EXERCISE 4 Single – Factor Experiments: CRD

Kyla Ayop and Charlene Garridos

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Contents

1 R Library

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.2     v readr     2.1.4
## v forcats   1.0.0     v stringr   1.5.0
## v ggplot2   3.4.2     v tibble    3.2.1
## v lubridate 1.9.2     v tidyr     1.3.0
## v purrr     1.0.1
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(agricolae)
library(car)
```

```
## Loading required package: carData
##
## Attaching package: 'car'
##
## The following object is masked from 'package:dplyr':
##
##     recode
##
## The following object is masked from 'package:purrr':
##
##     some
```

2 Problem

The tensile strength of Portland cement is being studied. Four different mixing techniques can be used economically. The following data have been collected.

MIXING	TECHNIQUE TENSILE STRENGTH (LB/IN2)
1	3129 3000 2865 2890
2	3200 3300 2975 3150
3	2800 2900 2985 3050
4	2600 2700 2600 2765

2.1 Data

```
# Dataset
mixing_technique <- rep(c(1, 2, 3, 4), each = 4)
tensile_strength <- c(3129, 3000, 2865, 2890, 3200, 3300, 2975, 3150,
                      2800, 2900, 2985, 3050, 2600, 2700, 2600, 2765)
```

```r
# Convert to factor
mixing_technique = as.factor(mixing_technique)

# Data Frame
Portland_cement <- data.frame(mixing_technique, tensile_strength)

# Class attribute of the object
class(Portland_cement$mixing_technique)
```

```
## [1] "factor"
```

```r
# Level attributes of a variable
levels(Portland_cement$mixing_technique)
```

```
## [1] "1" "2" "3" "4"
```

```r
# Display data
Portland_cement
```

```
##    mixing_technique tensile_strength
## 1                 1             3129
## 2                 1             3000
## 3                 1             2865
## 4                 1             2890
## 5                 2             3200
## 6                 2             3300
## 7                 2             2975
## 8                 2             3150
## 9                 3             2800
## 10                3             2900
## 11                3             2985
## 12                3             3050
## 13                4             2600
## 14                4             2700
## 15                4             2600
## 16                4             2765
```

```r
# str() function help inspect the structure and levels of the dataset
str(Portland_cement)
```

```
## 'data.frame':    16 obs. of  2 variables:
##  $ mixing_technique: Factor w/ 4 levels "1","2","3","4": 1 1 1 1 2 2 2 2 3 3 ...
##  $ tensile_strength: num  3129 3000 2865 2890 3200 ...
```

2.1.1 Data Summary

```r
# summary
desc.data <- Portland_cement %>%
```

```r
  group_by(mixing_technique) %>%
  summarize(
    total = sum(tensile_strength),
    mean = mean(tensile_strength),
    standard_deviation=sd(tensile_strength),
    no_of_replicates=n(),
)

desc.data
```

```
## # A tibble: 4 x 5
##   mixing_technique total  mean standard_deviation no_of_replicates
##   <fct>            <dbl> <dbl>              <dbl>            <int>
## 1 1                11884 2971               121.                 4
## 2 2                12625 3156.              136.                 4
## 3 3                11735 2934.              108.                 4
## 4 4                10665 2666.               81.0                4
```

3 Analysis

3.1 ANOVA

```r
anova = aov(tensile_strength~mixing_technique, data=Portland_cement)
summary(anova)
```

```
##                  Df Sum Sq Mean Sq F value   Pr(>F)
## mixing_technique  3 489740  163247   12.73 0.000489 ***
## Residuals        12 153908   12826
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Hypothesis and Test Statistic:

H_O: There is no significant difference in the mean tensile strength of Portland cement among the four mixing techniques that are used economically.

$$[\mu_1 = \mu_2 = \mu_3 = \mu_4]$$

H_a: At least one mixing technique gave a different mean tensile strength of Portland cement among the four mixing techniques that are used economically.

$$[\mu_i \neq \mu_j, i \neq j]$$

Test statistic: One-way analysis of Variance at $\alpha = 0.05$.

Decision Rule: Reject H_o at $\alpha = 0.05$ if $F_c > F_t = F_{3,12}(0.05) = 3.49$. Otherwise fail to reject H_o.

Decision: Since $F_c = 12.73 > F_t = 3.49$, then we reject H_o.

The results shows that the computed F-value is 12.73 and the p-value of 0.000489. This implies that a smaller p-value indicates stronger evidence against the null hypothesis.

Conclusion: Since $F_c = 12.73 > F_t = 3.49$, and $p - value = 0.000489 < \alpha = 0.05$, then we reject H_o. Thus, we have enough evidence to reject the null hypothesis at 5% level of significance. Therefore, there is sufficient evidence to conclude that at least one mixing technique yields a different mean tensile strength of Portland cement compared to the others among the four mixing techniques used economically.

3.2 Normality Assumption

3.2.1 QQ plot

```
plot(anova,which=2)
```

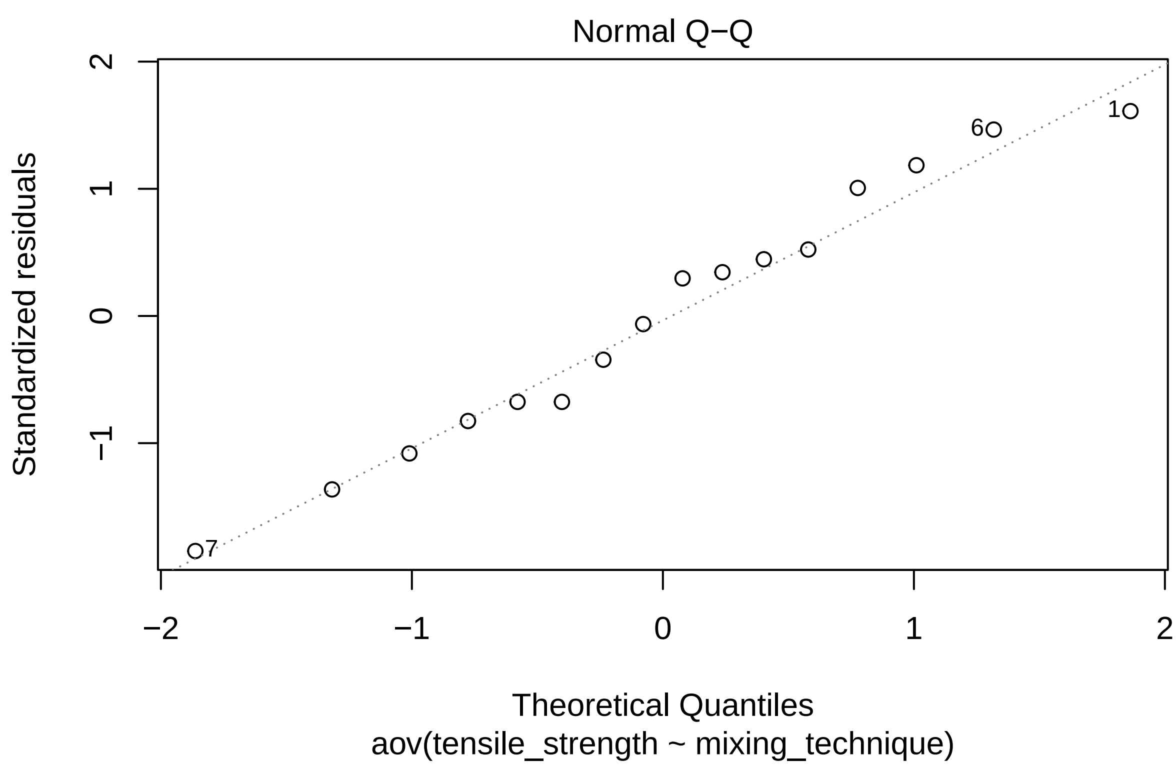

Figure 1: The Normal Q-Q Plot of Residuals

Interpretation

Hypotheses:

$H_o : X_i's$ comes from a normal distribution.

$H_a : X_i's$ do not come from a normal distribution.

The residuals plotted in Figure 1: the normal probability plot do not fall along a straight line, which suggests that the normality assumption is not valid. A data transformation is recommended.

3.3 Homogeneity of variances

3.3.1 Residual vs Fitted Plot

```
plot(anova,which=1)
```

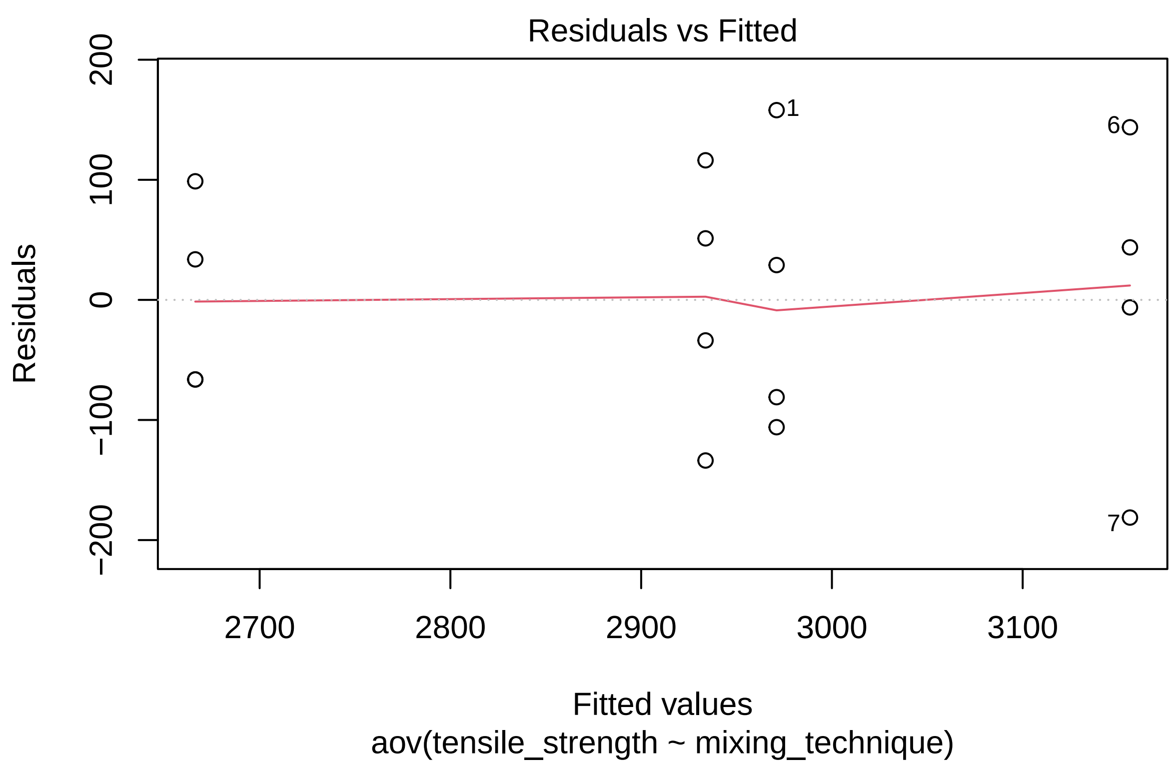

Figure 2: The Residual Vs Fitted Values

Interpretation

The figure 2: residuals-versus-predicted seems funnel-shaped. This demonstrates that the variance of the initial observations is not constant. The residuals depicted in the normal probability plot do not form a straight line, implying that the normality assumption is invalid. A data transformation is recommended, such as $\sqrt{Y}$ correction.

3.4 Visualization

```
#visual inspection using box plot
box_plot=ggplot(Portland_cement, aes(x = mixing_technique, y = tensile_strength)) +
  geom_boxplot(aes(fill = mixing_technique), fill="turquoise",show.legend = FALSE) +
  stat_summary(fun="mean", geom="point", shape=15, size=1, color="red")+ theme_classic()
box_plot + xlab("Mixing Technique") + ylab("Tensile Strength")
```

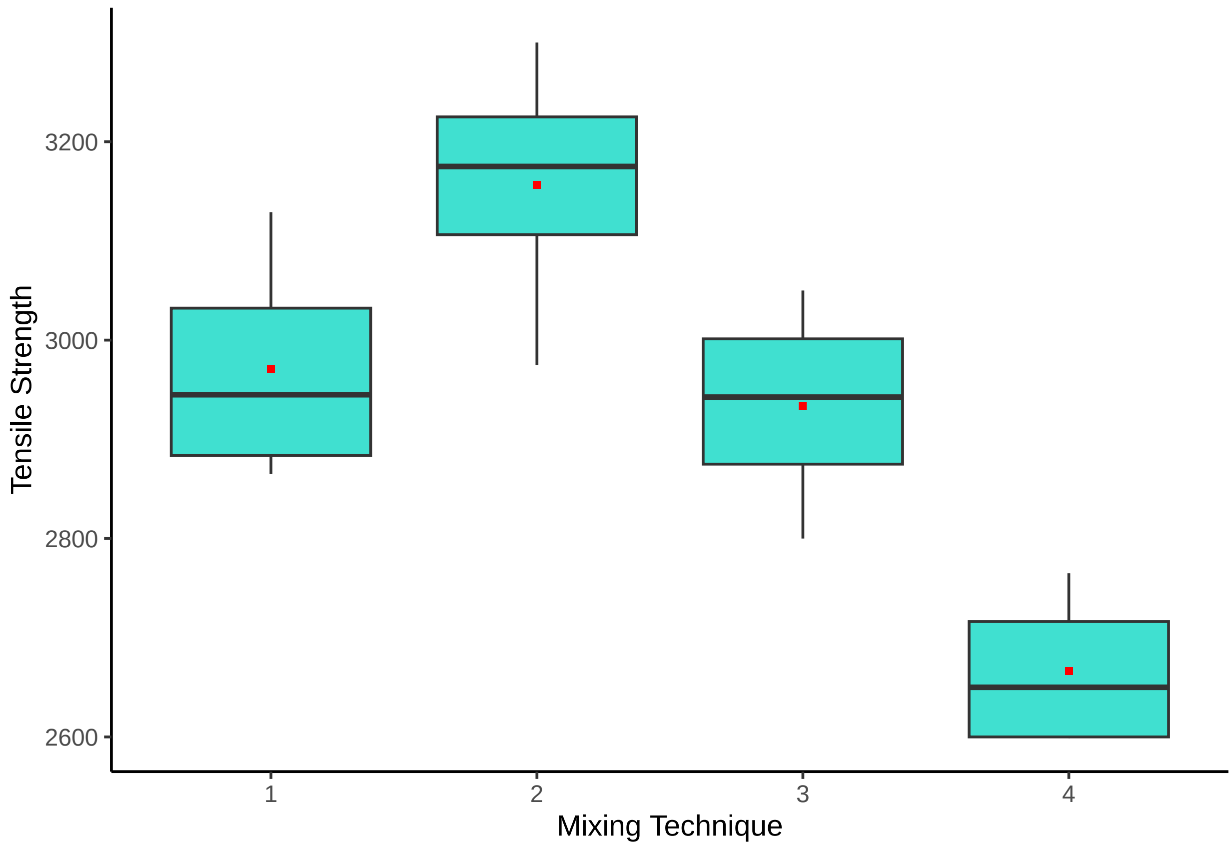

Figure 3: The Effect of Mixing Technique on Tesile Strength

Interpretation

In Figure 3, the distribution of mean tensile strength values for Portland cement is depicted across four mixing techniques. Each box represents the distribution of tensile strength values for a specific mixing technique, with red points indicating the mean tensile strength for each group. Mixing techniques 1 and 4 appear right-skewed, while mixing techniques 2 and 3 are left-skewed. The plot also highlights the differences between mixing techniques: 2 and 1, 2 and 3, 2 and 4, 1 and 4, and 3 and 4. Additionally, upon closer examination, no significant difference between mixing techniques 1 and 3.

3.5 Multiple Comparison Test

```
lsd=LSD.test(anova, "mixing_technique", alpha = 0.05)
lsd
```

```
## $statistics
##    MSerror Df     Mean       CV  t.value      LSD
##   12825.69 12 2931.812 3.862817 2.178813 174.4798
##
## $parameters
##         test p.ajusted           name.t ntr alpha
##   Fisher-LSD      none mixing_technique   4  0.05
##
## $means
##   tensile_strength       std r       se      LCL      UCL  Min  Max     Q25
## 1          2971.00 120.55704 4 56.62528 2847.624 3094.376 2865 3129 2883.75
## 2          3156.25 135.97641 4 56.62528 3032.874 3279.626 2975 3300 3106.25
## 3          2933.75 108.27242 4 56.62528 2810.374 3057.126 2800 3050 2875.00
## 4          2666.25  80.97067 4 56.62528 2542.874 2789.626 2600 2765 2600.00
##      Q50     Q75
## 1 2945.0 3032.25
## 2 3175.0 3225.00
## 3 2942.5 3001.25
## 4 2650.0 2716.25
##
## $comparison
## NULL
##
## $groups
##   tensile_strength groups
## 2          3156.25      a
## 1          2971.00      b
## 3          2933.75      b
## 4          2666.25      c
##
## attr(,"class")
## [1] "group"
```

```
plot(lsd)
```

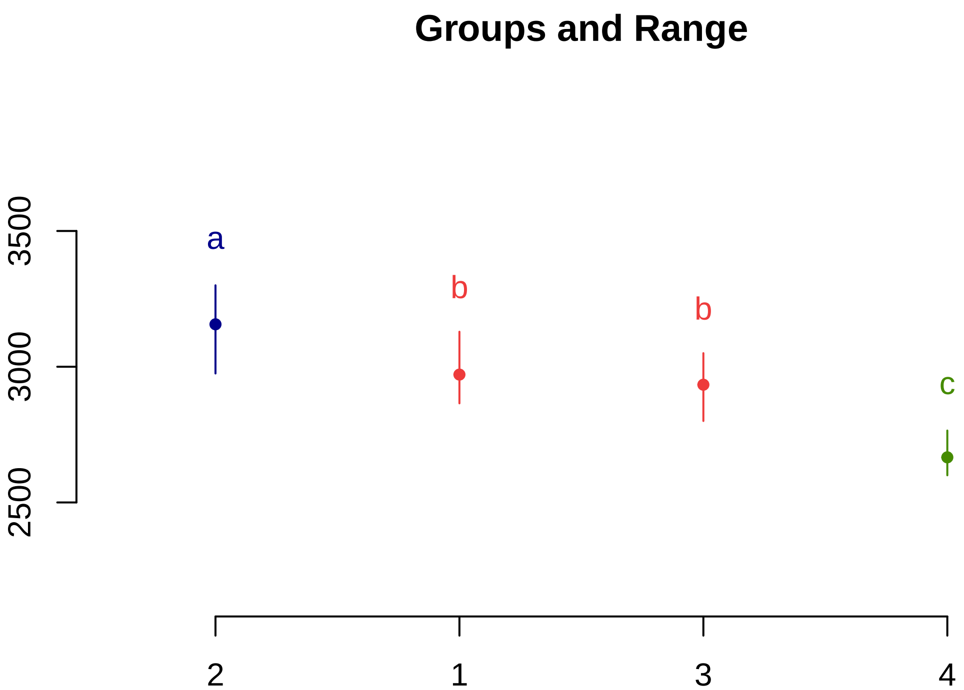

Figure 4: The Fisher's Least Significant Difference (LSD) test Of The Effect of Mixing Technique on Tesile Strength

Interpretation

Fisher's Least Significant Difference (LSD) test, conducted at an alpha level of 0.05, was employed to analyze the significant differences between mixing techniques as depicted in Figure 4. The results indicate that mixing techniques 2(a) and 1(b), 2(a) and 3(b), 2(a) and 4(c), 1(b) and 4(c), and 3(b) and 4(c) exhibit statistically significant differences in mean tensile strength of Portland cement. However, there is no significant difference observed between mixing techniques 1(b) and 3(b). Therefore, there is at least one mixing technique yields a different mean tensile strength of Portland cement compared to the others among the four economically utilized mixing techniques.