DESIGN OF EXPERIMENT PRACTICAL 2

THE RESPONSE SURFACE DESIGN

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Problem 1

- From our ANOVA table it was evident that factor A, factor AC and their interaction AC was significant.
- Hence we shall try to form a Response Surface design based on that.

```
r1<-c(550,669,633,642,1037,749,1075,729) ## replication 1
r2<- c(604,650,601,635,1052,868,1063,860) ## replication 2
y <- c(r1,r2)  ## average etch rate

## the coded variables
code.a <- rep(c(-1,1,-1,1,-1,1,-1,1),2)
code.b <- rep(c(-1,-1,1,1,-1,-1,1,1),2)
code.c <- rep(c(-1,-1,-1,-1,1,1,1,1),2)

## the modified data to perform rsm

library(rsm)
data <- data.frame(code.a,code.b,code.c,y)
data

##    code.a code.b code.c    y
## 1      -1     -1     -1  550
## 2       1     -1     -1  669
## 3      -1      1     -1  633
## 4       1      1     -1  642
## 5      -1     -1      1 1037
## 6       1     -1      1  749
## 7      -1      1      1 1075
## 8       1      1      1  729
## 9      -1     -1     -1  604
## 10      1     -1     -1  650
## 11     -1      1     -1  601
## 12      1      1     -1  635
## 13     -1     -1      1 1052
## 14      1     -1      1  868
## 15     -1      1      1 1063
## 16      1      1      1  860
```

```
## response surface

rsm.des1<- rsm(y~SO(code.a,code.c,code.b),data=data)

## Warning in rsm(y ~ SO(code.a, code.c, code.b), data = data): Some
coefficients are aliased - cannot use 'rsm' methods.
##   Returning an 'lm' object.

summary(rsm.des1)

##
## Call:
## rsm(formula = y ~ SO(code.a, code.c, code.b), data = data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -62.687  -9.906  -2.000  13.938  68.313
##
## Coefficients: (3 not defined because of singularities)
##                                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)                               776.062     11.226  69.131 1.40e-13
## FO(code.a, code.c, code.b)code.a          -50.812     11.226  -4.526  0.00143
## FO(code.a, code.c, code.b)code.c          153.062     11.226  13.635 2.58e-07
## FO(code.a, code.c, code.b)code.b            3.688     11.226   0.328  0.75006
## TWI(code.a, code.c, code.b)code.a:code.c  -76.812     11.226  -6.842 7.54e-05
## TWI(code.a, code.c, code.b)code.a:code.b  -12.438     11.226  -1.108  0.29662
## TWI(code.a, code.c, code.b)code.c:code.b   -1.063     11.226  -0.095  0.92667
## PQ(code.a, code.c, code.b)code.a^2             NA         NA      NA       NA
## PQ(code.a, code.c, code.b)code.c^2             NA         NA      NA       NA
## PQ(code.a, code.c, code.b)code.b^2             NA         NA      NA       NA
##
## (Intercept)                              ***
## FO(code.a, code.c, code.b)code.a         **
## FO(code.a, code.c, code.b)code.c         ***
## FO(code.a, code.c, code.b)code.b
## TWI(code.a, code.c, code.b)code.a:code.c ***
## TWI(code.a, code.c, code.b)code.a:code.b
## TWI(code.a, code.c, code.b)code.c:code.b
## PQ(code.a, code.c, code.b)code.a^2
## PQ(code.a, code.c, code.b)code.c^2
## PQ(code.a, code.c, code.b)code.b^2
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 44.9 on 9 degrees of freedom
## Multiple R-squared:  0.9659, Adjusted R-squared:  0.9431
## F-statistic: 42.43 on 6 and 9 DF,  p-value: 4.244e-06
```

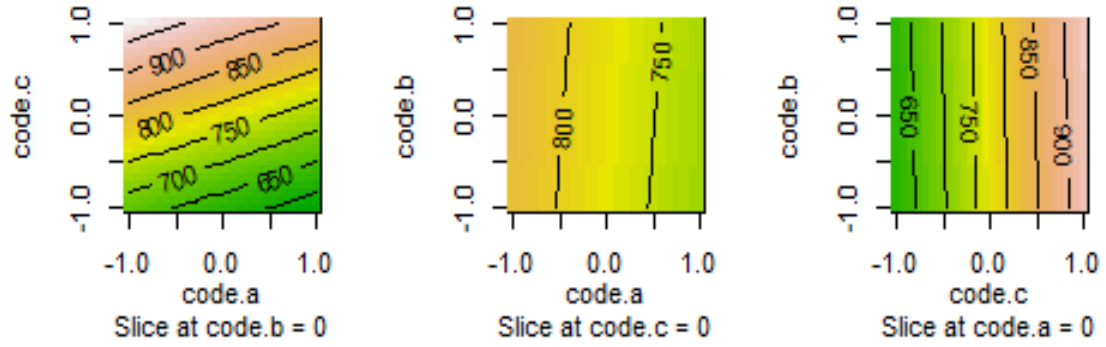
- We only have first order significant terms and one interaction term. Hence we try to fit a first order RSM model.

```
##Hence we go for the first order model,


rsm.des2<- rsm(y~FO(code.a,code.c,code.b),data=data)
summary(rsm.des2)

##
## Call:
## rsm(formula = y ~ FO(code.a, code.c, code.b), data = data)
##
##             Estimate Std. Error t value  Pr(>|t|)
## (Intercept) 776.0625    24.4782 31.7043 6.113e-13 ***
## code.a      -50.8125    24.4782 -2.0758   0.06007 .
## code.c      153.0625    24.4782  6.2530 4.235e-05 ***
## code.b        3.6875    24.4782  0.1506   0.88276
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.7835, Adjusted R-squared:  0.7294
## F-statistic: 14.48 on 3 and 12 DF,  p-value: 0.0002724
##
## Analysis of Variance Table
##
## Response: y
##                            Df Sum Sq Mean Sq F value    Pr(>F)
## FO(code.a, code.c, code.b)  3 416378  138793  14.477 0.0002724
## Residuals                  12 115043    9587
## Lack of fit                 4  97022   24256  10.768 0.0026330
## Pure error                  8  18020    2253
##
## Direction of steepest ascent (at radius 1):
##      code.a      code.c      code.b
## -0.31498260  0.94882214  0.02285852
##
## Corresponding increment in original units:
##      code.a      code.c      code.b
## -0.31498260  0.94882214  0.02285852
```

-
  - Also it tells us the steepest ascent path and the unit by which we should increase our original unit.

Contour Plots

```
par(mfrow=c(2,3))
contour(rsm.des2,~code.a+code.c+code.b,image=TRUE)
```



Problem 2

- From our ANOVA table it was evident that factor A, factor AC and their interaction AC was significant.

```
rp1<- c(22,32,35,55,44,40,60,39)  ## replication 1
rp2<-c(31,43,34,47,45,37,50,41)  ## replication 2
rp3<-c(25,29,50,46,38,36,54,47)  ## replication 3
tool.life <- c(rp1,rp2,rp3)  ## average tool life

## coded variables
coded.a <- rep(c(-1,1,-1,1,-1,1,-1,1),3)
coded.b <- rep(c(-1,-1,1,1,-1,-1,1,1),3)
coded.c <- rep(c(-1,-1,-1,-1,1,1,1,1),3)
```

```
data2 <- data.frame(coded.a,coded.b,coded.c,tool.life)
data2
```

```
##    coded.a coded.b coded.c tool.life
## 1       -1      -1      -1        22
## 2        1      -1      -1        32
## 3       -1       1      -1        35
## 4        1       1      -1        55
## 5       -1      -1       1        44
## 6        1      -1       1        40
## 7       -1       1       1        60
## 8        1       1       1        39
## 9       -1      -1      -1        31
## 10       1      -1      -1        43
## 11      -1       1      -1        34
## 12       1       1      -1        47
## 13      -1      -1       1        45
## 14       1      -1       1        37
## 15      -1       1       1        50
## 16       1       1       1        41
## 17      -1      -1      -1        25
## 18       1      -1      -1        29
## 19      -1       1      -1        50
## 20       1       1      -1        46
## 21      -1      -1       1        38
## 22       1      -1       1        36
## 23      -1       1       1        54
## 24       1       1       1        47
```

```
## response surface
```

```
rsm.pr21<- rsm(tool.life~SO(coded.a,coded.b,coded.c),data=data2)
```

```
## Warning in rsm(tool.life ~ SO(coded.a, coded.b, coded.c), data = data2):
Some coefficients are aliased - cannot use 'rsm' methods.
##   Returning an 'lm' object.
```

```
summary(rsm.pr21)
```

```
##
## Call:
## rsm(formula = tool.life ~ SO(coded.a, coded.b, coded.c), data = data2)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -6.750 -3.625 -0.250  3.458  9.250
##
## Coefficients: (3 not defined because of singularities)
##                                            Estimate Std. Error t value
## (Intercept)                                 40.8333     1.1189  36.493
```

```
## FO(coded.a, coded.b, coded.c)coded.a             0.1667     1.1189   0.149
## FO(coded.a, coded.b, coded.c)coded.b             5.6667     1.1189   5.064
## FO(coded.a, coded.b, coded.c)coded.c             3.4167     1.1189   3.053
## TWI(coded.a, coded.b, coded.c)coded.a:coded.b   -0.8333     1.1189  -0.745
## TWI(coded.a, coded.b, coded.c)coded.a:coded.c   -4.4167     1.1189  -3.947
## TWI(coded.a, coded.b, coded.c)coded.b:coded.c   -1.4167     1.1189  -1.266
## PQ(coded.a, coded.b, coded.c)coded.a^2               NA         NA      NA
## PQ(coded.a, coded.b, coded.c)coded.b^2               NA         NA      NA
## PQ(coded.a, coded.b, coded.c)coded.c^2               NA         NA      NA
##                                                Pr(>|t|)
## (Intercept)                                     < 2e-16 ***
## FO(coded.a, coded.b, coded.c)coded.a            0.88335
## FO(coded.a, coded.b, coded.c)coded.b           9.58e-05 ***
## FO(coded.a, coded.b, coded.c)coded.c            0.00719 **
## TWI(coded.a, coded.b, coded.c)coded.a:coded.b   0.46660
## TWI(coded.a, coded.b, coded.c)coded.a:coded.c   0.00104 **
## TWI(coded.a, coded.b, coded.c)coded.b:coded.c   0.22256
## PQ(coded.a, coded.b, coded.c)coded.a^2               NA
## PQ(coded.a, coded.b, coded.c)coded.b^2               NA
## PQ(coded.a, coded.b, coded.c)coded.c^2               NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 5.482 on 17 degrees of freedom
## Multiple R-squared:  0.7562, Adjusted R-squared:  0.6702
## F-statistic: 8.788 on 6 and 17 DF,  p-value: 0.000188
```

The First Order Model

```
rsm.pr22<- rsm(tool.life~FO(coded.a,coded.b,coded.c),data=data2)
summary(rsm.pr22)

##
## Call:
## rsm(formula = tool.life ~ FO(coded.a, coded.b, coded.c), data = data2)
##
##             Estimate Std. Error t value  Pr(>|t|)
## (Intercept) 40.83333    1.47467 27.6898 < 2.2e-16 ***
## coded.a      0.16667    1.47467  0.1130  0.911142
## coded.b      5.66667    1.47467  3.8427  0.001016 **
## coded.c      3.41667    1.47467  2.3169  0.031232 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.5018, Adjusted R-squared:  0.4271
## F-statistic: 6.716 on 3 and 20 DF,  p-value: 0.002575
##
## Analysis of Variance Table
##
```

```
## Response: tool.life
##                                Df  Sum Sq Mean Sq F value   Pr(>F)
## FO(coded.a, coded.b, coded.c)   3 1051.50  350.50  6.7156 0.002575
## Residuals                      20 1043.83   52.19
## Lack of fit                     4  561.17  140.29  4.6506 0.011078
## Pure error                     16  482.67   30.17
##
## Direction of steepest ascent (at radius 1):
##    coded.a    coded.b    coded.c
## 0.02517965 0.85610818 0.51618288
##
## Corresponding increment in original units:
##    coded.a    coded.b    coded.c
## 0.02517965 0.85610818 0.51618288
```

Contour Plots

```
par(mfrow=c(2,3))
contour(rsm.pr22,~coded.a+coded.c+coded.b,image=TRUE)
```