Minitab Exercises-Session 5

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1. TR 18532:2009 12.1.4.2.3 Pages 154-155

> On Silk screen printing, visual blemishes, termed "trail-marks" are being experienced. Squeegee speed, ink viscosity and dwell time were investigated. Factors and levels are shown in Table 1 below.
>
> Ten blank sheets of polyester material were taken from each run of a standard 2^3 design and a defect count was taken with the aid of a 200 square matrix. The total number of squares affected by trail-marks was counted for each run. This response was then recorded as a percentage. Resuts are shown in Table 2.

Design Factor	Level 1	Level 2
Squeegee speed	45	80
Ink viscocity	700 mPa.s	2,200 mPa.s
Dwell time	Auto	4.5

Table 1: Silk screen printing design factors and levels

Run	Squeegee speed	Ink viscosity	Dwell time	% Trail marks
1	−	−	−	0.00
2	+	−	−	1.05
3	−	+	−	5.40
4	+	+	−	0.05
5	−	−	+	0.20
6	+	−	+	0.05
7	−	+	+	5.85
8	+	+	+	0.00

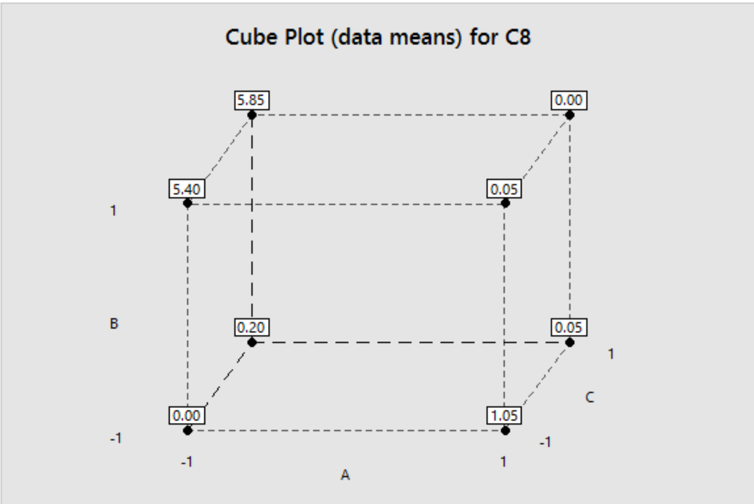
Table 2: Results from the runs on the silk screen printing experiment

(a) Create a 2^3 factorial design.

Stat/DOE/Factorial/Create Factorial Design
Create Factorial Design: 2 Level Factorial (default generators)
Number of factors:3
Designs: Full Factorial OK
Options: Undo Randomise Runs OK

(b) Add results in C8 and make a cube plot.

Stat/DOE/Cube Plot
Cube Plot/Response: C8 OK



(c) Analyse the experiment.

Stat/DOE/Analyze Factorial Design
Analyze Factorial Design/Responses: C8
Graphs Check Pareto, Normal Plot
Stat/DOE/Factorial/Factorial Plots
Factorial Plots OK

Factorial Regression: C8 versus A, B, C

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	44.6850	6.3836	*	*
Linear	3	25.7813	8.5938	*	*
A	1	13.2613	13.2613	*	*
B	1	12.5000	12.5000	*	*
C	1	0.0200	0.0200	*	*
2-Way Interactions	3	18.8425	6.2808	*	*
A*B	1	18.3012	18.3012	*	*
A*C	1	0.3613	0.3613	*	*
B*C	1	0.1800	0.1800	*	*
3-Way Interactions	1	0.0613	0.0613	*	*
A*B*C	1	0.0613	0.0613	*	*
Error	0	*	*		
Total	7	44.6850			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1.575	*	*	*	
A	-2.575	-1.287	*	*	*	1.00
B	2.500	1.250	*	*	*	1.00
C	-0.10000	-0.05000	*	*	*	1.00
A*B	-3.025	-1.512	*	*	*	1.00
A*C	-0.4250	-0.2125	*	*	*	1.00
B*C	0.3000	0.1500	*	*	*	1.00
A*B*C	0.17500	0.08750	*	*	*	1.00

Regression Equation in Uncoded Units

C8 = 1.575 - 1.287 A + 1.250 B - 0.05000 C - 1.512 A*B - 0.2125 A*C + 0.1500 B*C + 0.08750 A*B*C

Alias Structure

Factor	Name

A	A
B	B
C	C

Aliases

I

A

B

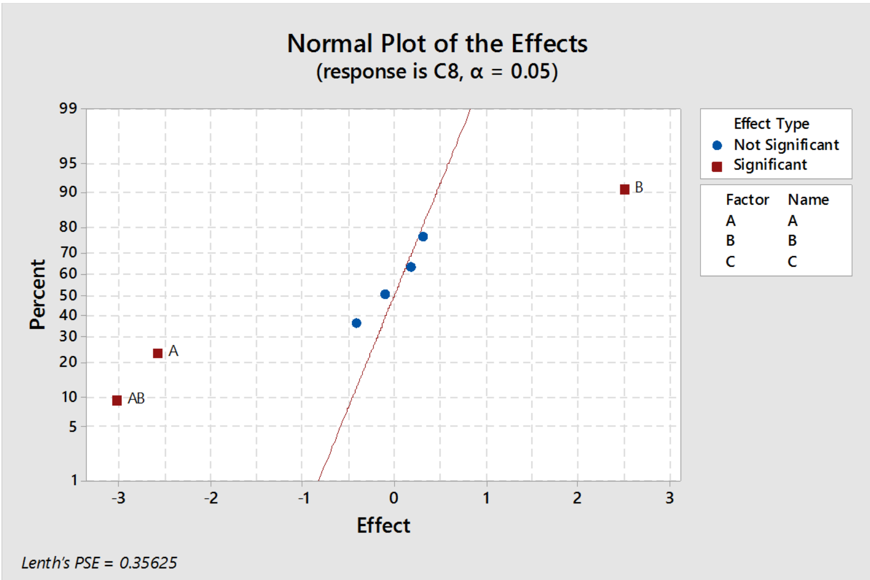
C

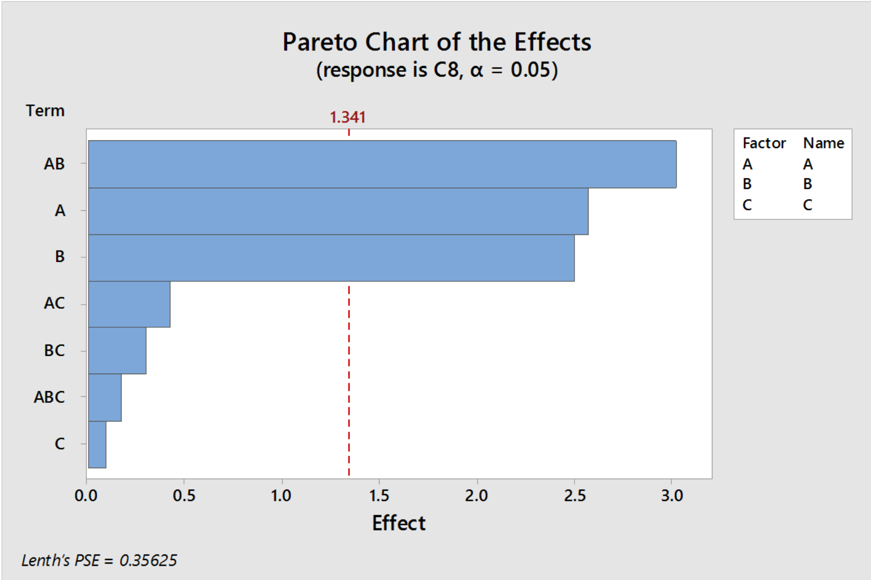
AB

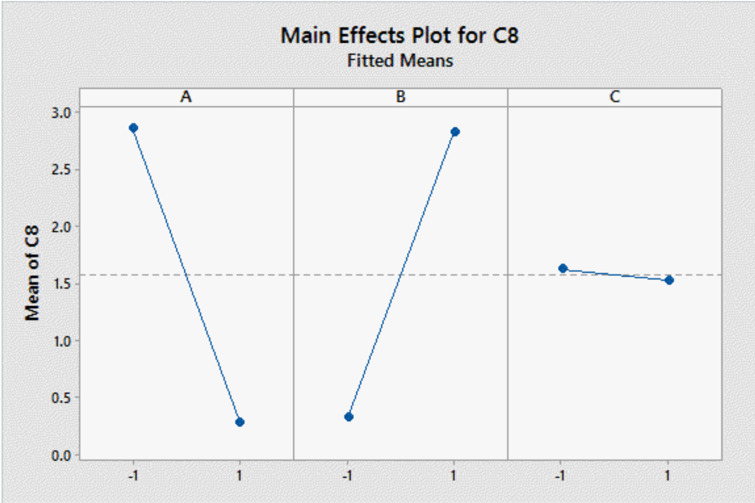
AC

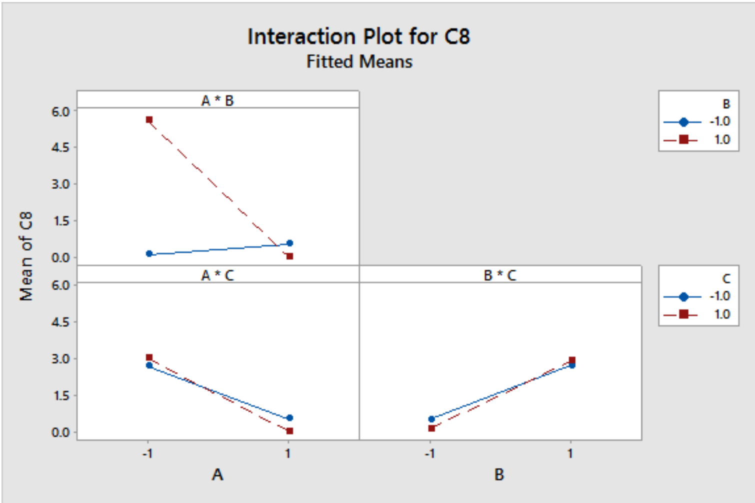
BC

ABC




Pareto Chart of the Effects
(response is C8, α = 0.05)
Term
1.341
AB
A
B
AC
BC
ABC
C
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Effect
Factor Name
A A
B B
C C
Lenth's PSE = 0.35625





There is an interaction between A and B. At low B there is little A effect while at high B there is a large positive A effect.

2. TR 18532:2009 12.1.4.2.2 Pages 150-154

> This example shows an application of experimental design 2 of Table 32. It has two roles; one, as a design development tool to determine the suitability of a sintered part for a particular application and two, as a development tool in the sense of searching for preferred operating conditions. Four design factors were investigated each at two levels as indicated in Table 3.
>
> The experimental layout uses columns 1, 2, 4, and 7 of a standard $L8$ array. Strength of fit, in kN, at minimum interference conditions was recorded for each part subjected to each experimental combination.
>
> Three parts were used for each run in order to separate means from variation in order to permit a search for design factors that would enhance mean strength (signal factors) and those that would reduce variation (control factors). Variation is expressed in terms of standard deviation. The results are given in Table 4.

(a) Create a 2^{4-1} design.

Design Factor	Level 1	Level 2
A: Surface finish	Fine turned	Microlled
B: Lubrication	Yes–number 2 oil	No
C: Speed	Low	High
D: Density	6.5	6.8

Table 3: Sintered part design factors and their levels

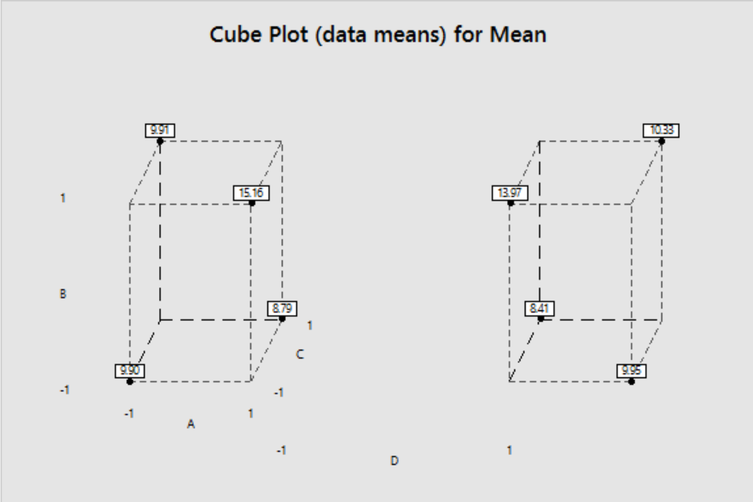
Run	A	B	C	D	Result1	Result2	Result3	Mean	StdDev
1	-1	-1	-1	-1	12.7	7.27	9.74	9.9	2.72
2	1	-1	-1	1	10.36	10.45	9.05	9.95	0.78
3	-1	1	-1	1	12.61	15.19	14.11	13.97	1.3
4	1	1	-1	-1	16.8	14.76	13.92	15.16	1.48
5	-1	-1	1	1	9.41	8.52	7.29	8.41	1.06
6	1	-1	1	-1	7.45	8.9	10.02	8.79	1.29
7	-1	1	1	-1	13.99	7.65	8.1	9.91	3.54
8	1	1	1	1	11.52	13.92	10.33	10.33	0.74

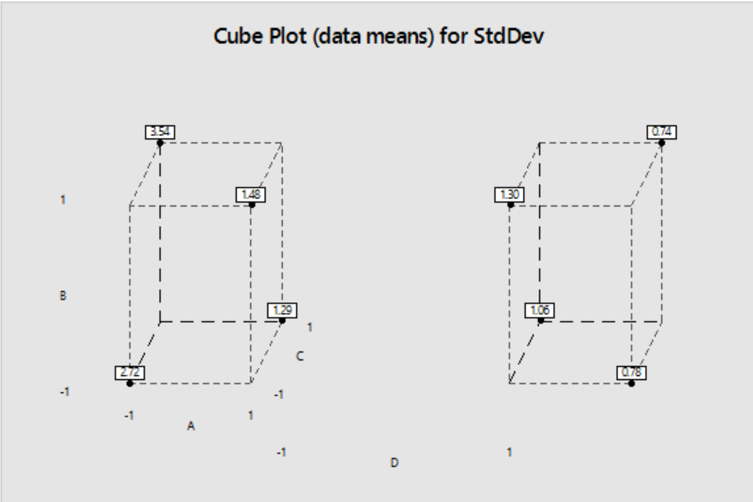
Table 4: Results from the runs on sintered part experiment

File/Open/DOE_ExampleOne.csv OK
Stat/DOE/Define Custom Factorial Design
Factors: A B C D
Low/High OK
Design/Standard Order Column/Specify By Column: Run OK
OK

(b) Make cube plots of the data.

Stat/DOE/Factorial/CubePlot
Response: Mean OK
Stat/DOE/Factorial/CubePlot
Response: StdDev OK





(c) Analyse the experiment.

Stat/DOE/Factorial/Analyze Factorial Data
Responses: Mean StdDev OK
Graphs/Pareto Normal OK
Stat/DOE/Factorial/Factorial Plots OK

ESQUANT Statistical Consulting

Factorial Regression: Mean versus A, B, C, D

The following terms are totally confounded with other terms and were removed:
B*C, B*D, C*D, A*B*C, A*B*D, A*C*D, B*C*D, A*B*C*D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	41.3561	5.9080	*	*
Linear	4	36.2907	9.0727	*	*
A	1	0.5202	0.5202	*	*
B	1	18.9728	18.9728	*	*
C	1	16.6464	16.6464	*	*
D	1	0.1513	0.1513	*	*
2-Way Interactions	3	5.0654	1.6885	*	*
A*B	1	0.1741	0.1741	*	*
A*C	1	0.0242	0.0242	*	*
A*D	1	4.8672	4.8672	*	*
Error	0	*	*		
Total	7	41.3561			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		10.80	*	*	*	
A	0.5100	0.2550	*	*	*	1.00
B	3.080	1.540	*	*	*	1.00
C	-2.885	-1.443	*	*	*	1.00
D	-0.2750	-0.1375	*	*	*	1.00
A*B	0.2950	0.1475	*	*	*	1.00
A*C	-0.11000	-0.05500	*	*	*	1.00
A*D	-1.5600	-0.7800	*	*	*	1.00

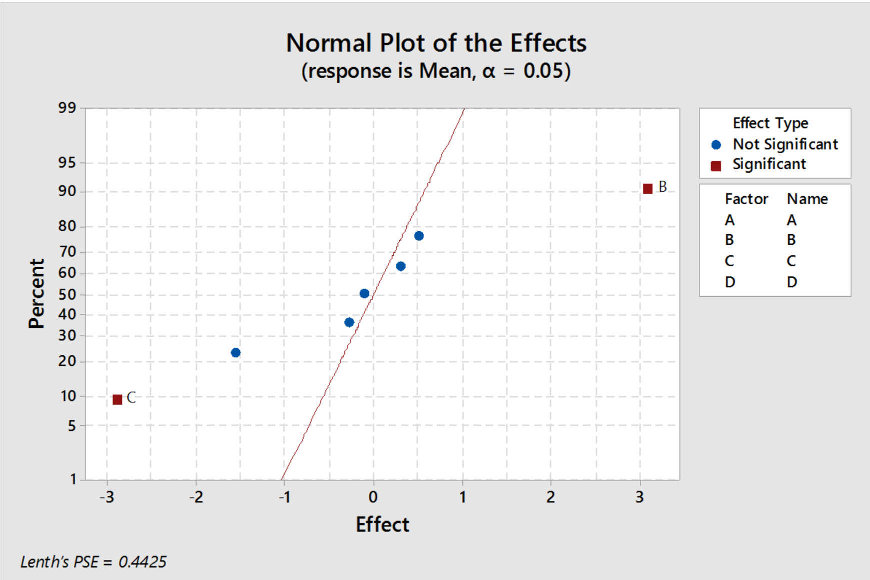
Regression Equation in Uncoded Units

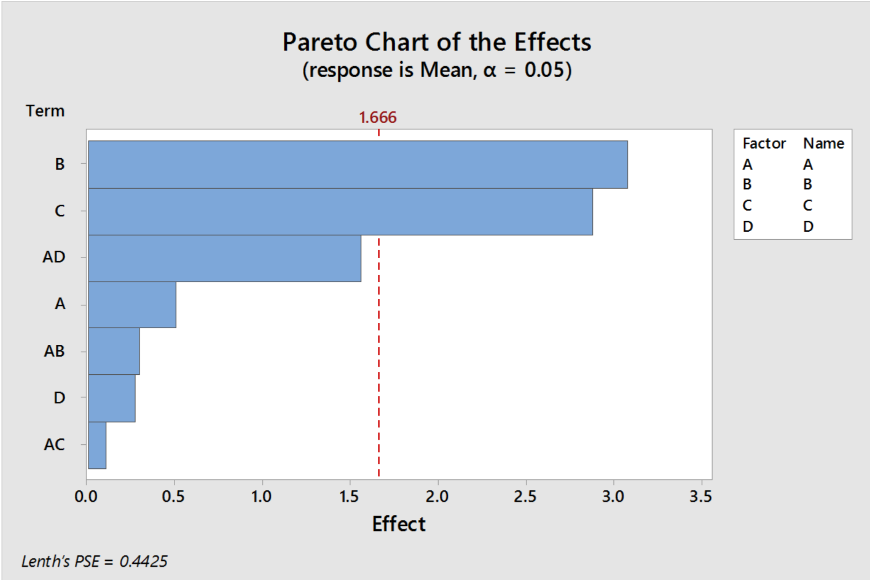
Mean = 10.80 + 0.2550 A + 1.540 B - 1.443 C - 0.1375 D + 0.1475 A*B - 0.05500 A*C - 0.7800 A*D

Alias Structure

Factor	Name
A	A
B	B
C	C
D	D

Aliases
I + ABCD
A + BCD
B + ACD
C + ABD
D + ABC
AB + CD
AC + BD
AD + BC





Factorial Regression: StdDev versus A, B, C, D

The following terms are totally confounded with other terms and were removed:
B*C, B*D, C*D, A*B*C, A*B*D, A*C*D, B*C*D, A*B*C*D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	6.92059	0.98866	*	*
Linear	4	5.85725	1.46431	*	*
A	1	2.34361	2.34361	*	*
B	1	0.18301	0.18301	*	*
C	1	0.01531	0.01531	*	*
D	1	3.31531	3.31531	*	*
2-Way Interactions	3	1.06334	0.35445	*	*
A*B	1	0.10351	0.10351	*	*
A*C	1	0.08201	0.08201	*	*
A*D	1	0.87781	0.87781	*	*
Error	0	*	*		
Total	7	6.92059			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)

*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1.614	*	*	*	
A	-1.0825	-0.5413	*	*	*	1.00
B	0.3025	0.1512	*	*	*	1.00
C	0.08750	0.04375	*	*	*	1.00
D	-1.2875	-0.6438	*	*	*	1.00
A*B	-0.2275	-0.1137	*	*	*	1.00
A*C	-0.2025	-0.1012	*	*	*	1.00
A*D	0.6625	0.3313	*	*	*	1.00

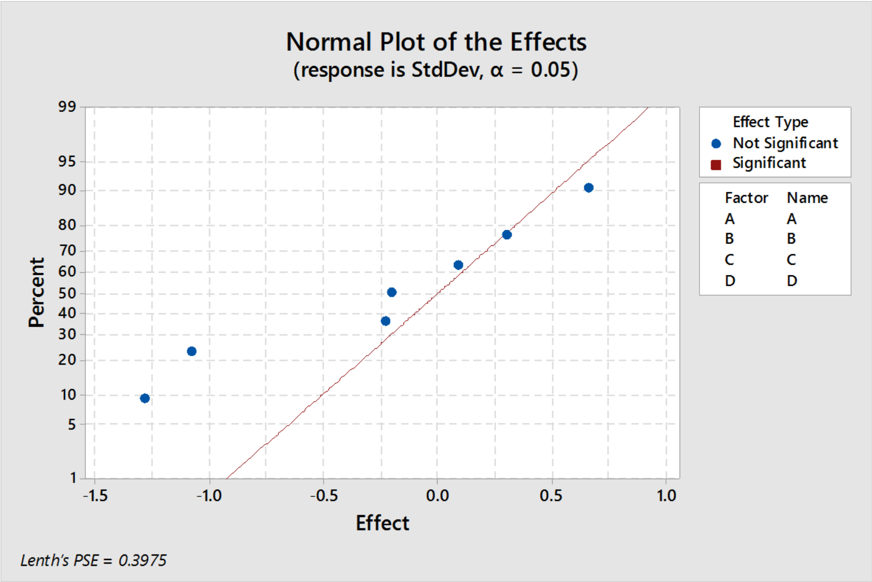
Regression Equation in Uncoded Units

StdDev = 1.614 - 0.5413 A + 0.1512 B + 0.04375 C - 0.6438 D - 0.1137 A*B - 0.1012 A*C + 0.3313 A*D

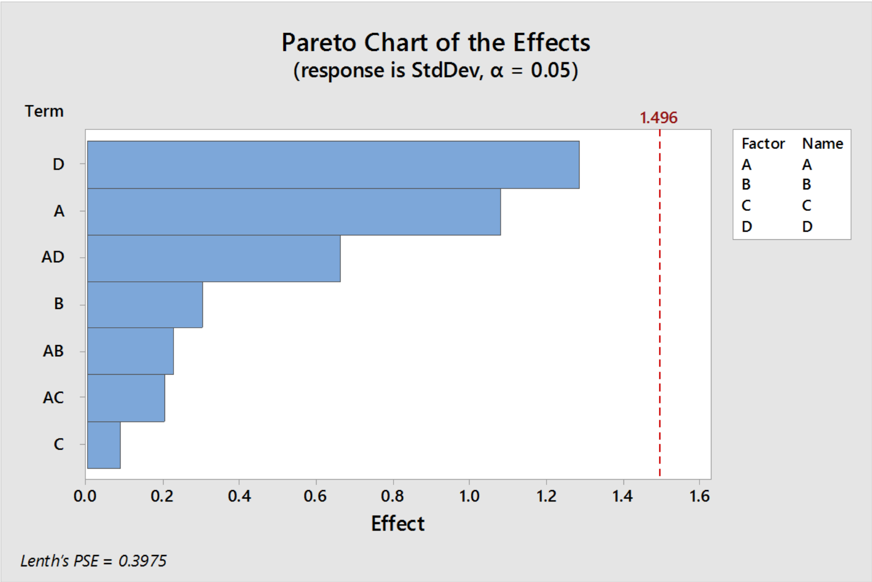
Alias Structure

Factor	Name
A	A
B	B
C	C
D	D

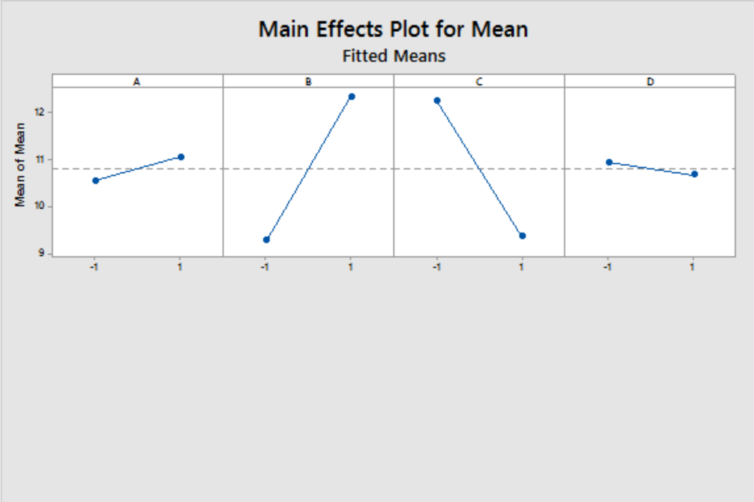
Aliases
I + ABCD
A + BCD
B + ACD
C + ABD
D + ABC
AB + CD
AC + BD
AD + BC

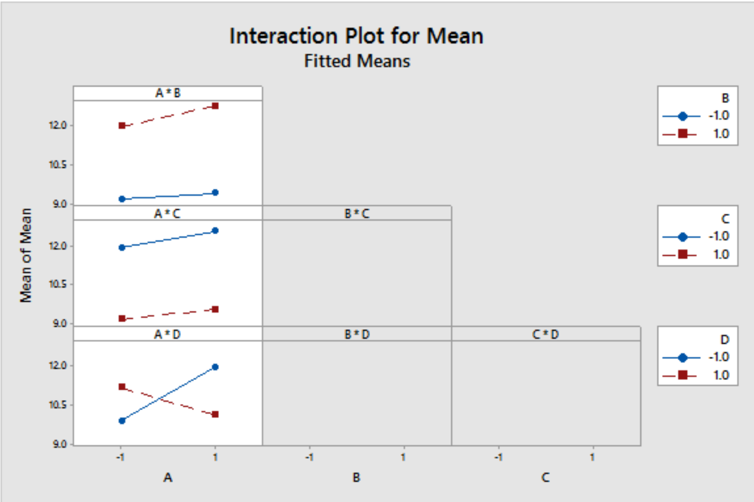


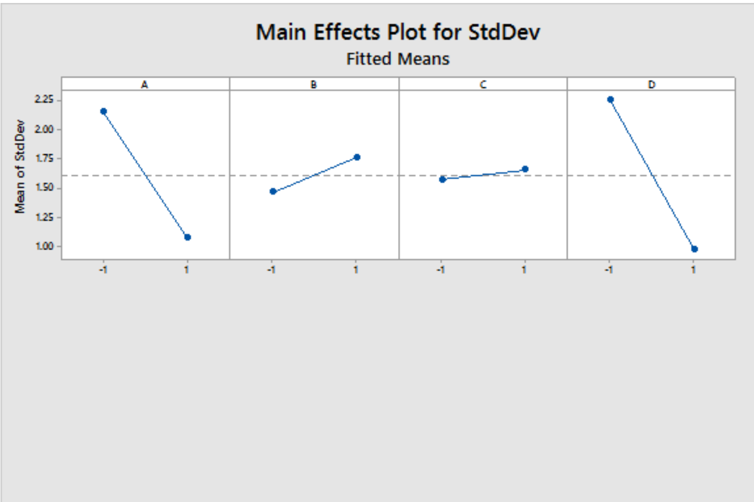
Normal Plot of the Effects
(response is StdDev, α = 0.05)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-1.5
-1.0
-0.5
0.0
0.5
1.0
Effect
Effect Type
Not Significant
Significant
Factor Name
A A
B B
C C
D D
Lenth's PSE = 0.3975

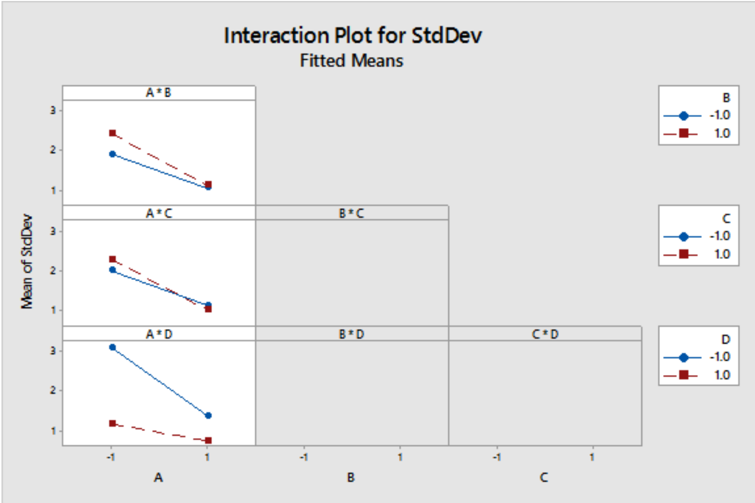


Pareto Chart of the Effects
(response is StdDev, α = 0.05)
Term
1.496
D
A
AD
B
AB
AC
C
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Effect
Factor Name
A A
B B
C C
D D
Lenth's PSE = 0.3975


Main Effects Plot for Mean
Fitted Means
Mean of Mean
A
B
C
D


Interaction Plot for Mean
Fitted Means
Mean of Mean
A * B
A * C
B * C
A * D
B * D
C * D
A
B
C
D


Main Effects Plot for StdDev
Fitted Means
Mean of StdDev
A
B
C
D



For means, factor B has a large positive effect while factor C has a large negative effect. There may be an interaction between B and C (which is aliased with AD). There do not appear to be any noticeable effects for standard deviations.

3. The Bush Experiment

In a VU student project conducted by Peter Kostaridis and Nick Condilis, an experiment was carried out to improve the rubber composition of the bush, an important part of the suspension system, used in a locally manufactured car. The levels of six components were varied and the resulting compound was tested to determine the Loss Angle and Dynamic Stiffness. The factors have been coded as 301 (A), 302 (B), 303 (C), 304 (D), 308 (E), and 309 (F) for confidentiality reasons and the levels given as $-$ and $+$. The design and results are given in Table 5.

Run	A	B	C	D	E	F	Loss Angle	Dynamic Stiffness
1	$-$	$-$	$-$	$-$	$-$	$-$	5.45	520
2	$+$	$-$	$-$	$+$	$+$	$+$	4.55	501
3	$-$	$+$	$-$	$+$	$+$	$-$	7.23	864
4	$+$	$+$	$-$	$-$	$-$	$+$	6.11	999
5	$-$	$-$	$+$	$-$	$+$	$+$	4.93	573
6	$+$	$-$	$+$	$+$	$-$	$-$	6.37	523
7	$-$	$+$	$+$	$+$	$-$	$+$	5.59	946
8	$+$	$+$	$+$	$-$	$+$	$-$	7.72	686

Table 5: Design and results for the Bush Experiment

(a) Read the design and results into Minitab and set up the Experimental Design.

```
File/Open/DOE_Bush1.csv OK
Stat/DOE/Define Custom Factorial Design
Factors: A B C D
Low/High OK
Design/Standard Order Column/Specify By Column: Run OK
OK
```

(b) Analyse the experiment.

```
Stat/DOE/Factorial/Analyze Factorial Data
Responses: LossAngle DynamicStiffness OK
Graphs/Pareto Normal OK
Stat/DOE/Factorial/Factorial Plots OK
```

Factorial Regression: LossAngle versus A, B, C, D, E, FF

The following terms are totally confounded with other terms and were removed:
A*B, A*C, A*D, A*FF, B*C, B*D, B*E, B*FF, C*D, C*E, C*FF, D*E, D*FF, E*FF, A*B*C, A*B*D, A*B*E, A*B*FF, A*C*D, A*C*E, A*C*FF, A*D*E, A*D*FF, A*E*FF, B*C*D, B*C*E, B*C*FF, B*D*E, B*D*FF, B*E*FF, C*D*E, C*D*FF, C*E*FF, D*E*FF, A*B*C*D, A*B*C*E, A*B*C*FF, A*B*D*E, A*B*D*FF, A*B*E*FF, A*C*D*E, A*C*D*FF, A*C*E*FF, A*D*E*FF, B*C*D*E, B*C*D*FF, B*C*E*FF, B*D*E*FF, C*D*E*FF, A*B*C*D*E, A*B*C*D*FF, A*B*C*E*FF, A*B*D*E*FF, A*C*D*E*FF, B*C*D*E*FF, A*B*C*D*E*FF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	8.36300	1.19471	*	*
Linear	6	8.13180	1.35530	*	*
A	1	0.31205	0.31205	*	*
B	1	3.53780	3.53780	*	*
C	1	0.19220	0.19220	*	*
D	1	0.03125	0.03125	*	*
E	1	0.11045	0.11045	*	*
FF	1	3.94805	3.94805	*	*
2-Way Interactions	1	0.23120	0.23120	*	*
A*E	1	0.23120	0.23120	*	*
Error	0	*	*		
Total	7	8.36300			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		5.990	*	*	*	
A	0.3950	0.1975	*	*	*	1.00
B	1.3300	0.6650	*	*	*	1.00
C	0.3100	0.1550	*	*	*	1.00
D	-0.12500	-0.06250	*	*	*	1.00
E	0.2350	0.1175	*	*	*	1.00
FF	-1.4050	-0.7025	*	*	*	1.00
A*E	-0.3400	-0.1700	*	*	*	1.00

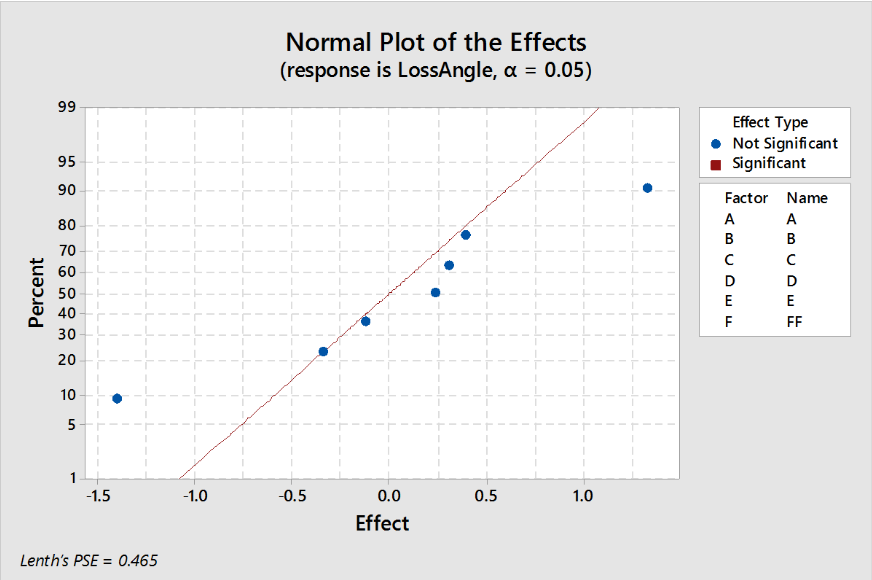
Regression Equation in Uncoded Units

LossAngle = 5.990 + 0.1975 A + 0.6650 B + 0.1550 C - 0.06250 D + 0.1175 E - 0.7025 FF - 0.1700 A*E

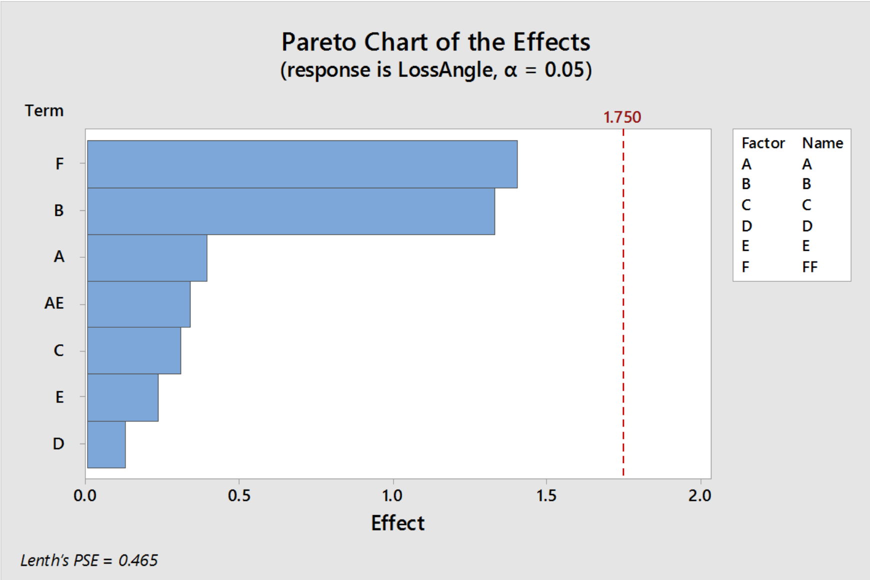
Alias Structure

Factor	Name
A	A
B	B
C	C
D	D
E	E
F	FF

Aliases
I - ABD - ACF - BEF - CDE + ABCE + ADEF + BCDF
A - BD - CF + BCE + DEF - ABEF - ACDE + ABCDF
B - AD - EF + ACE + CDF - ABCF - BCDE + ABDEF
C - AF - DE + ABE + BDF - ABCD - BCEF + ACDEF
D - AB - CE + AEF + BCF - ACDF - BDEF + ABCDE
E - BF - CD + ABC + ADF - ABDE - ACEF + BCDEF
F - AC - BE + ADE + BCD - ABDF - CDEF + ABCEF
AE + BC + DF - ABF - ACD - BDE - CEF + ABCDEF



ESQUANT
Statistical Consulting



Factorial Regression: DynamicStiffness versus A, B, C, D, E, FF

The following terms are totally confounded with other terms and were removed:
A*B, A*C, A*D, A*FF, B*C, B*D, B*E, B*FF, C*D, C*E, C*FF, D*E, D*FF, E*FF, A*B*C, A*B*D, A*B*E, A*B*FF, A*C*D, A*C*E, A*C*FF, A*D*E, A*D*FF, A*E*FF, B*C*D, B*C*E, B*C*FF, B*D*E, B*D*FF, B*E*FF, C*D*E, C*D*FF, C*E*FF, D*E*FF, A*B*C*D, A*B*C*E, A*B*C*FF, A*B*D*E, A*B*D*FF, A*B*E*FF, A*C*D*E, A*C*D*FF, A*C*E*FF, A*D*E*FF, B*C*D*E, B*C*D*FF, B*C*E*FF, B*D*E*FF, C*D*E*FF, A*B*C*D*E, A*B*C*D*FF, A*B*C*E*FF, A*B*D*E*FF, A*C*D*E*FF, B*C*D*E*FF, A*B*C*D*E*FF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	296450	42350	*	*
Linear	6	284745	47458	*	*
A	1	4705	4705	*	*
B	1	237361	237361	*	*
C	1	3042	3042	*	*
D	1	392	392	*	*
E	1	16562	16562	*	*
FF	1	22684	22684	*	*
2-Way Interactions	1	11705	11705	*	*
A*E	1	11705	11705	*	*
Error	0	*	*		
Total	7	296450			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		701.5	*	*	*	
A	-48.50	-24.25	*	*	*	1.00
B	344.5	172.3	*	*	*	1.00
C	-39.00	-19.50	*	*	*	1.00
D	14.000	7.000	*	*	*	1.00
E	-91.00	-45.50	*	*	*	1.00
FF	106.50	53.25	*	*	*	1.00
A*E	-76.50	-38.25	*	*	*	1.00

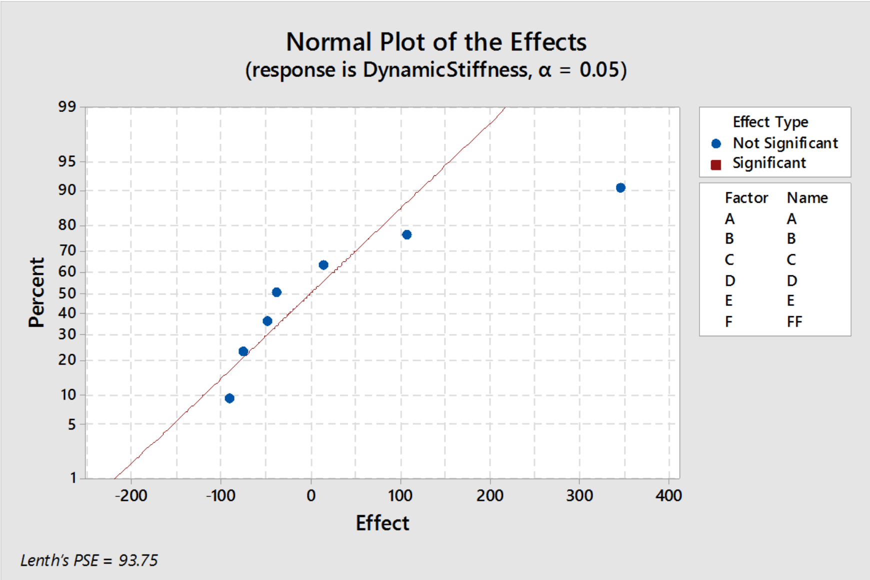
Regression Equation in Uncoded Units

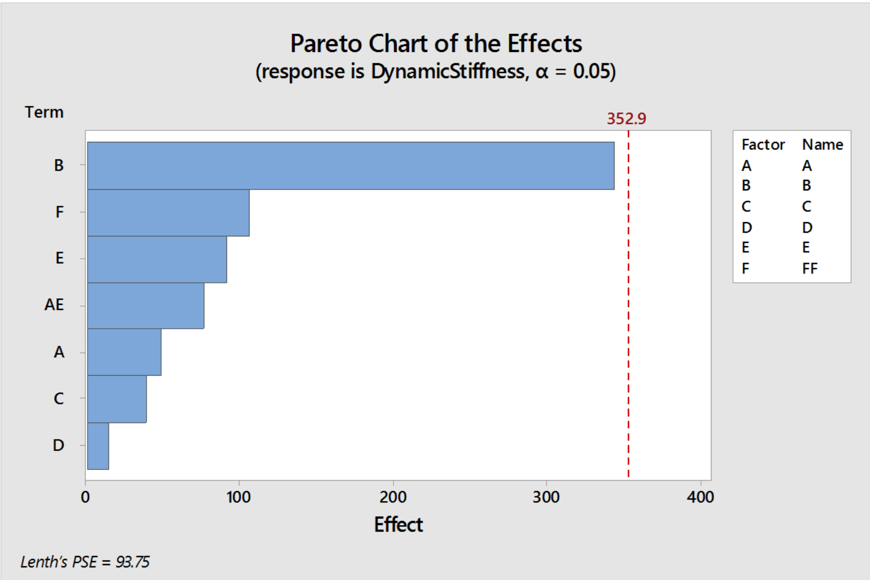
DynamicStiffness = 701.5 - 24.25 A + 172.3 B - 19.50 C + 7.000 D - 45.50 E + 53.25 FF - 38.25 A*E

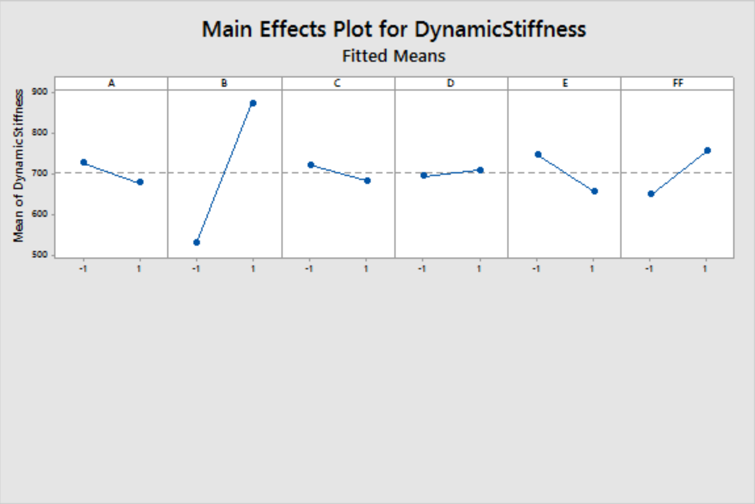
Alias Structure

Factor	Name
A	A
B	B
C	C
D	D
E	E
F	FF

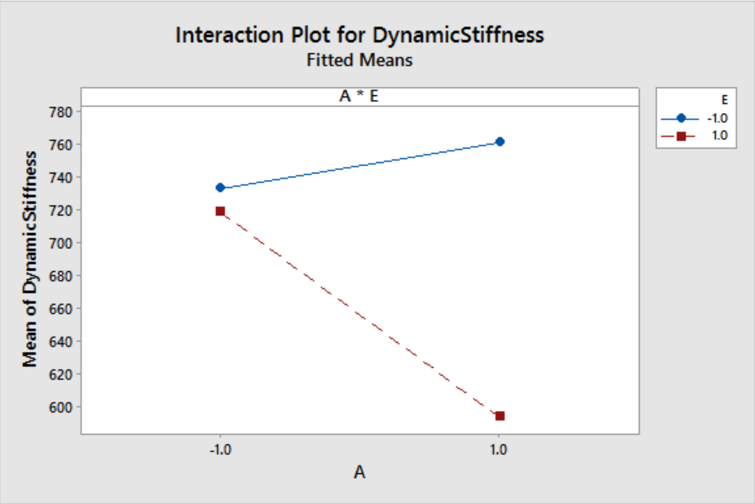
Aliases
I - ABD - ACF - BEF - CDE + ABCE + ADEF + BCDF
A - BD - CF + BCE + DEF - ABEF - ACDE + ABCDF
B - AD - EF + ACE + CDF - ABCF - BCDE + ABDEF
C - AF - DE + ABE + BDF - ABCD - BCEF + ACDEF
D - AB - CE + AEF + BCF - ACDF - BDEF + ABCDE
E - BF - CD + ABC + ADF - ABDE - ACEF + BCDEF
F - AC - BE + ADE + BCD - ABDF - CDEF + ABCEF
AE + BC + DF - ABF - ACD - BDE - CEF + ABCDEF


Normal Plot of the Effects
(response is DynamicStiffness, α = 0.05)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-200
-100
0
100
200
300
400
Effect
Effect Type
Not Significant
Significant
Factor Name
A A
B B
C C
D D
E E
F FF
Lenth's PSE = 93.75

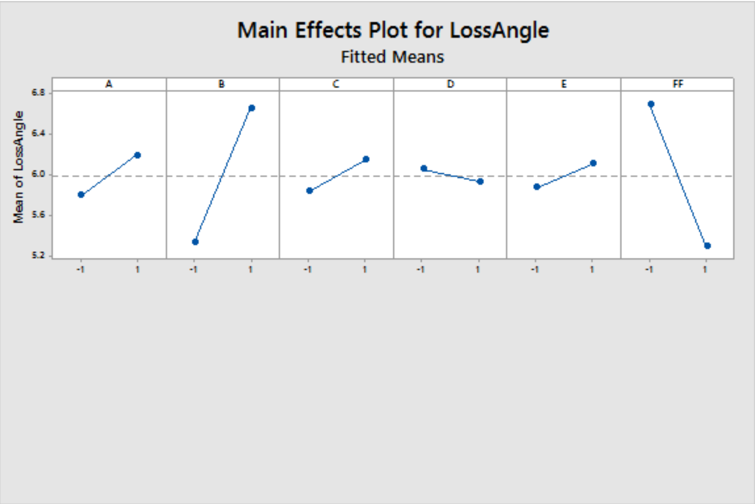

Pareto Chart of the Effects
(response is DynamicStiffness, α = 0.05)
Term
352.9
B
F
E
AE
A
C
D
0
100
200
300
400
Effect
Factor Name
A A
B B
C C
D D
E E
F FF
Lenth's PSE = 93.75



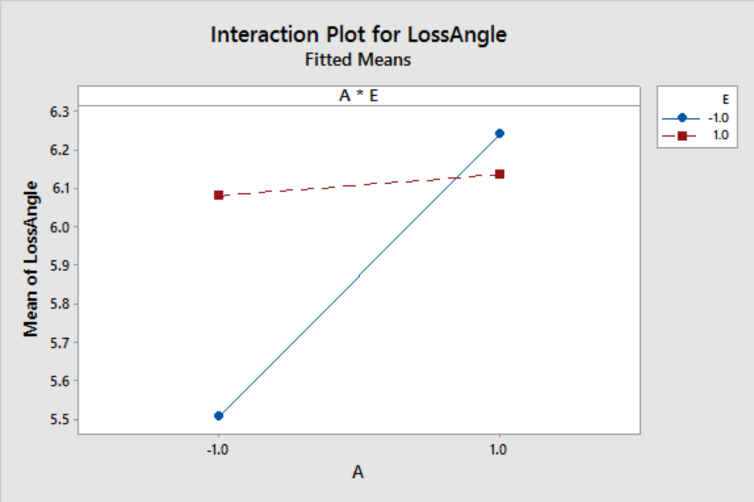
Main Effects Plot for DynamicStiffness
Fitted Means
Mean of DynamicStiffness
A
B
C
D
E
FF



Interaction Plot for DynamicStiffness
Fitted Means
A * E
Mean of DynamicStiffness
E
-1.0
1.0
A



Main Effects Plot for LossAngle
Fitted Means
Mean of LossAngle
A
B
C
D
E
FF



For Loss Angle, factor B has a large positive effect while factor B has a large negative effect. For Dynamic Stiffness, factor B has a large negative effect.

4. Explosives Development

In the development of a new explosive, a set of experiments were run involving five factors with A, Age of Gum; B, Age of Thiourea; C, pH controlled; D, Aluminium level; and E, Crosslinker Level. The response was the Gel Strength after 10 minutes. The design and results are given in Table 6.

A	B	C	D	E	Gel Strength (10 Mins)
−	−	−	−	+	469
+	−	−	−	−	330
−	+	−	−	−	266
+	+	−	−	+	351
−	−	+	−	−	316
+	−	+	−	+	522
−	+	+	−	+	357
+	+	+	−	−	430
−	−	−	+	−	293
+	−	−	+	+	708
−	+	−	+	+	267
+	+	−	+	−	341
−	−	+	+	+	502
+	−	+	+	−	453
−	+	+	+	−	197
+	+	+	+	+	568

Table 6: Design and results for the Explosives Development Experiment

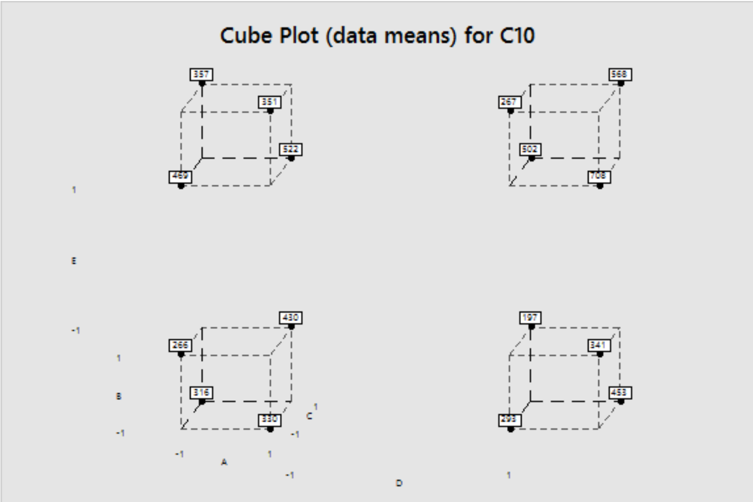
(a) Read the design and results into Minitab and set up the Experimental Design.

Stat/DOE/Factorial/Create Factorial Design
Create Factorial Design: 2 Level Factorial (default generators)
Number of factors:5

Designs: Half Factorial OK
Options: Undo Randomise Runs OK

(b) Add results in C10 and make a cube plot.

Stat/DOE/Cube Plot
Cube Plot/Response: C10 OK



(c) Analyse the experiment.

Stat/DOE/Factorial/Analyze Factorial Data
Responses: C10 OK
Graphs/Pareto Normal OK
Stat/DOE/Factorial/Factorial Plots OK

Fractional Factorial Design

Design Summary

Factors:	5	Base Design:	5, 16	Resolution:	V
Runs:	16	Replicates:	1	Fraction:	1/2
Blocks:	1	Center pts (total):	0		

Design Generators: E = ABCD

Alias Structure

I + ABCDE

A + BCDE

B + ACDE

C + ABDE

D + ABCE

E + ABCD

AB + CDE

AC + BDE

AD + BCE

AE + BCD

BC + ADE

BD + ACE

BE + ACD

CD + ABE

CE + ABD

DE + ABC

Factorial Regression: C10 versus A, B, C, D, E

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	264780	17652.0	*	*
Linear	5	198401	39680.3	*	*
A	1	67081	67081.0	*	*
B	1	41616	41616.0	*	*
C	1	6400	6400.0	*	*
D	1	5184	5184.0	*	*
E	1	78120	78120.2	*	*
2-Way Interactions	10	66379	6637.9	*	*

A*B	1	1806	1806.2	*	*
A*C	1	1722	1722.2	*	*
A*D	1	21462	21462.3	*	*
A*E	1	324	324.0	*	*
B*C	1	6972	6972.3	*	*
B*D	1	7656	7656.2	*	*
B*E	1	15625	15625.0	*	*
C*D	1	600	600.3	*	*
C*E	1	9	9.0	*	*
D*E	1	10201	10201.0	*	*
Error	0	*	*		
Total	15	264780			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		398.1	*	*	*	
A	129.50	64.75	*	*	*	1.00
B	-102.00	-51.00	*	*	*	1.00
C	40.00	20.00	*	*	*	1.00
D	36.00	18.00	*	*	*	1.00
E	139.75	69.88	*	*	*	1.00
A*B	21.25	10.63	*	*	*	1.00
A*C	20.75	10.38	*	*	*	1.00
A*D	73.25	36.63	*	*	*	1.00
A*E	9.000	4.500	*	*	*	1.00
B*C	41.75	20.88	*	*	*	1.00
B*D	-43.75	-21.87	*	*	*	1.00
B*E	-62.50	-31.25	*	*	*	1.00
C*D	-12.250	-6.125	*	*	*	1.00
C*E	-1.5000	-0.7500	*	*	*	1.00
D*E	50.50	25.25	*	*	*	1.00

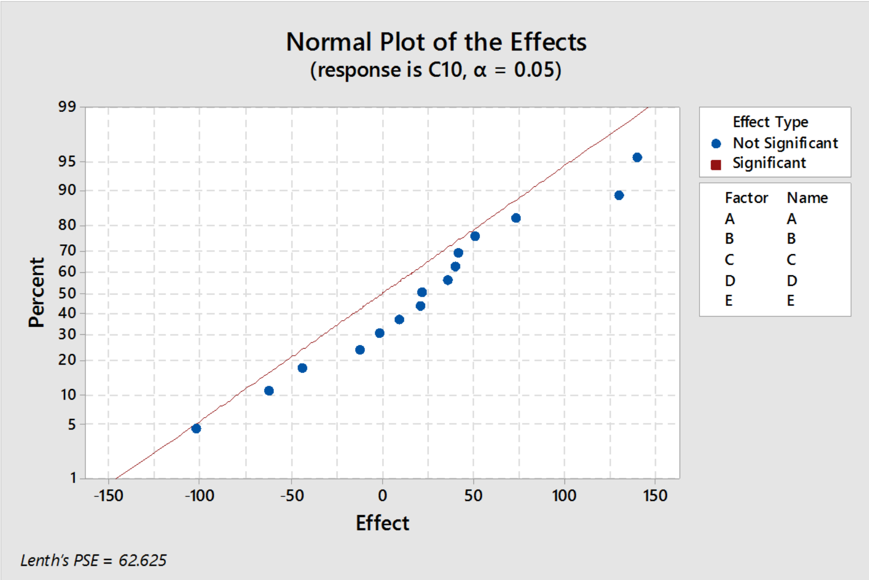
Regression Equation in Uncoded Units

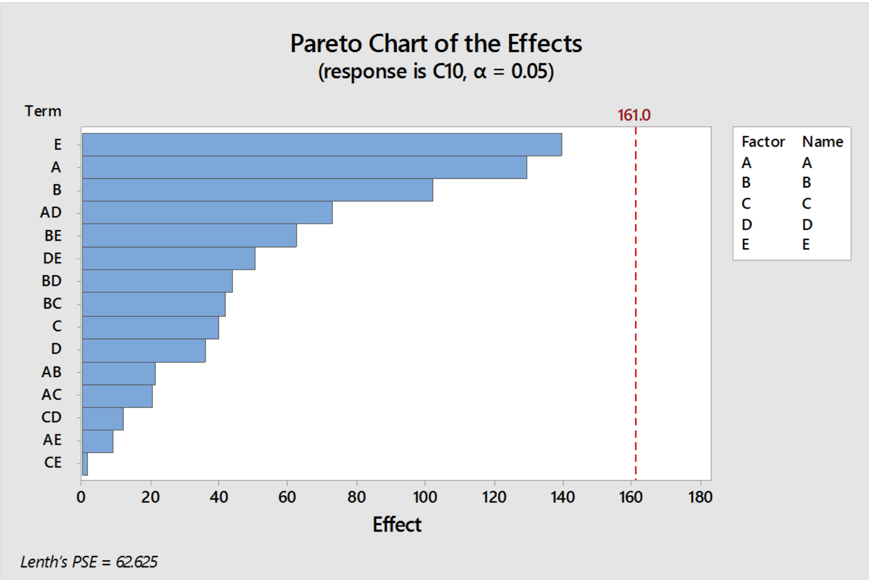
C10 = 398.1 + 64.75 A - 51.00 B + 20.00 C + 18.00 D + 69.88 E + 10.63 A*B + 10.38 A*C
+ 36.63 A*D + 4.500 A*E + 20.88 B*C - 21.87 B*D - 31.25 B*E - 6.125 C*D - 0.7500 C*E
+ 25.25 D*E

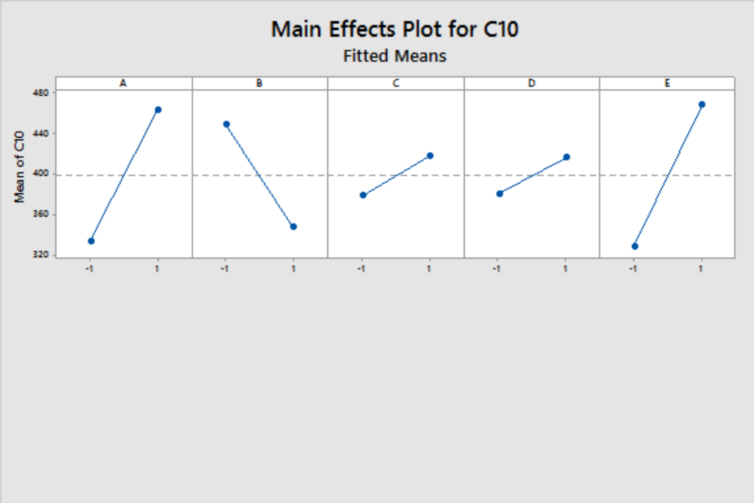
Alias Structure

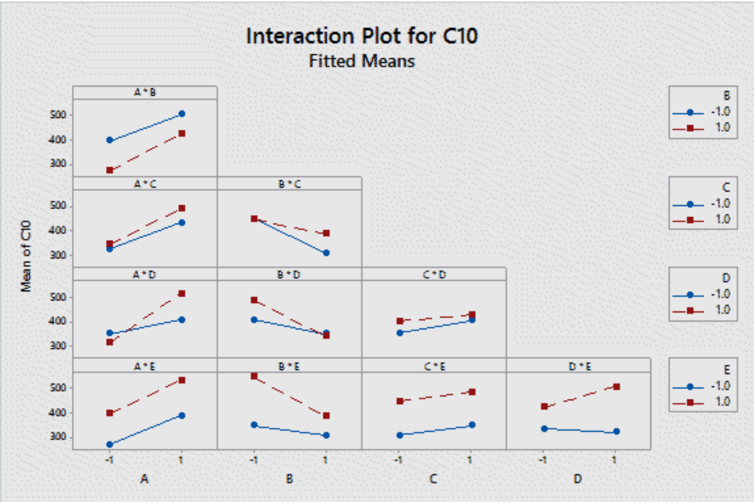
Factor	Name
A	A
B	B
C	C
D	D
E	E

Aliases
I + ABCDE
A + BCDE
B + ACDE
C + ABDE
D + ABCE
E + ABCD
AB + CDE
AC + BDE
AD + BCE
AE + BCD
BC + ADE
BD + ACE
BE + ACD
CD + ABE
CE + ABD
DE + ABC


Normal Plot of the Effects
(response is C10, α = 0.05)
Percent
Effect
Effect Type
Not Significant
Significant
Factor Name
A A
B B
C C
D D
E E
Lenth's PSE = 62.625


Pareto Chart of the Effects
(response is C10, α = 0.05)
Term
161.0
Effect
Factor Name
A A
B B
C C
D D
E E
Lenth's PSE = 62.625





The results are inconclusive. Possiblr factors E, A, and B have significant effects. Follow up experiments should be suggested.

5. Injection Molding Experiment

In an injection molding experiment eight variables were studied in 16 runs. The response was percentage shrinkage. The variables are given in Table 6 while the design and results are given in Table 7.

A	Mold Temperature
B	Moisture Content
C	Holding Pressure
D	Cavity Thickness
E	Booster Pressure
F	Cycle Time
G	Gate Size
H	Screw Speed

Table 7: Variables for Injection Molding Experiment

(a) Read the design and results into Minitab and set up the Experimental Design.

File/Open/InjectionMolding.csv OK
Stat/DOE/Define Custom Factorial Design
Factors: A B C D E FF G H
Low/High OK
Design/Standard Order Column/Specify By Column: Run OK
OK

(b) Analyse the experiment.

Stat/DOE/Factorial/Analyze Factorial Data
Responses: Shrinkage OK
Graphs/Pareto Normal OK
Stat/DOE/Factorial/Factorial Plots OK

Factorial Regression: Shrinkage versus A, B, C, D, E, FF, G, H

The following terms are totally confounded with other terms and were removed:
B*C, B*D, B*E, B*FF, B*G, B*H, C*D, C*E, C*FF, C*G, C*H, D*E, D*FF, D*G, D*H, E*FF, E*G, E*H, FF*G, FF*H, G*H, A*B*C, A*B*D, A*B*E, A*B*FF, A*B*G, A*B*H, A*C*D, A*C*E, A*C*FF, A*C*G, A*C*H, A*D*E, A*D*FF, A*D*G, A*D*H, A*E*FF, A*E*G, A*E*H, A*FF*G, A*FF*H, A*G*H, B*C*D, B*C*E, B*C*FF, B*C*G, B*C*H, B*D*E, B*D*FF, B*D*G, B*D*H, B*E*FF, B*E*G, B*E*H, B*FF*G, B*FF*H, B*G*H, C*D*E, C*D*FF, C*D*G, C*D*H, C*E*FF, C*E*G, C*E*H, C*FF*G, C*FF*H, C*G*H, D*E*FF, D*E*G, D*E*H, D*FF*G, D*FF*H, D*G*H, E*FF*G, E*FF*H, E*G*H, FF*G*H

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	278.759	18.584	*	*
Linear	8	187.295	23.412	*	*
A	1	1.891	1.891	*	*
B	1	0.051	0.051	*	*
C	1	120.451	120.451	*	*
D	1	0.331	0.331	*	*
E	1	57.381	57.381	*	*
FF	1	0.051	0.051	*	*
G	1	1.501	1.501	*	*
H	1	5.641	5.641	*	*
2-Way Interactions	7	91.464	13.066	*	*
A*B	1	1.381	1.381	*	*
A*C	1	3.331	3.331	*	*
A*D	1	0.681	0.681	*	*
A*E	1	84.181	84.181	*	*
A*FF	1	0.331	0.331	*	*
A*G	1	0.181	0.181	*	*
A*H	1	1.381	1.381	*	*
Error	0	*	*		
Total	15	278.759			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
*	100.00%	*	*

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		19.74	*	*	*	
A	-0.6875	-0.3437	*	*	*	1.00

B	-0.11250	-0.05625	*	*	*	1.00
C	5.488	2.744	*	*	*	1.00
D	-0.2875	-0.1438	*	*	*	1.00
E	-3.787	-1.894	*	*	*	1.00
FF	-0.11250	-0.05625	*	*	*	1.00
G	0.6125	0.3062	*	*	*	1.00
H	1.1875	0.5938	*	*	*	1.00
A*B	-0.5875	-0.2938	*	*	*	1.00
A*C	0.9125	0.4562	*	*	*	1.00
A*D	-0.4125	-0.2062	*	*	*	1.00
A*E	4.587	2.294	*	*	*	1.00
A*FF	-0.2875	-0.1437	*	*	*	1.00
A*G	-0.2125	-0.1062	*	*	*	1.00
A*H	-0.5875	-0.2937	*	*	*	1.00

Regression Equation in Uncoded Units

Shrinkage = 19.74 - 0.3437 A - 0.05625 B + 2.744 C - 0.1438 D - 1.894 E - 0.05625 FF
+ 0.3062 G + 0.5938 H - 0.2938 A*B + 0.4562 A*C - 0.2062 A*D + 2.294 A*E
- 0.1437 A*FF - 0.1062 A*G - 0.2937 A*H

Alias Structure (up to order 3)

Factor	Name
A	A
B	B
C	C
D	D
E	E
F	FF
G	G
H	H

Aliases
I
A + BCG + BDH + BEF + CDF + CEH + DEG + FGH
B + ACG + ADH + AEF + CDE + CFH + DFG + EGH
C + ABG + ADF + AEH + BDE + BFH + DGH + EFG
D + ABH + ACF + AEG + BCE + BFG + CGH + EFH
E + ABF + ACH + ADG + BCD + BGH + CFG + DFH
F + ABE + ACD + AGH + BCH + BDG + CEG + DEH

G + ABC + ADE + AFH + BDF + BEH + CDH + CEF

H + ABD + ACE + AFG + BCF + BEG + CDG + DEF

AB + CG + DH + EF

AC + BG + DF + EH

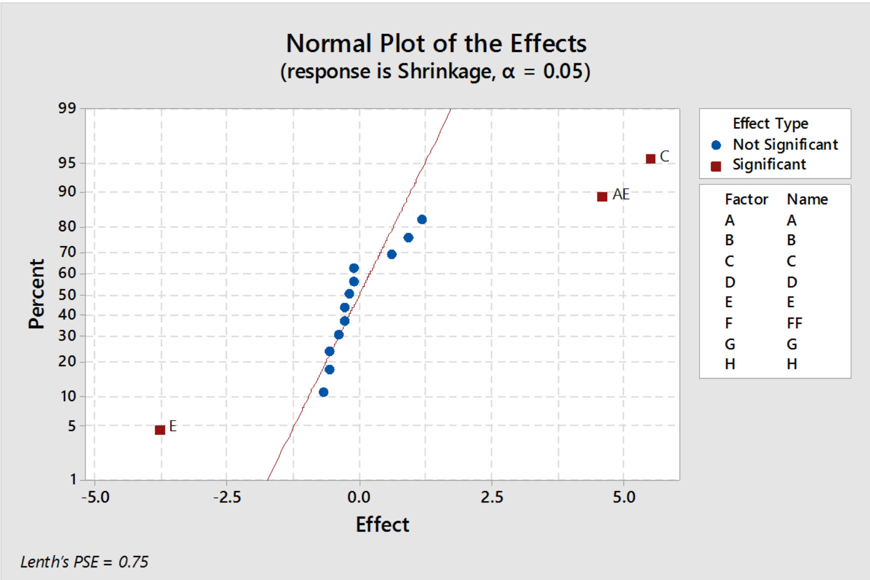
AD + BH + CF + EG

AE + BF + CH + DG

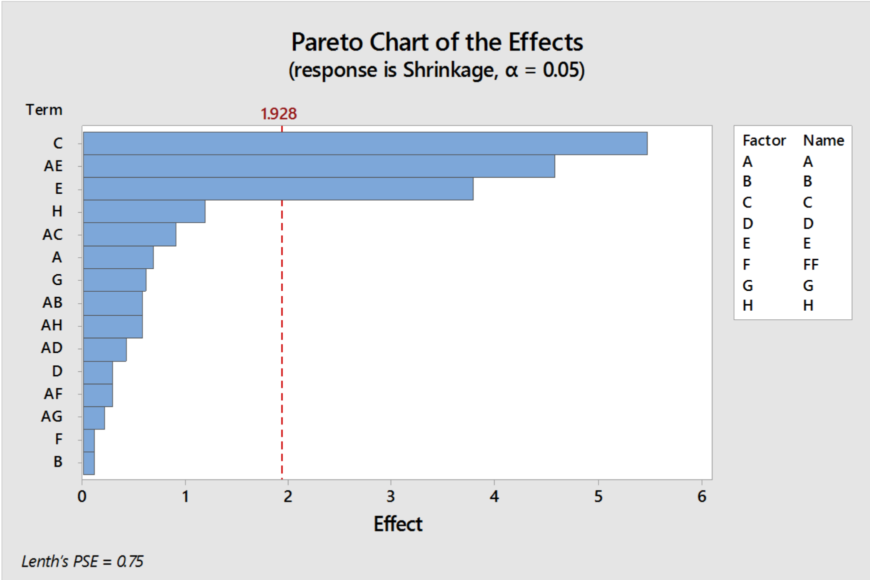
AF + BE + CD + GH

AG + BC + DE + FH

AH + BD + CE + FG

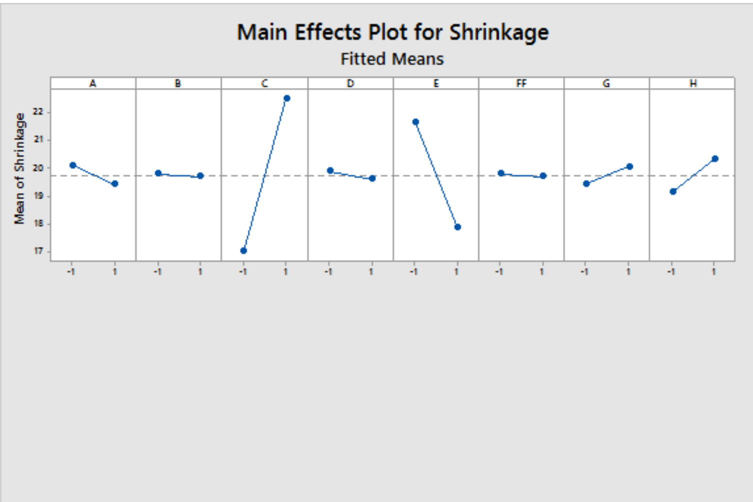


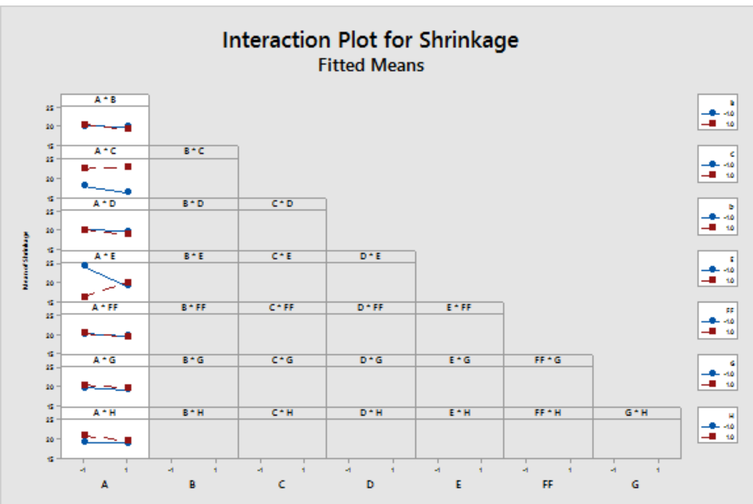
ESQUANT
Statistical Consulting


Pareto Chart of the Effects
(response is Shrinkage, α = 0.05)
Term
1.928
C
AE
E
H
AC
A
G
AB
AH
AD
D
AF
AG
F
B
0
1
2
3
4
5
6
Effect
Lenth's PSE = 0.75
Factor Name
A A
B B
C C
D D
E E
F FF
G G
H H

Run	A	B	C	D	E	F	G	H	Shrinkage
1	−	−	−	−	−	−	−	−	20.3
2	+	−	−	−	−	+	+	+	16.8
3	−	+	−	−	+	−	+	+	15.0
4	+	+	−	−	+	+	−	+	15.9
5	−	−	+	−	+	+	+	−	17.5
6	+	−	+	−	+	−	−	+	24.0
7	−	+	+	−	−	+	−	+	27.4
8	+	+	+	−	−	−	+	−	22.3
9	−	−	−	+	+	+	−	−	14.0
10	+	−	−	+	+	−	+	+	16.7
11	−	+	−	+	−	+	+	−	21.9
12	+	+	−	+	−	−	−	+	15.4
13	−	−	+	+	−	−	+	+	27.6
14	+	−	+	+	−	+	−	−	21.5
15	−	+	+	+	+	−	−	−	17.1
16	+	+	+	+	+	+	+	+	22.6

Table 8: Design and results for the Injection Molding Experiment





C and E have significant effects with a significant interaction string involving AE+BF+CH+DG. Follow up experiments are probably required.

6. Response Surface Example TR18532:2009 Pages 156-158.

> Technical and operational considerations indicate that three factors, gas ratio, power and pulse may influence oxide uniformity. Non-linearity and interactions are expected so each factor was investigated at three levels using an 18 run central composite (face-centred cube) design. The three levels of each factor were coded −1, 0, and 1 for convenience. Results are shown in Table 8.

Gas Ratio	Pulse	Power	Oxide Uniformity
0	0	0	29.4
0	0	0	32.1
0	0	0	31.5
0	0	0	30.9
−1	−1	−1	16.9
−1	1	−1	17.2
−1	1	1	22.7
−1	−1	1	52.4
1	−1	−1	10.7
1	1	−1	22.6
1	1	1	23.8
1	−1	1	43.5
0	−1	0	32.7
0	0	−1	16.4
0	1	0	24.1
0	0	1	37.5
−1	0	0	27.6
1	0	0	31.8

Table 9: Results for experiment runs on etching process

(a) Read the design and results into Minitab and set up the Experimental Design.

> File/Open/rsmexample.csv OK
> Stat/DOE/Response Surface/Define Custom Response Surface Design
> Factors: GasRatio Pulse Power
> Low/High OK
> Design/Standard Order Column/Specify By Column: OxideUniformity OK
> OK

(b) Analyse the experiment.

Stat/DOE/Response Surface/Analyze Response Surface Design
Responses: OxideUniformity OK
Stat/DOE/Response Surface/Contour Plot
Generate plots of all pairs of continuous variables OK

Response Surface Regression: OxideUniformity versus ... , Pulse, Power

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1753.62	194.847	128.25	0.000
Linear	3	1149.67	383.223	252.25	0.000
GasRatio	1	16.38	16.384	10.78	0.011
Pulse	1	209.76	209.764	138.07	0.000
Power	1	923.52	923.521	607.89	0.000
Square	3	65.19	21.730	14.30	0.001
GasRatio*GasRatio	1	0.02	0.019	0.01	0.913
Pulse*Pulse	1	5.19	5.194	3.42	0.102
Power*Power	1	21.77	21.771	14.33	0.005
2-Way Interaction	3	538.77	179.588	118.21	0.000
GasRatio*Pulse	1	58.32	58.320	38.39	0.000
GasRatio*Power	1	6.13	6.125	4.03	0.080
Pulse*Power	1	474.32	474.320	312.21	0.000
Error	8	12.15	1.519		
Lack-of-Fit	5	8.13	1.625	1.21	0.467
Pure Error	3	4.03	1.343		
Total	17	1765.78			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.23257	99.31%	98.54%	96.57%

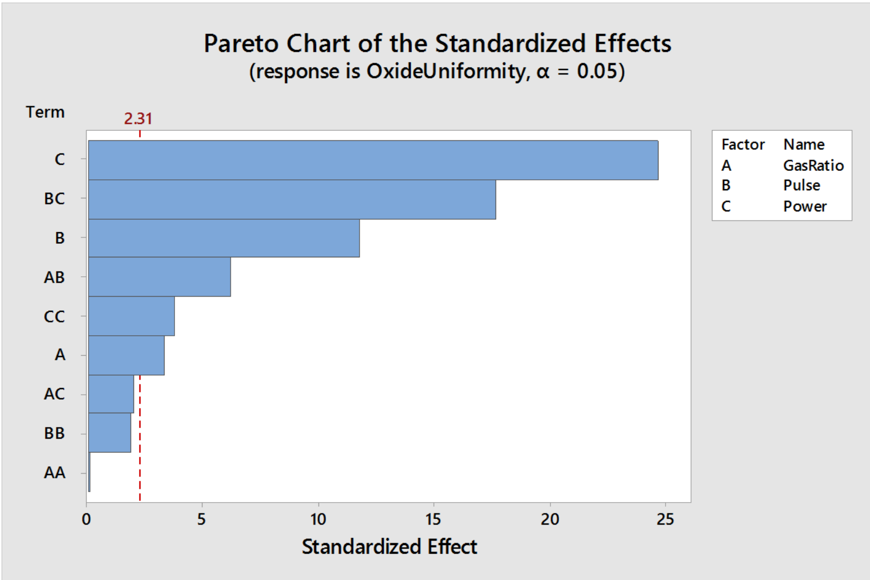
Coded Coefficients

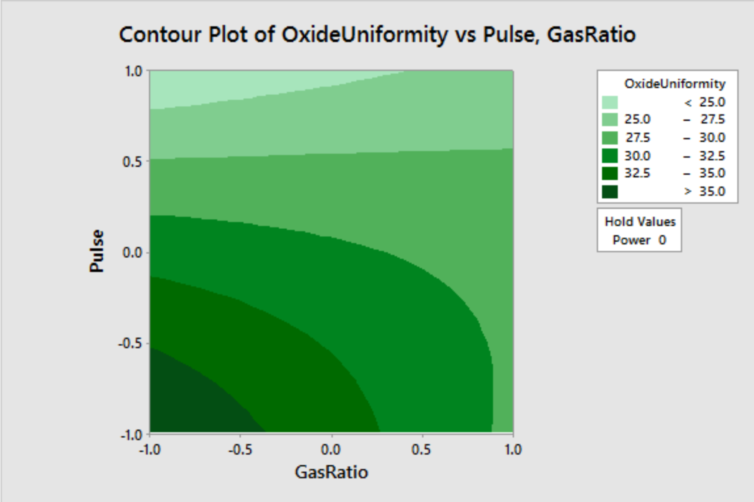
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	30.380	0.485	62.65	0.000	
GasRatio	-1.280	0.390	-3.28	0.011	1.00
Pulse	-4.580	0.390	-11.75	0.000	1.00
Power	9.610	0.390	24.66	0.000	1.00
GasRatio*GasRatio	-0.085	0.749	-0.11	0.913	1.64
Pulse*Pulse	-1.385	0.749	-1.85	0.102	1.64
Power*Power	-2.835	0.749	-3.79	0.005	1.64
GasRatio*Pulse	2.700	0.436	6.20	0.000	1.00

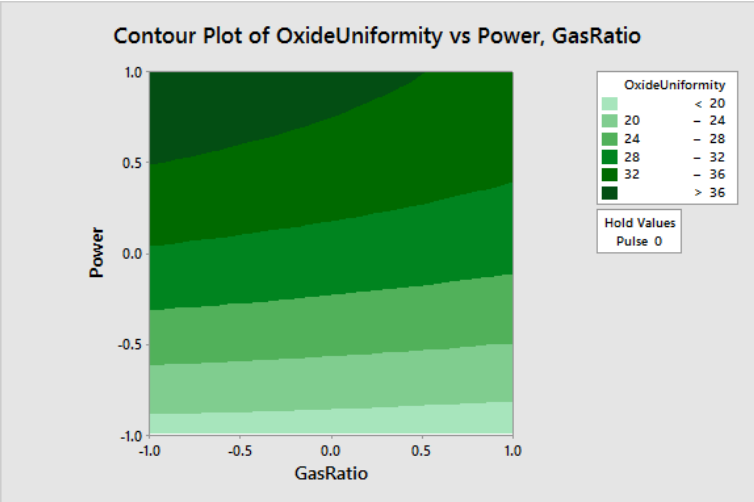
GasRatio*Power	-0.875	0.436	-2.01	0.080	1.00
Pulse*Power	-7.700	0.436	-17.67	0.000	1.00

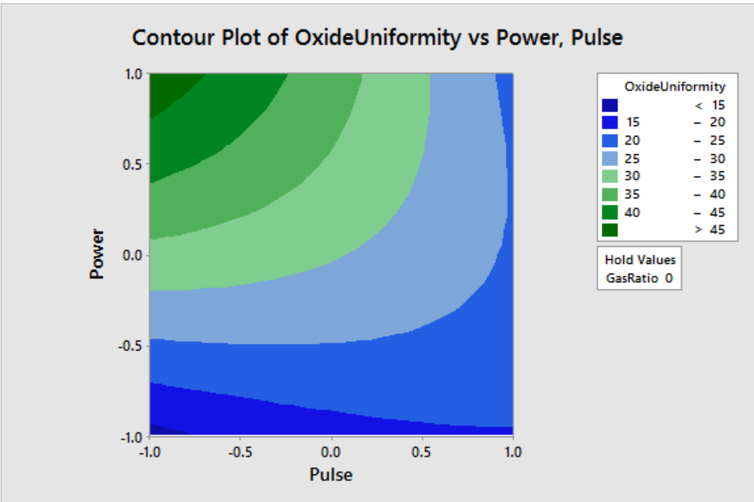
Regression Equation in Uncoded Units

OxideUniformity = 30.380 - 1.280 GasRatio - 4.580 Pulse + 9.610 Power
- 0.085 GasRatio*GasRatio - 1.385 Pulse*Pulse - 2.835 Power*Power
+ 2.700 GasRatio*Pulse - 0.875 GasRatio*Power - 7.700 Pulse*Power




Contour Plot of OxideUniformity vs Pulse, GasRatio
OxideUniformity
< 25.0
25.0 – 27.5
27.5 – 30.0
30.0 – 32.5
32.5 – 35.0
> 35.0
Hold Values
Power 0
Pulse
GasRatio
1.0
0.5
0.0
-0.5
-1.0


Contour Plot of OxideUniformity vs Power, GasRatio
OxideUniformity
< 20
20 – 24
24 – 28
28 – 32
32 – 36
> 36
Hold Values
Pulse 0
Power
GasRatio
1.0
0.5
0.0
-0.5
-1.0


Contour Plot of OxideUniformity vs Power, Pulse
OxideUniformity
< 15
15 – 20
20 – 25
25 – 30
30 – 35
35 – 40
40 – 45
> 45
Hold Values
GasRatio 0
Power
Pulse
1.0
0.5
0.0
-0.5
-1.0