0.73
Painting Filling	299.60	238	1.26	240.00	34.16	0.28	1.54
Sanding no 80	1.85	14	0.13	195.00	21.00	0.14	0.27
Sanding no 150	1.56	20	0.08	195.00	25.00	0.17	0.25
						total cost	2.79

Table 4.14: Rework cost for Cavity

	Unit Cost	no. cavity/unit	Cost/cavity	Wage rate (28800 second)	time/cavity (second)	Wage for work	total cost
Grinding	11.77	0	0.00	0.00	0.00	0.00	0.00
Painting Filling	299.60	238	1.26	240.00	22.73	0.19	1.45
Sanding no 80	1.85	0	0.00	195.00	0.00	0.00	0.00
Sanding no 150	1.56	20	0.08	195.00	25.00	0.17	0.25
						total cost	1.70

Table 4.15: Rework cost for Defective surface

Level 1

	Unit Cost	no. leg/unit	Cost/leg	Wage rate (28800 second)	time/leg (second)	Wage for work	total cost
Grinding	11.77	10	1.18	180.00	83.00	0.52	1.70
Painting Filling	299.60	238	1.26	240.00	180.00	1.50	2.76
Sanding no 80	1.85	4	0.46	195.00	115.00	0.78	1.24
Sanding no 150	1.56	4	0.39	195.00	57.00	0.39	0.78
						total cost	6.47

Level 2

	Unit Cost	no. leg/unit	Cost/leg	Wage rate (28800 second)	time/leg (second)	Wage for work	total cost
Grinding	11.77	10	1.18	180.00	103.00	0.64	1.82
Painting Filling	299.60	119	2.52	240.00	240.00	2.00	4.52
Sanding no 80	1.85	4	0.46	195.00	148.00	1.00	1.46
Sanding no 150	1.56	4	0.39	195.00	121.00	0.82	1.21
						total cost	9.01

Level 3

	Unit Cost	no. leg/unit	Cost/leg	Wage rate (28800 second)	time/leg (second)	Wage for work	total cost
Grinding	11.77	10	1.18	180.00	112.00	0.70	1.88
Painting Filling	299.60	79.33	3.78	240.00	364.00	3.03	6.81
Sanding no 80	1.85	4	0.46	195.00	163.00	1.10	1.57
Sanding no 150	1.56	4	0.39	195.00	155.00	1.05	1.44
						total cost	11.69

Level 4

	Unit Cost	no. leg/unit	Cost/leg	Wage rate (28800 second)	time/leg (second)	Wage for work	total cost
Grinding	11.77	10	1.18	180.00	150.00	0.94	2.11
Painting Filling	299.60	59.50	5.04	240.00	504.00	4.20	9.24
Sanding no 80	1.85	4	0.46	195.00	167.00	1.13	1.59
Sanding no 150	1.56	4	0.39	195.00	208.00	1.41	1.80
						total cost	14.74

4.4.4 Gate Size Analysis

Apply rework costs into response of 2^{6-1} factorial design (*Table 4.4 and 4.5*), which split the responses into two tables. One table illustrates responses with Factor F at Level + and level -1 in another table as shown in *Table 4.16 and 4.17.*

Table 4.16: Rework cost for F = +

F = +		Run No.																
Part Name	**Defect Types**	**2**	**3**	**5**	**8**	**9**	**12**	**14**	**15**	**17**	**20**	**22**	**23**	**26**	**27**	**29**	**32**	**Total**
Front Leg	Metallic Projection	8.37	2.79	5.58	2.79	5.58	0	5.58	8.37	11.16	8.37	8.37	0	8.37	8.37	11.16	11.16	106.02
	Cavities	17	18.7	6.8	0	11.9	8.5	20.4	6.8	25.5	18.7	27.2	8.5	15.3	17	6.8	20.4	229.5
	Defective Surface	36.18	36.32	38.72	58.96	30.96	41.4	46.76	46.76	52.86	44.08	52.86	52.86	46.76	55.91	53.23	41.4	736.02
Back Leg	Metallic Projection	8.37	2.79	8.37	11.16	2.79	5.58	5.58	8.37	5.58	13.95	2.79	5.58	5.58	8.37	8.37	5.58	108.81
	Cavities	3.4	10.2	6.8	20.4	10.2	3.4	13.6	13.6	8.5	35.7	5.1	11.9	10.2	13.6	10.2	13.6	190.4
	Defective Surface	36.18	36.32	38.72	58.96	25.88	38.72	46.76	44.08	52.86	46.76	49.81	49.81	46.76	46.76	55.91	41.4	715.69

Table 4.17: Rework cost for F = -

F = -		Run No.																
Part Name	**Defect Types**	**1**	**4**	**6**	**7**	**10**	**11**	**13**	**16**	**18**	**19**	**21**	**24**	**25**	**28**	**30**	**31**	**Total**
Front Leg	Metallic Projection	2.79	2.79	0	0	2.79	2.79	8.37	0	11.16	5.58	8.37	16.74	11.16	16.74	11.16	13.95	114.39
	Cavities	13.6	6.8	0	5.1	11.9	20.4	3.4	11.9	8.5	11.9	17	35.7	15.3	20.4	17	18.7	217.6
	Defective Surface	36.04	44.08	58.96	58.96	28.42	38.72	49.81	55.91	58.96	52.86	55.91	58.96	49.81	49.81	52.86	44.08	794.15
Back Leg	Metallic Projection	2.79	2.79	2.79	8.37	0	5.58	0	0	0	5.58	8.37	16.74	8.37	13.95	8.37	11.16	94.86
	Cavities	10.2	6.8	0	5.1	6.8	11.9	11.9	6.8	13.6	20.4	15.3	30.6	15.3	34	27.2	18.7	234.6
	Defective Surface	36.04	41.4	58.96	58.96	28.42	41.4	52.86	55.91	58.96	49.81	52.86	58.96	52.86	52.86	58.96	44.08	803.3

Table 4.18: Rework Cost Summary

	Front Leg		Back Leg	
F level	**1**	**-1**	**1**	**-1**
Metallic Projection	106.02	114.4	108.8	94.86
Cavities	229.5	217.6	190.4	234.6
Defective Surface	736.02	794.2	715.7	803.3
Total	**1071.54**	**1126**	**1015**	**1133**

From *Table 4.18*, the cost with F = -1 has more correction cost than F = 1 in either legs so it means that the best level of F Factor is 1 (gate size = 2 cm x 7 cm).

Hence the best factors levels for casting process are

Table 4.19: Best Factor Levels

Factors	Level	Definition
A = Pouring Height	-1	10 cm
B = No. of gates	-1	1
C = Snow powder quantity	-1	10 grams
D = Solidification time	1	10 minutes
E = Aluminum Combination	-1	(18,2)
F = Gate Size	1	2x7 cm

4.5 Analysis of the Effects of New Setting

4.5.1 Effect on production time

After finishing the experiment, the casting procedure has a new setting that decreases the defect occurrence in the product. This new setting does not affect to overall production time. Although the solidification time is set to 10 minutes, the overall production time is still not affected. Because, while the operators wait for aluminum alloy to be transformed, they can prepare a new mold for the new casting. And the new settings for other factors do not affect the production time as well because those factors do not concern the time consumption.

4.5.2 Effect on Maximum Load

After the experiment, chair's leg has to be put on the load test to see the difference between before and after experiment and see whether new setting yields enough load. The testing takes place in MTEC (National Metal and Materials Technology Center, Thailand). The following table lists the weight load that a chair's leg with the new setting and old setting can support.

Table 4.20: Maximum Load of Chair Front Leg

Sample	Specimen Number	Maximum Load (kg)	
		Old setting	New setting
Chair Front leg	1	299.75	352.32
	2	293.82	330.00
	3	314.52	359.42
	4	330.12	326.75
	5	327.87	341.08
Average		**313.22**	**341.91**

Table 4.21: Maximum Load of Chair Back Leg

Sample	Specimen Number	Maximum Load (kg)	
		Old setting	New setting
Chair Back leg	1	288.74	307.93
	2	340.90	318.50
	3	313.90	306.49
	4	299.89	325.64
	5	360.56	344.13
Average		**320.80**	**320.54**

Refer to the result of the load test; the new setting for the chair's front leg has increased the maximum load weight from 313.22 kg to 341.91 kg. On the other hand the maximum load weight for chair's back leg remains indifferent between old and new settings.

However the results of testing need to be analyzed by t-test. The t-test assesses whether the mean maximum load of new setting and old setting are statistically different from each other.

4.5.2.1 T-test for Chair's Front leg

Null Hypothesis $H_0 : \mu_{old} = \mu_{new}$

Alternative Hypothesis $H_1 : \mu_{old} \neq \mu_{new}$

μ_{old} = Mean maximum load of front leg with old setting can endure

μ_{new} = Mean maximum load of front leg with new setting can endure

	N	Mean	StDev	SE Mean
Old setting	5	313.2	16.3	7.3
New setting	5	341.9	14.0	6.3

Difference = mu (Old setting) - mu (New setting)
Estimate for difference: -28.6980
95% CI for difference: (-51.4221, -5.9739)
T-Test of difference = 0 (vs not =): T-Value = -2.99 P-Value = 0.020 DF = 7

As the result of t-test for Chair's Front leg, the mean maximum load of front leg with new setting is significantly different from the mean maximum load of front leg with old setting as the P-Value is below the significance level of 0.05 and T-value falls in the rejection region, therefore H_0 is rejected. Then, the one-sided t-test has been performed and can conclude that the maximum load of chair's front leg has improved after the new setting to the casting process is applied.

4.5.2.2 T-test for Chair's Back leg

Null Hypothesis $H_0 : \mu_{old} = \mu_{new}$

Alternative Hypothesis $H_1 : \mu_{old} \neq \mu_{new}$

μ_{old} = Mean maximum load of back leg with old setting can endure

μ_{new} = Mean maximum load of back leg with new setting can endure

	N	Mean	StDev	SE Mean
Old setting	5	320.8	29.6	13
New setting	5	320.5	15.4	6.9

Difference = mu (Old setting) - mu (New setting)
Estimate for difference: 0.260000
95% CI for difference: (-36.200725, 36.720725)
T-Test of difference = 0 (vs not =): T-Value = 0.02 P-Value = 0.987 DF = 6

As the result of t-test for Chair's Back leg, the mean maximum load of back leg with new setting is not significantly different from the mean maximum load of back leg with old setting as the P-Value is above the significance level of 0.05 and the T-Value does not fall in the rejection region. Therefore, the H_0 is not rejected. Thus, the mean maximum load of chair's back leg has not improved after the new setting is applied.

Although the results from front and back legs are not consistent but at least the new setting give maximum load equal to or greater than the old setting. However, if considers about the safety factor, these chair's legs are reliable since either front or back leg can bear the weight over 320 kg. Therefore, when assembled to a chair these legs can support the weight roughly over 1,200 kg. However, this number does not represent maximum load of chair, because these number only represent maximum load of chair legs only. To determine the maximum load of a chair, other components of chair, such as seat, backrest, and armrest need to be taken into account as well.

4.6 Opportunity Gain from Defect Reduction

There is an opportunity related to productivity that the company can gain from this new setting. In order to calculate opportunity gain, the total production time of before and after implementing the new setting must be calculated. Total production time is calculated by sum of the time of processes that involve with production of garden set. The times shown in the table are the total production time of total parts that need to be produced for one full garden set. One full garden set consists of 4 chairs and 1 table. Each chair consists of 2 front legs, 2 back legs, 1 seat, 1 backrest, 1 left arm, and 1 right arm. A table consists of 4 table's legs and 1 desktop. There are 6 processes to produce the garden set. They are casting, grinding, assembling, smoothing, primer coasting, and coloring.

The casting process consists of 4 main activities 1. Melt down the aluminum alloy, 2. Mold making, 3. Pour alloy, and 4. Solidification time, but to calculate the production time, it only needs 3 activities to be taken account. The foundry requires about 45 minutes for the aluminum alloy to become molten but the longest mold making time only takes 40 minutes. Therefore, the operator can make the mold while waiting the aluminum to be melted then the mold making does not need to take it into the account of production time. For the pouring time it will take about 5 minutes to complete all the molds for one full garden set and take about 10 minutes for solidification. Therefore, the production time for casting process is 60 minutes for one full garden set.

The production time of grinding process and smoothing process are calculated by summing up their production times of each part then dividing it by number of operators in their process. The jobs of these processes can be shared, which mean the operators in those processes after done with their job they can go help other operators. For production time of assembling, primer coating, and coloring process, it is very difficult to classify the production time of each part therefore the time shown in *Table 4.22* are the total production time of one full garden set.

The table below shows the production time before new setting is implemented; the total production time for one full garden set is 5 hours and 57 minutes.

Table 4.22: Production time before new setting

Before	**Production time**					
Part	Casting	Grinding	Assembling	Smoothing	Primer Coating	Coloring
Front leg	1:00:00	0:21:21	1:00:00	2:02:49	0:10:00	1:30:00
Back leg	1:00:00	0:22:11		2:02:06		
Seat	1:00:00	0:20:00		1:00:00		
Backrest	1:00:00	0:20:00		1:00:00		
Left arm	1:00:00	0:20:00		1:00:00		
Right arm	1:00:00	0:20:00		1:00:00		
Table's leg	1:00:00	0:20:00		1:00:00		
Desktop	1:00:00	0:05:00		0:15:00		
No. of Operators	12	5	1	5	1	1
Production time	1:00:00	0:29:42	1:00:00	1:51:59	0:10:00	1:30:00
Total Production time	**6:01:41**					

Remark: time formats h:mm:ss

The new setting has decreased the number of defects in chair's leg. This decrease reduces grinding time and smoothing time, since these two processes are the rework methods for correcting the defects occur from casting process. Therefore, after implementing the new setting, the production time for one full garden set has decreased to 5 hours and 35 minutes as shown in *Table 4.23*.

Table 4.23: Production time after new setting

After	Process					
Part	Casting	Grinding	Assembling	Smoothing	Primer Coating	Coloring
Front leg	1:00:00	0:15:01		1:15:23		
Back leg	1:00:00	0:14:55		1:14:39		
Seat	1:00:00	0:20:00		1:00:00		
Backrest	1:00:00	0:20:00		1:00:00		
Left arm	1:00:00	0:20:00		1:00:00		
Right arm	1:00:00	0:20:00		1:00:00		
Table's leg	1:00:00	0:20:00		1:00:00		
Desktop	1:00:00	0:05:00	1:00:00	0:15:00	0:10:00	1:30:00
No. of Operators	12	5	1	5	1	1
Production time	1:00:00	0:26:59	1:00:00	1:33:00	0:10:00	1:30:00
Total Production time	**5:39:59**					

The production time has reduced after the new setting is implemented by about 21 minutes or 6 %. However if calculate it in term of products that the company can gain after implementing this new setting. The company can actually produce the products 26.43 extra garden sets from the original setting and gain the income by about **330,313.49** baht as shown in *Table 4.24*.

Table 4.24: Income gaining

	Before	After	Difference	Difference (%)
Production time	6:01:41	5:39:59	0:21:42	6.00
Working hours/day	08:00:00	08:00:00	-	0
Working hours/year	2496:00:00	2496:00:00	-	0
Production/year	414.06	440.48	26.43	6.00
Price/set	12,500.00	12,500.00	-	0
Income (baht)	5,175,736.11	5,506,049.60	**330,313.49**	6.00

However, the new setting only applies to the chair's legs. If this experiment expands to the rest of the chair parts the income will likely increase.