

Lab-5

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Question 1.

```
depth_of_cut.data <- c(0.15, 0.15, 0.15, 0.18, 0.18, 0.18, 0.2, 0.2, 0.2, 0.25, 0.25, 0.25, 0.15, 0.15,
feed_rate.data<-c(0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.2, 0.25, 0.25, 0.25, 0.25, 0
surface_finish <- c(74, 64, 60, 79, 68, 73, 82, 88, 92, 99, 104, 96, 92, 86, 88, 98, 104, 88, 99, 108, 9
df <- data.frame(depth_of_cut.data, feed_rate.data, surface_finish)
df$depth_of_cut <- factor(df$depth_of_cut, levels = c(0.15,0.18,0.20,0.25), labels = c("dc.0.15", "dc.0
df$feed_rate <- factor(df$feed_rate, levels = c(0.20,0.25,0.30), labels = c("fr.0.20", "fr.0.25", "fr.0.
str(df)
```

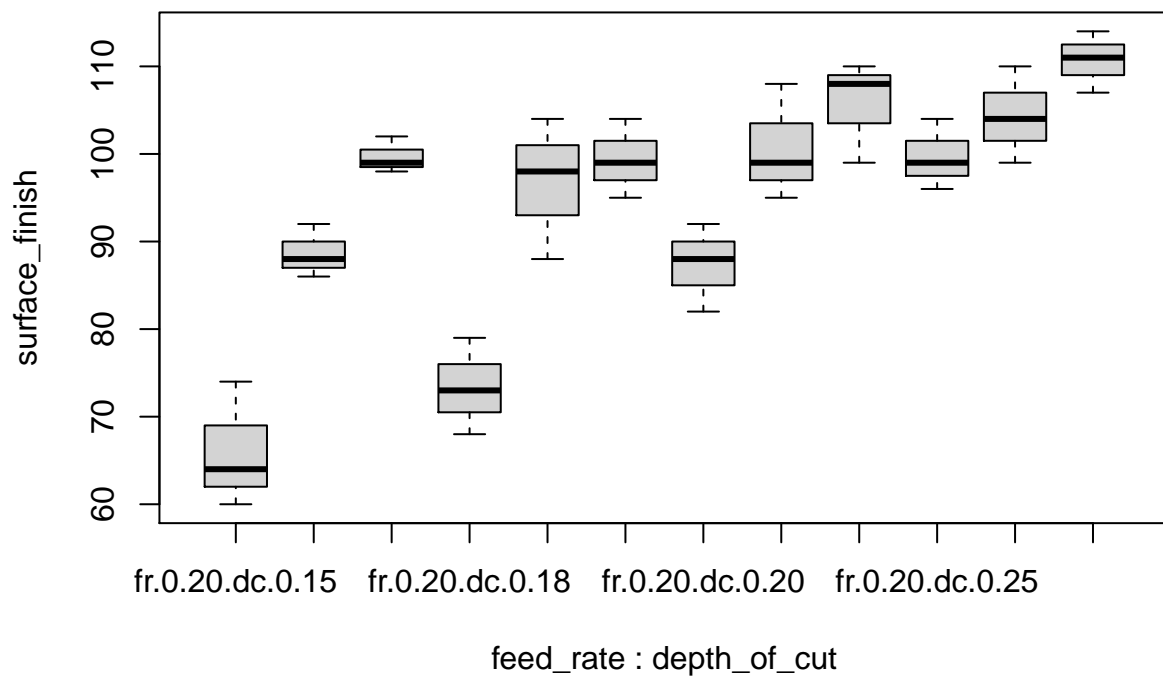
```
## 'data.frame':    36 obs. of  5 variables:
## $ depth_of_cut.data: num  0.15 0.15 0.15 0.18 0.18 0.18 0.2 0.2 0.2 0.25 ...
## $ feed_rate.data   : num  0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 0.2 ...
## $ surface_finish   : num  74 64 60 79 68 73 82 88 92 99 ...
## $ depth_of_cut     : Factor w/ 4 levels "dc.0.15","dc.0.18",...: 1 1 1 2 2 2 3 3 3 4 ...
## $ feed_rate        : Factor w/ 3 levels "fr.0.20","fr.0.25",...: 1 1 1 1 1 1 1 1 1 1 ...
```

```
attach(df)
```

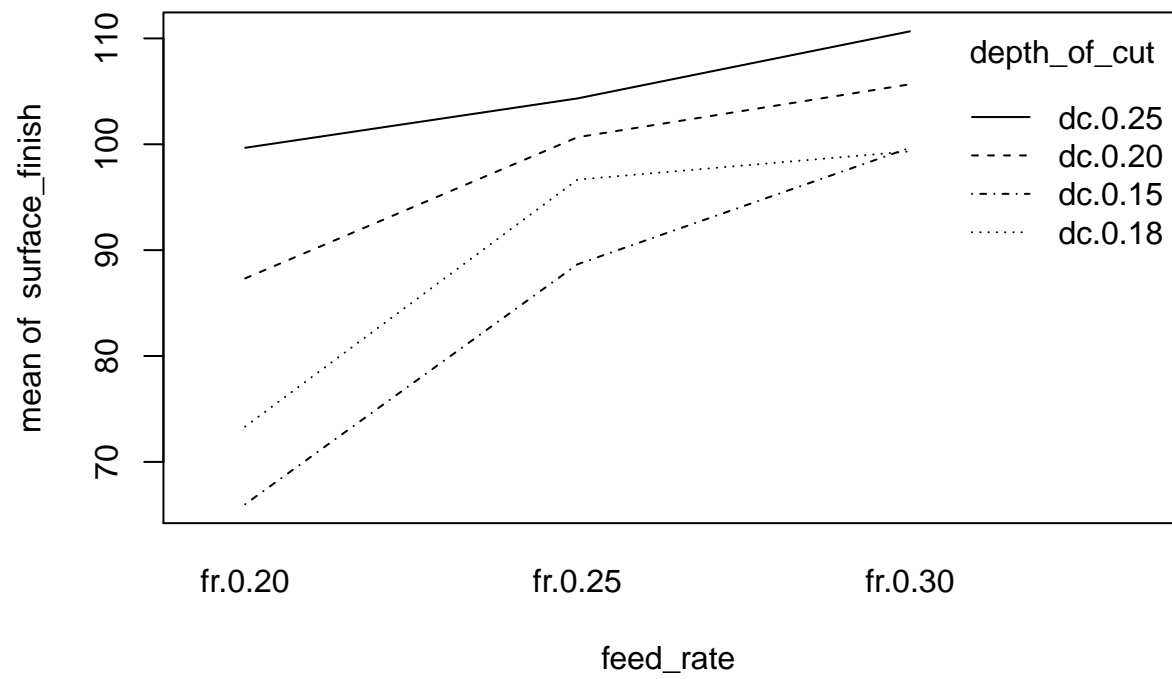
```
## The following objects are masked by_ .GlobalEnv:
##
##   depth_of_cut.data, feed_rate.data, surface_finish
```

a. Analyze the data and draw conclusions

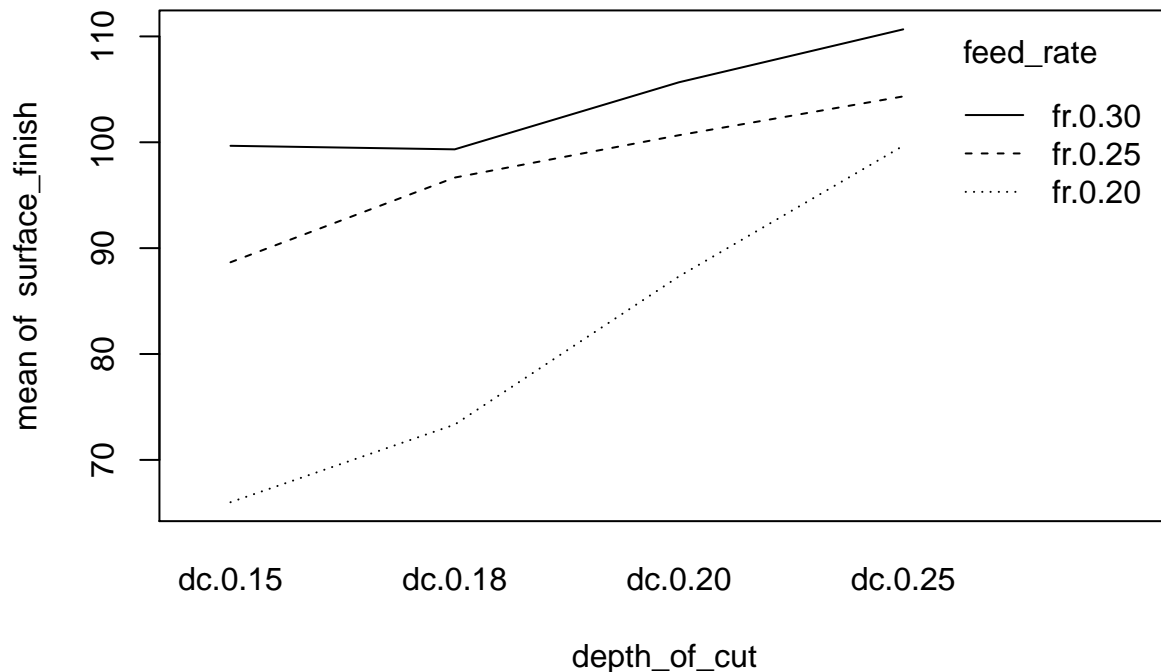
```
boxplot(surface_finish~feed_rate*depth_of_cut)
```



```
interaction.plot(feed_rate, depth_of_cut, surface_finish)
```



```
interaction.plot(depth_of_cut, feed_rate, surface_finish)
```



Interactive plot appears to suggest that there is no interaction between depth of cut and feed rate

```
sf.aov <- aov(surface_finish~feed_rate*depth_of_cut)
summary.aov(sf.aov)
```

```
##              Df Sum Sq Mean Sq F value    Pr(>F)
## feed_rate      2 3160.5  1580.2   55.018 1.09e-09 ***
## depth_of_cut   3 2125.1    708.4   24.663 1.65e-07 ***
## feed_rate:depth_of_cut  6  557.1     92.8    3.232  0.018 *
## Residuals     24  689.3     28.7
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Pvalue is small (<0.05) for feed_rate*depth_of_cut, so there appears to be some interaction between feed_Rate and depth_of_cut

Interaction probability is significant, so we can test it using FO and TWI or the SO and check its suitability.

b. prepare appropriate residual plots and comment on the model's adequacy

```
library(rsm)
sf.rsm<- rsm(surface_finish ~ FO(feed_rate.data, depth_of_cut.data)
              + TWI(feed_rate.data, depth_of_cut.data)
              + PQ(feed_rate.data, depth_of_cut.data))
summary(sf.rsm)
```

```
##
## Call:
## rsm(formula = surface_finish ~ F0(feed_rate.data, depth_of_cut.data) +
##     TWI(feed_rate.data, depth_of_cut.data) + PQ(feed_rate.data,
##     depth_of_cut.data))
##
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)      -255.557      64.324 -3.9730 0.0004113 ***
## feed_rate.data      1642.075     405.569  4.0488 0.0003338 ***
## depth_of_cut.data    1024.559     355.443  2.8825 0.0072269 **
## feed_rate.data:depth_of_cut.data -2279.874     613.619 -3.7155 0.0008293 ***
## feed_rate.data^2     -1950.000     773.744 -2.5202 0.0172825 *
## depth_of_cut.data^2     -613.681     792.037 -0.7748 0.4445143
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.8625, Adjusted R-squared:  0.8396
## F-statistic: 37.64 on 5 and 30 DF,  p-value: 4.745e-12
##
## Analysis of Variance Table
##
## Response: surface_finish
##
##               Df Sum Sq Mean Sq F value    Pr(>F)
## F0(feed_rate.data, depth_of_cut.data)  2 5012.7  2506.33  83.7286 5.306e-13
## TWI(feed_rate.data, depth_of_cut.data)  1  413.2   413.23  13.8046 0.0008293
## PQ(feed_rate.data, depth_of_cut.data)  2  208.1   104.05   3.4759 0.0438816
## Residuals                               30  898.0    29.93
## Lack of fit                             6  208.7    34.78   1.2109 0.3348559
## Pure error                             24  689.3    28.72
##
## Stationary point of response surface:
##   feed_rate.data depth_of_cut.data
##      0.7794569      -0.6131068
##
## Eigenanalysis:
## eigen() decomposition
## $values
## [1]  39.48199 -2603.16329
##
## $vectors
##               [,1]      [,2]
## feed_rate.data  0.4971546 -0.8676620
## depth_of_cut.data -0.8676620 -0.4971546
```

All parameters are significant except for depth_of_cut^2 . The lack of fit is not significant and r^2 is high.

Rerun it with depth_of_cut .data removed from the quadratic

```
library(rsm)
sf.rsm<- rsm(surface_finish ~ F0(feed_rate.data, depth_of_cut.data)
+ TWI(feed_rate.data, depth_of_cut.data)
+ PQ(feed_rate.data))
summary(sf.rsm)
```

```
##
```

```
## Call:
## rsm(formula = surface_finish ~ F0(feed_rate.data, depth_of_cut.data) +
##     TWI(feed_rate.data, depth_of_cut.data) + PQ(feed_rate.data))
##
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)      -231.410      55.906  -4.1393 0.0002477 ***
## feed_rate.data    1642.075     402.946   4.0752 0.0002963 ***
## depth_of_cut.data   776.887     154.431   5.0306 1.967e-05 ***
## feed_rate.data:depth_of_cut.data -2279.874     609.650  -3.7396 0.0007490 ***
## feed_rate.data^2    -1950.000     768.740  -2.5366 0.0164449 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.8598, Adjusted R-squared:  0.8417
## F-statistic: 47.52 on 4 and 31 DF,  p-value: 8.555e-13
##
## Analysis of Variance Table
##
## Response: surface_finish
##
##               Df Sum Sq Mean Sq F value    Pr(>F)
## F0(feed_rate.data, depth_of_cut.data)  2 5012.7 2506.33 84.8221 2.682e-13
## TWI(feed_rate.data, depth_of_cut.data)  1  413.2  413.23 13.9849 0.000749
## PQ(feed_rate.data)                     1  190.1  190.13   6.4344 0.016445
## Residuals                             31  916.0   29.55
## Lack of fit                             7  226.7   32.38   1.1273 0.379080
## Pure error                             24  689.3   28.72
##
## Stationary point of response surface:
##   feed_rate.data depth_of_cut.data
##      0.3407586      0.1373395
##
## Eigenanalysis:
## eigen() decomposition
## $values
## [1]  525.0272 -2475.0272
##
## $vectors
##               [,1]      [,2]
## feed_rate.data  0.4183371 -0.9082919
## depth_of_cut.data -0.9082919 -0.4183371
```

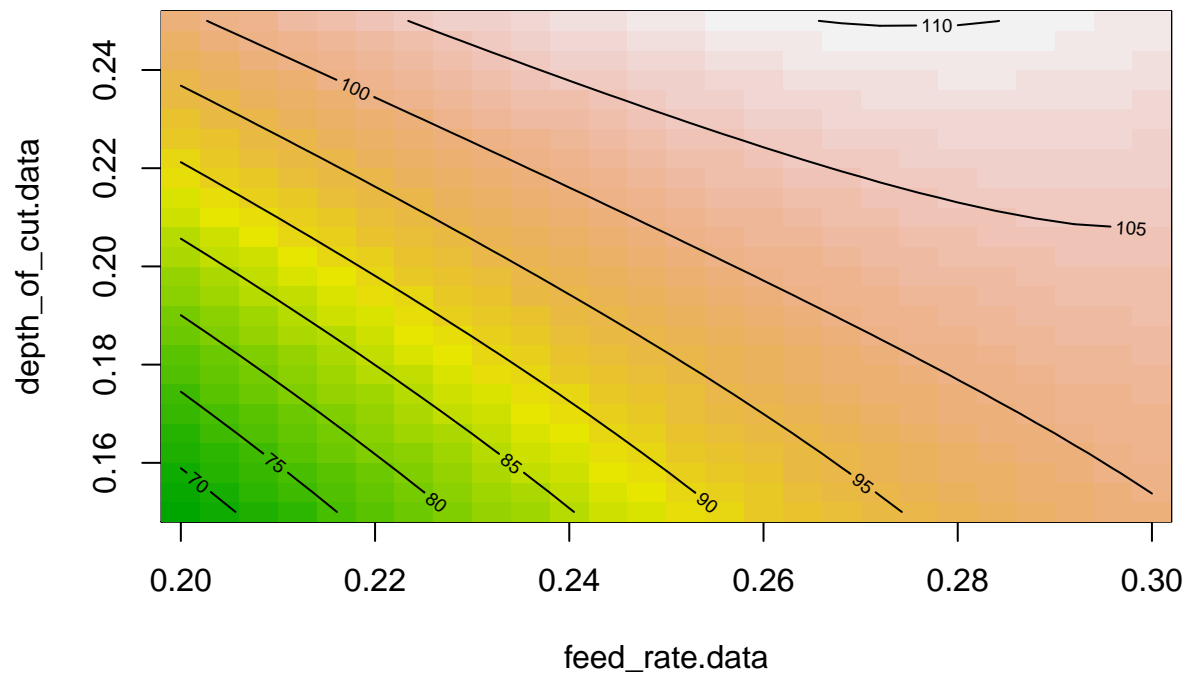
All the parameters are significant and lack of fit is not significant and r^2 is significant.

```
canonical(sf.rsm)
```

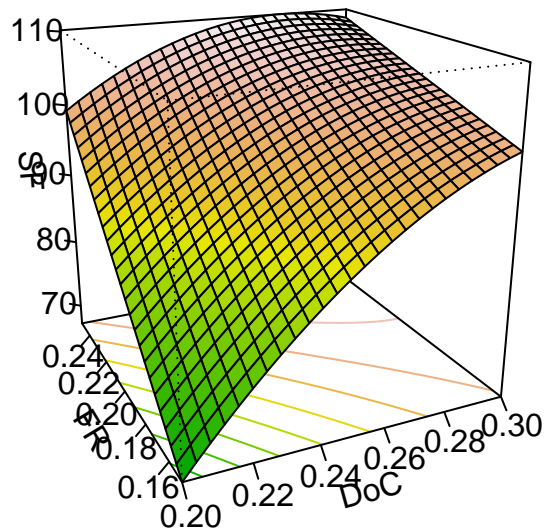
```
## $xs
##   feed_rate.data depth_of_cut.data
##      0.3407586      0.1373395
##
## $eigen
## eigen() decomposition
## $values
## [1]  525.0272 -2475.0272
```

```
##
## $vectors
##           [,1]      [,2]
## feed_rate.data    0.4183371 -0.9082919
## depth_of_cut.data -0.9082919 -0.4183371
```

```
xs <-canonical(sf.rsm)$xs
contour(sf.rsm,~feed_rate.data+depth_of_cut.data, at=xs, image=TRUE)
```



```
persp(sf.rsm, ~ feed_rate.data+depth_of_cut.data, col = terrain.colors(50), contours = "colors",
      zlab = "SF",
      xlab=c("FR", "DoC"))
```



surface finish is best achieved at: feed_rate.data depth_of_cut.data 0.3407586 0.1373395

Question 2.

```
DrillSpeed.data<- c(125, 125, 200, 200, 125, 125, 200, 200, 125, 125, 200, 200, 125, 125, 200, 200)
FeedRate.data <- c(0.015, 0.015, 0.015, 0.015, 0.03, 0.03, 0.03, 0.03, 0.045, 0.045, 0.045, 0.045, 0.06
Force<- c(2.7, 2.78, 2.83, 2.86, 2.45, 2.49, 2.85, 2.8, 2.6, 2.72, 2.86, 2.87, 2.75, 2.86, 2.94, 2.88)
drillpress <- data.frame(DrillSpeed.data, FeedRate.data, Force)
drillpress$DrillSpeed <- as.factor(drillpress$DrillSpeed.data)
drillpress$FeedRate <- as.factor(drillpress$FeedRate.data)
str(drillpress)

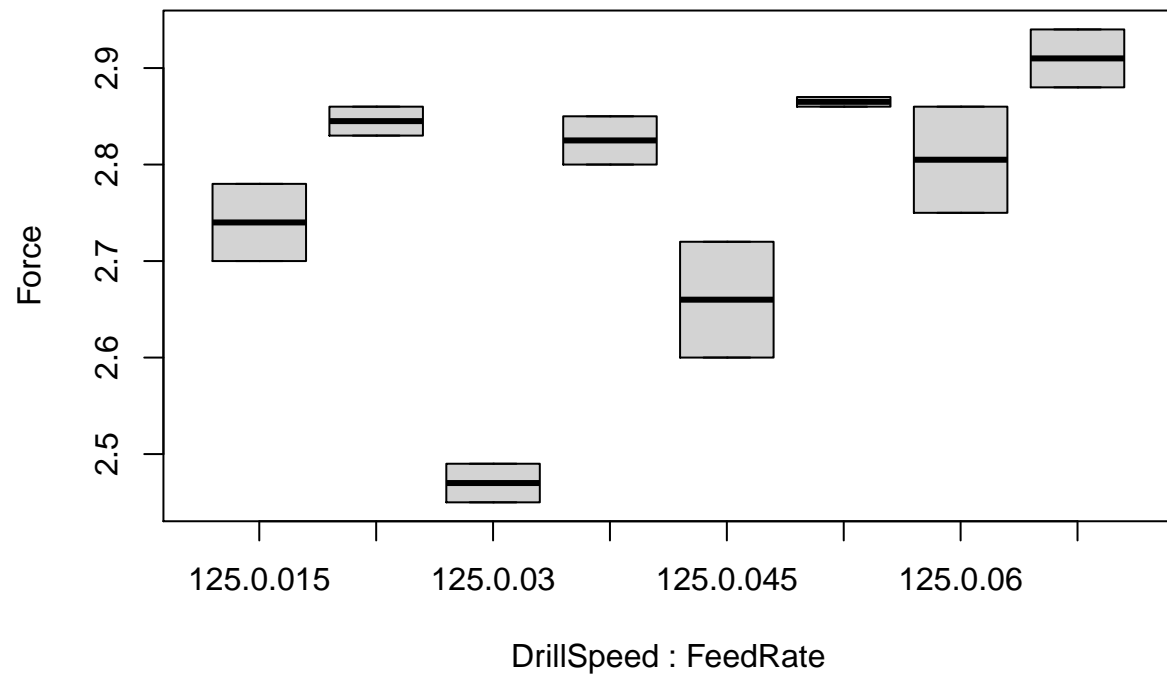
## 'data.frame':  16 obs. of  5 variables:
## $ DrillSpeed.data: num  125 125 200 200 125 125 200 200 125 125 ...
## $ FeedRate.data  : num  0.015 0.015 0.015 0.015 0.03 0.03 0.03 0.03 0.045 0.045 ...
## $ Force          : num  2.7 2.78 2.83 2.86 2.45 2.49 2.85 2.8 2.6 2.72 ...
## $ DrillSpeed     : Factor w/ 2 levels "125","200": 1 1 2 2 1 1 2 2 1 1 ...
## $ FeedRate       : Factor w/ 4 levels "0.015","0.03",...: 1 1 1 1 2 2 2 2 3 3 ...

## The following objects are masked _by_ .GlobalEnv:
```

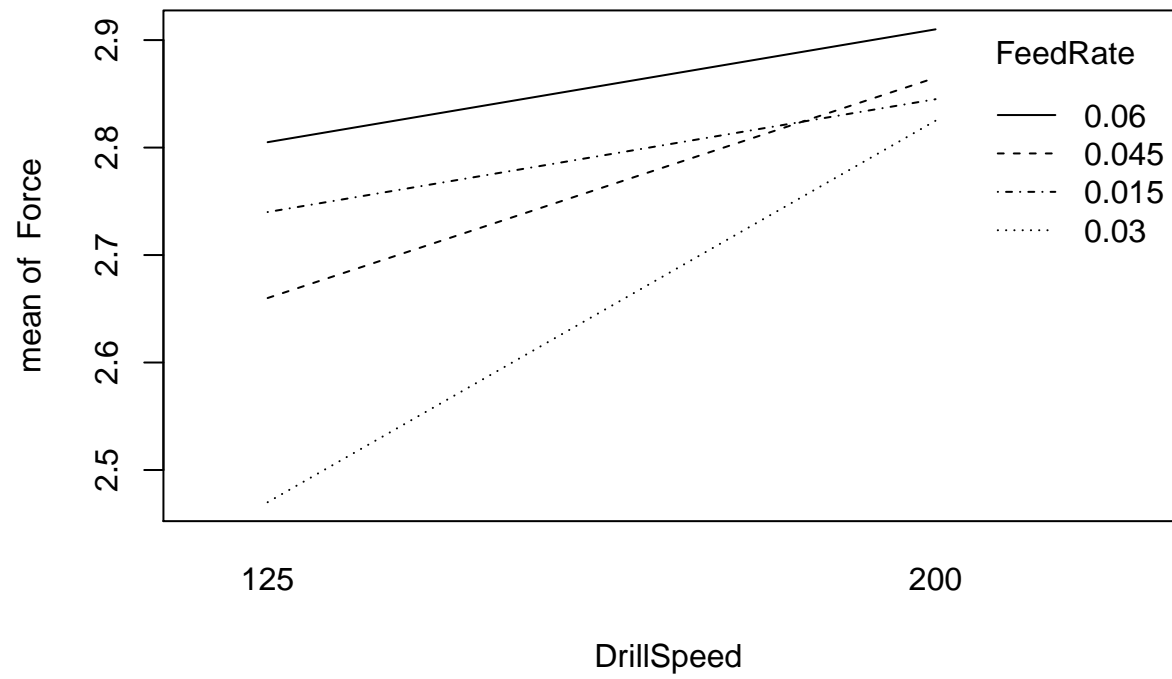


```
##  
## DrillSpeed.data, FeedRate.data, Force
```

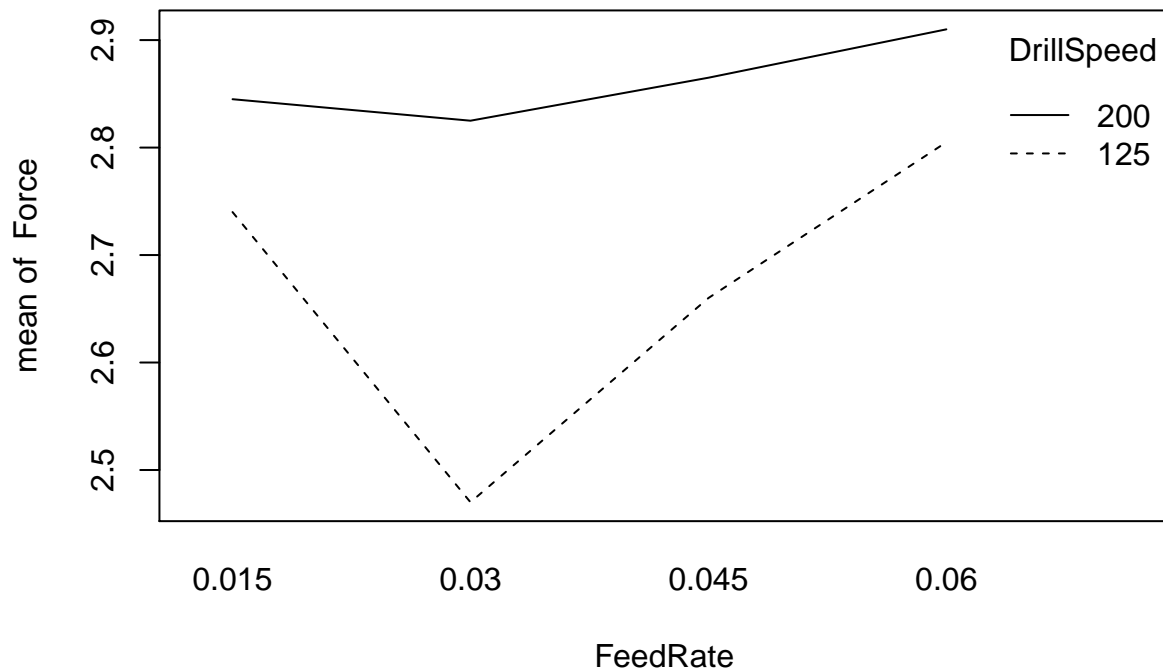
```
boxplot(Force~DrillSpeed*FeedRate)
```



```
interaction.plot(DrillSpeed, FeedRate, Force)
```



```
interaction.plot(FeedRate,DrillSpeed, Force)
```



```
force.aov <- aov(Force~FeedRate*DrillSpeed)
summary.aov(force.aov)
```

```
##              Df  Sum Sq Mean Sq F value    Pr(>F)
## FeedRate      3  0.09250  0.03083   11.859  0.00258 **
## DrillSpeed    1  0.14822  0.14822   57.010  6.61e-05 ***
## FeedRate:DrillSpeed 3  0.04187  0.01396    5.369  0.02557 *
## Residuals     8  0.02080  0.00260
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The interaction term is significant

```
drillpress.rsm<- rsm(Force ~ FO(FeedRate.data, DrillSpeed.data)
+ TWI(FeedRate.data, DrillSpeed.data)
+ PQ(FeedRate.data, DrillSpeed.data), data=drillpress)
```

```
## Warning in rsm(Force ~ FO(FeedRate.data, DrillSpeed.data) + TWI(FeedRate.data, : Some coefficients a
## Returning an 'lm' object.
```

```
summary(drillpress.rsm)
```

```
##
```

```
## Call:
## rsm(formula = Force ~ FO(FeedRate.data, DrillSpeed.data) + TWI(FeedRate.data,
##   DrillSpeed.data) + PQ(FeedRate.data, DrillSpeed.data), data = drillpress)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.13950 -0.04138 -0.00300  0.05788  0.10900
##
## Coefficients: (1 not defined because of singularities)
##                                     Estimate Std. Error
## (Intercept)                       2.489167   0.251081
## FO(FeedRate.data, DrillSpeed.data)FeedRate.data -15.766667   8.922648
## FO(FeedRate.data, DrillSpeed.data)DrillSpeed.data  0.003067   0.001368
## TWI(FeedRate.data, DrillSpeed.data)          -0.013333   0.033309
## PQ(FeedRate.data, DrillSpeed.data)FeedRate.data^2 266.666667  93.100961
## PQ(FeedRate.data, DrillSpeed.data)DrillSpeed.data^2      NA      NA
##                                     t value Pr(>|t|)
## (Intercept)                       9.914 8.06e-07 ***
## FO(FeedRate.data, DrillSpeed.data)FeedRate.data -1.767  0.1049
## FO(FeedRate.data, DrillSpeed.data)DrillSpeed.data  2.241  0.0466 *
## TWI(FeedRate.data, DrillSpeed.data)          -0.400  0.6966
## PQ(FeedRate.data, DrillSpeed.data)FeedRate.data^2  2.864  0.0154 *
## PQ(FeedRate.data, DrillSpeed.data)DrillSpeed.data^2      NA      NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.08379 on 11 degrees of freedom
## Multiple R-squared:  0.7455, Adjusted R-squared:  0.6529
## F-statistic: 8.053 on 4 and 11 DF,  p-value: 0.00275
```

Quadratic term is not significant, interaction term is not significant and r^2 is too low.

```
drillpress.rsm<- rsm(Force ~ FO(FeedRate.data, DrillSpeed.data)
+ PQ(FeedRate.data), data=drillpress)
summary(drillpress.rsm)
```

```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
##
## Call:
## rsm(formula = Force ~ FO(FeedRate.data, DrillSpeed.data) + PQ(FeedRate.data),
##   data = drillpress)
##
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    2.5704e+00 1.4253e-01 18.0345 4.65e-10 ***
## FeedRate.data -1.7933e+01 6.8407e+00 -2.6216 0.0223206 *
## DrillSpeed.data 2.5667e-03 5.3871e-04  4.7645 0.0004606 ***
## FeedRate.data^2 2.6667e+02 8.9784e+01  2.9701 0.0116994 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.7417, Adjusted R-squared:  0.6772
```

```
## F-statistic: 11.49 on 3 and 12 DF, p-value: 0.0007676
##
## Analysis of Variance Table
##
## Response: Force
##


|                                    | Df | Sum Sq   | Mean Sq  | F value | Pr(>F)   |
|------------------------------------|----|----------|----------|---------|----------|
| F0(FeedRate.data, DrillSpeed.data) | 2  | 0.167445 | 0.083722 | 12.8220 | 0.001049 |
| PQ(FeedRate.data)                  | 1  | 0.057600 | 0.057600 | 8.8214  | 0.011699 |
| Residuals                          | 12 | 0.078355 | 0.006530 |         |          |
| Lack of fit                        | 4  | 0.057555 | 0.014389 | 5.5341  | 0.019556 |
| Pure error                         | 8  | 0.020800 | 0.002600 |         |          |


##
## Stationary point of response surface:
##   FeedRate.data DrillSpeed.data
##      0.033625      0.000000
##
## Eigenanalysis:
## eigen() decomposition
## $values
## [1] 266.6667  0.0000
##
## $vectors
##           [,1] [,2]
## FeedRate.data  -1    0
## DrillSpeed.data  0   -1
```

```
canonical(drillpress.rsm)
```

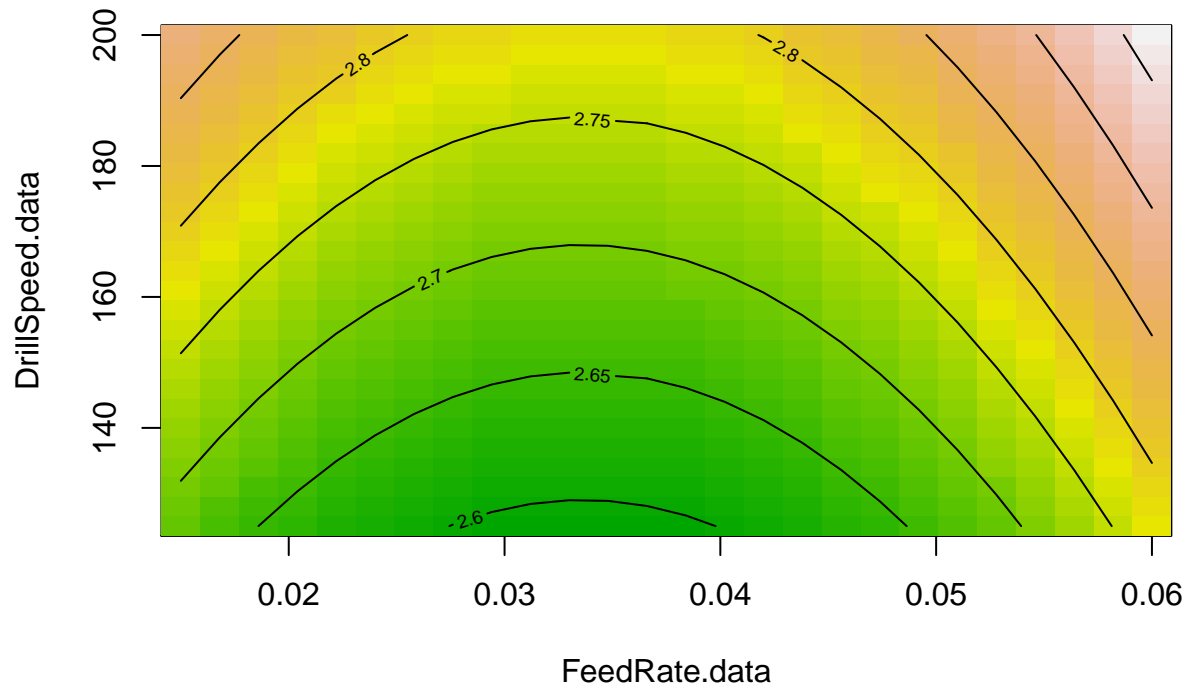
```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
## $xs
##   FeedRate.data DrillSpeed.data
##      0.033625      0.000000
##
## $eigen
## eigen() decomposition
## $values
## [1] 266.6667  0.0000
##
## $vectors
##           [,1] [,2]
## FeedRate.data  -1    0
## DrillSpeed.data  0   -1
```

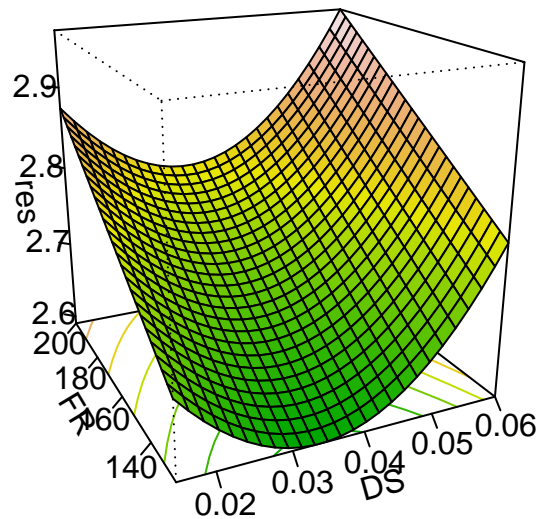
```
xs <-canonical(drillpress.rsm)$xs
```

```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
contour(drillpress.rsm, ~FeedRate.data+DrillSpeed.data, at=xs, image=TRUE)
```



```
persp(drillpress.rsm, ~ FeedRate.data+DrillSpeed.data, col = terrain.colors(50), contours = "colors",
      zlab = "res",
      xlab=c("FR", "DS"))
```



FeedRate.data DrillSpeed.data 0.033625 0.000000

Question 3.

```
Pressure.data <-c(120, 130, 140, 150, 120, 130, 140, 150, 120, 130, 140, 150)
Temperature.data <- c(250, 250, 250, 250, 250, 260, 260, 260, 260, 270, 270, 270)
Strength <- c(9.60, 9.69, 8.43, 9.98, 11.28, 10.10, 11.01, 10.44, 9.00, 9.57, 9.03, 9.80)
Adhesive<- data.frame(Pressure.data, Temperature.data, Strength)
Adhesive$Pressure <-as.factor(Pressure.data)
Adhesive$Temperature <-as.factor(Temperature.data)
```

```
attach(Adhesive)
```

```
## The following objects are masked _by_ .GlobalEnv:
##
##      Pressure.data, Strength, Temperature.data
```

```
Adhesive.aov<-aov(Strength~Temperature*Pressure)
summary.aov(Adhesive.aov)
```

```
##              Df Sum Sq Mean Sq
```

```
## Temperature      2  4.658  2.3288
## Pressure         3  0.581  0.1936
## Temperature:Pressure  6  2.154  0.3590
```

```
adhesive.rsm <- rsm(Strength ~ FO(Pressure.data, Temperature.data)
                    +TWI(Pressure.data, Temperature.data)
                    +PQ(Pressure.data, Temperature.data))
summary(adhesive.rsm)
```

```
##
## Call:
## rsm(formula = Strength ~ FO(Pressure.data, Temperature.data) +
##     TWI(Pressure.data, Temperature.data) + PQ(Pressure.data,
##     Temperature.data))
##
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    -8.1171e+02  2.6168e+02 -3.1019  0.02107 *
## Pressure.data   -7.6772e-01  6.8726e-01 -1.1171  0.30669
## Temperature.data  6.7266e+00  1.9486e+00  3.4520  0.01360 *
## Pressure.data:Temperature.data  9.9000e-04  1.9178e-03  0.5162  0.62418
## Pressure.data^2  1.8917e-03  1.7507e-03  1.0805  0.32143
## Temperature.data^2 -1.3200e-02  3.7139e-03 -3.5542  0.01201 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.7015, Adjusted R-squared:  0.4527
## F-statistic:  2.82 on 5 and 6 DF,  p-value: 0.1196
##
## Analysis of Variance Table
##
## Response: Strength
##
##              Df Sum Sq Mean Sq F value  Pr(>F)
## FO(Pressure.data, Temperature.data)  2  0.0115  0.00577   0.0157  0.98449
## TWI(Pressure.data, Temperature.data)  1  0.0980  0.09801   0.2665  0.62418
## PQ(Pressure.data, Temperature.data)  2  5.0758  2.53790   6.9000  0.02783
## Residuals                                6  2.2069  0.36781
## Lack of fit                                6  2.2069  0.36781
## Pure error                                0  0.0000
##
## Stationary point of response surface:
##   Pressure.data Temperature.data
##      134.9234      259.8551
##
## Eigenanalysis:
## eigen() decomposition
## $values
## [1]  0.001907885 -0.013216218
##
## $vectors
##              [,1]      [,2]
## Pressure.data -0.99946368 -0.03274678
## Temperature.data -0.03274678  0.99946368
```

Interaction term and one quadratic term is not significant, so removing it.


```
adhesive.rsm <- rsm(Strength ~ FO(Pressure.data, Temperature.data)
                    +PQ(Temperature.data))
summary(adhesive.rsm)
```

```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
##
## Call:
## rsm(formula = Strength ~ FO(Pressure.data, Temperature.data) +
##     PQ(Temperature.data))
##
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    -8.8070e+02  2.4184e+02 -3.6416 0.006574 **
## Pressure.data     4.3333e-04  1.5095e-02  0.0287 0.977801
## Temperature.data   6.8602e+00  1.8618e+00  3.6848 0.006176 **
## Temperature.data^2 -1.3200e-02  3.5801e-03 -3.6871 0.006156 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Multiple R-squared:  0.6301, Adjusted R-squared:  0.4914
## F-statistic: 4.543 on 3 and 8 DF, p-value: 0.03862
##
## Analysis of Variance Table
##
## Response: Strength
##
##              Df Sum Sq Mean Sq F value    Pr(>F)
## FO(Pressure.data, Temperature.data) 2 0.0115  0.0058  0.0169 0.983307
## PQ(Temperature.data)                1 4.6464  4.6464 13.5944 0.006156
## Residuals                          8 2.7343  0.3418
## Lack of fit                         8 2.7343  0.3418
## Pure error                          0 0.0000
##
## Stationary point of response surface:
##   Pressure.data Temperature.data
##           0.000           259.858
##
## Eigenanalysis:
## eigen() decomposition
## $values
## [1] 0.0000 -0.0132
##
## $vectors
##           [,1] [,2]
## Pressure.data    -1    0
## Temperature.data  0    1
```

```
canonical(adhesive.rsm)
```

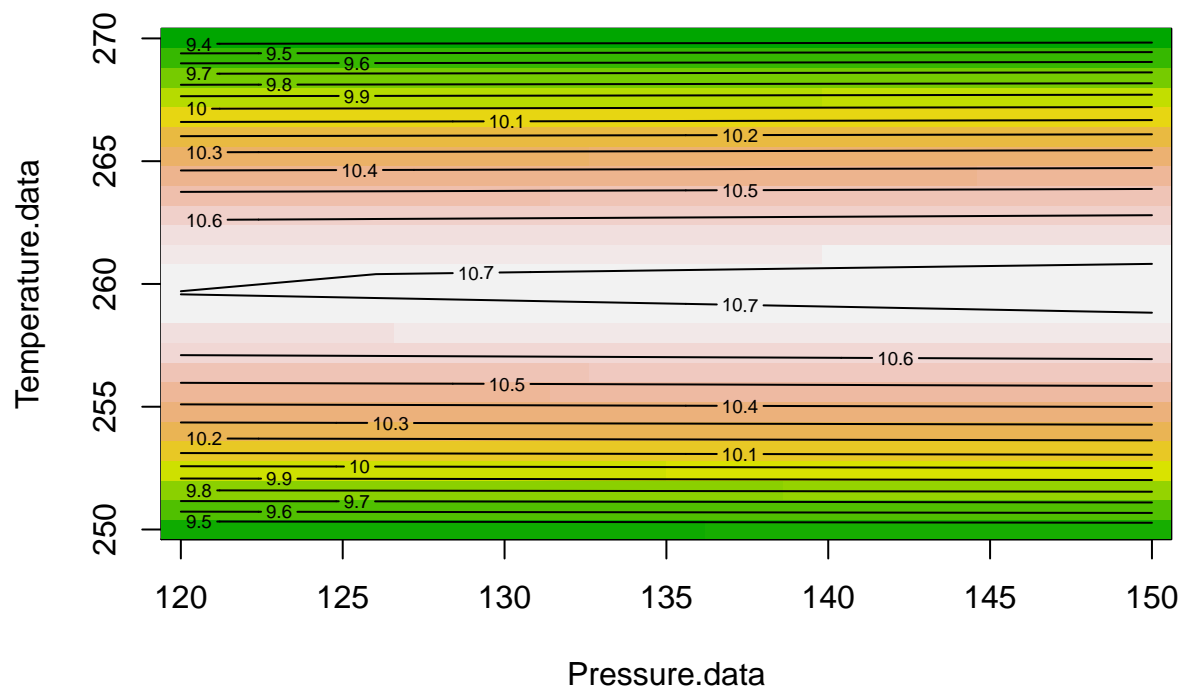
```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
## $xs
##      Pressure.data Temperature.data
##           0.000           259.858
##
## $eigen
## eigen() decomposition
## $values
## [1]  0.0000 -0.0132
##
## $vectors
##           [,1] [,2]
## Pressure.data    -1    0
## Temperature.data  0    1
```

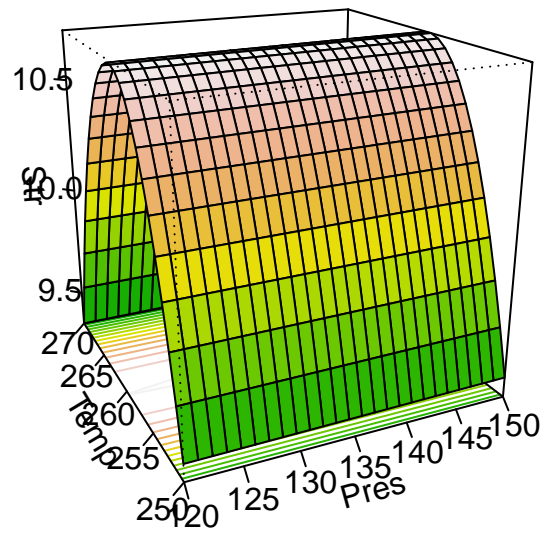
```
xs <-canonical(adhesive.rsm)$xs
```

```
## Near-stationary-ridge situation detected -- stationary point altered
## Change 'threshold' if this is not what you intend
```

```
contour(adhesive.rsm,~Pressure.data+Temperature.data, at=xs, image=TRUE)
```



```
persp(adhesive.rsm, ~ Pressure.data+ Temperature.data, col = terrain.colors(50), contours = "colors",
      zlab = "Str",
      xlab=c("Pres", "Temp"))
```



Pressure.data Temperature.data 0.000 259.858 ***