## ECS526

## Final Project Paper <br> Group 1 <br> December 10, 2003

## Evaluation of

## Monofilament Testing for Product Mixing

Parvez Bahadur<br>Gino Duca - Group Leader<br>Prasanna Jagannathan<br>Batul Mukadana<br>Anirudha Kishor Parab<br>Tushar Dwarka Sainani<br>Jr-Hung Tsai

Section: ..... Page
I. Problem Statement ..... 3
II. Executive Summary .....  4
III.Problem Restatement .....  5
Objective. ..... 5
Statistical Problem Statement ..... 5
Method ..... 5
Data Set ..... 6
IV. Data Analysis ..... 8
Data Collection. ..... 8
Data Organization ..... 8
Data Investigation. ..... 8
V. Hypothesis Testing ..... 43
Paired-t test for \%Strain@3GPD. ..... 43
Paired-t test for \% Tenacity@Break ..... 43
VI. Correlation Analysis. ..... 44
Sample 1. ..... 44
Sample 2. ..... 45
VII. Modeling: ANOVA and Regression ..... 46
ANOVA: Sample 1 Strain ..... 46
ANOVA: Sample 2 Strain ..... 50
ANOVA: Sample 1 Tenacity ..... 53
ANOVA: Sample 2 Tenacity ..... 55
ANOVA: Tester 1 Sample 1 Strain. ..... 58
ANOVA: Tester 1 Sample 2 Strain ..... 60
Hypothesis Testing Confirmation ..... 62
Regression Analysis: Tester 1A versus Tester2A, 3A, 4A ..... 63
Regression Analysis: Tester 1B versus Tester2B, 3B, 4B ..... 64
VIII. Conclusion and Recommendations ..... 65

## I. Problem Statement:

Polyester monofilament is produced at a local company for use in paper machine fabrics around the world. Products are currently produced on demand for delivery in six weeks with each ordered lot produced entirely on one production line. This company would like to produce many products at scheduled times and inventory material made on several different production lines. The company is confident that it can meet the quality specifications as long as the test method and the tester are not introducing significant error.

## II. Executive Summary:

Monofilament samples were collected from 2 production lines that produce product X . The samples were stress-strain tested by using standard test techniques by four different testers. The project should not move forward as all properties for each sample were not found to be equal. The tested samples were found to statistically different mean values for the property of "\% Strain @ 3 GPD", but for the property of "Tenacity @ Break", the mean values were the same. Tester error or sampling error are believed to be the largest contributing factors. The experiment and analysis should be repeated.

## III. Problem Restatement

Objective:
Statistical methods will be used to analyze the collected data to determine if this project can move forward. Having the ability to mix lots will give the company a
competitive advantage, but reducing yield loss and lead times to meet customer orders.

## Statistical Problem Statement:

Each of the four testers perform standard "Stress-strain Testing", and all the data from the testers will be analyzed. Monofilament samples are chosen from two different production line; sample 1 and sample 2. Data is sampled randomly in order ensure the statistical independence of the sample.

Each tester performed ten tests of each of the samples on three different days. We gathered all the data after their test and divided them into the two most critical properties:

Percent Strain at 3 grams/denier (\%Strain@3GPD)
Tenacity at break (ten@break)

## Method:

Various methods will be used to analyze the data and determine if any differences exist between the properties of each sample and potentially, between the testers.

## Data Set (tabular form)

\% Strain @ 3GPD:

|  | Tester 1 A | Tester 1 B | Tester 2 A | Tester 2 B | Tester 3 A | Tester 3 B | Tester 4 A | Tester 4 B |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 1 | 3.479 | 3.493 | 3.607 | 3.591 | 3.632 | 3.635 | 3.555 | 3.592 |
| 2 | 3.489 | 3.536 | 3.561 | 3.595 | 3.592 | 3.574 | 3.569 | 3.646 |
| 3 | 3.507 | 3.529 | 3.603 | 3.605 | 3.587 | 3.579 | 3.554 | 3.604 |
| 4 | 3.539 | 3.516 | 3.606 | 3.589 | 3.629 | 3.57 | 3.582 | 3.594 |
| 5 | 3.548 | 3.443 | 3.611 | 3.567 | 3.624 | 3.537 | 3.634 | 3.615 |
| 6 | 3.54 | 3.49 | 3.611 | 3.616 | 3.623 | 3.628 | 3.571 | 3.617 |
| 7 | 3.533 | 3.493 | 3.632 | 3.63 | 3.583 | 3.587 | 3.628 | 3.656 |
| 8 | 3.516 | 3.563 | 3.588 | 3.563 | 3.591 | 3.617 | 3.634 | 3.693 |


| 9 | 3.535 | 3.512 | 3.606 | 3.586 | 3.572 | 3.578 | 3.645 | 3.614 |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| 10 | 3.574 | 3.429 | 3.579 | 3.551 | 3.588 | 3.535 | 3.578 | 3.576 |
| 11 | 3.57 | 3.658 | 3.609 | 3.508 | 3.62 | 3.633 | 3.593 | 3.592 |
| 12 | 3.576 | 3.569 | 3.665 | 3.556 | 3.637 | 3.631 | 3.605 | 3.606 |
| 13 | 3.521 | 3.611 | 3.672 | 3.585 | 3.655 | 3.591 | 3.577 | 3.608 |
| 14 | 3.55 | 3.549 | 3.661 | 3.568 | 3.676 | 3.571 | 3.556 | 3.609 |
| 15 | 3.54 | 3.547 | 3.626 | 3.67 | 3.652 | 3.596 | 3.554 | 3.535 |
| 16 | 3.533 | 3.573 | 3.636 | 3.655 | 3.643 | 3.549 | 3.588 | 3.55 |
| 17 | 3.569 | 3.561 | 3.695 | 3.606 | 3.672 | 3.545 | 3.609 | 3.634 |
| 18 | 3.55 | 3.522 | 3.682 | 3.565 | 3.688 | 3.507 | 3.625 | 3.575 |
| 19 | 3.59 | 3.522 | 3.669 | 3.607 | 3.674 | 3.573 | 3.575 | 3.512 |
| 20 | 3.48 | 3.508 | 3.66 | 3.604 | 3.707 | 3.543 | 3.585 | 3.587 |
| 21 | 3.586 | 3.559 | 3.677 | 3.638 | 3.719 | 3.562 | 3.661 | 3.648 |
| 22 | 3.594 | 3.581 | 3.657 | 3.609 | 3.654 | 3.581 | 3.644 | 3.645 |
| 23 | 3.557 | 3.547 | 3.634 | 3.589 | 3.656 | 3.498 | 3.643 | 3.489 |
| 24 | 3.599 | 3.509 | 3.68 | 3.645 | 3.694 | 3.553 | 3.734 | 3.65 |
| 25 | 3.612 | 3.533 | 3.631 | 3.612 | 3.641 | 3.579 | 3.607 | 3.641 |
| 26 | 3.597 | 3.548 | 3.618 | 3.663 | 3.715 | 3.567 | 3.626 | 3.638 |
| 27 | 3.563 | 3.594 | 3.624 | 3.632 | 3.678 | 3.585 | 3.657 | 3.56 |
| 28 | 3.479 | 3.565 | 3.637 | 3.584 | 3.694 | 3.593 | 3.617 | 3.6 |
| 29 | 3.555 | 3.562 | 3.631 | 3.558 | 3.656 | 3.598 | 3.659 | 3.621 |
| 30 | 3.54 | 3.616 | 3.661 | 3.548 | 3.665 | 3.558 | 3.701 | 3.71 |
|  |  |  |  |  |  |  |  |  |

Tenacity @ Break:

|  | Tester 1 AA | Tester 1 BB | Tester 2 AA | Tester 2 BB | Tester 3 AA | Tester 3 BB | Tester 4 AA | Tester 4 BB |
| ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 6.779 | 7.1475 | 6.925 | 6.737 | 6.83 | 6.9395 | 6.983 | 6.8275 |
| 2 | 6.6045 | 6.686 | 6.565 | 7.1625 | 6.9995 | 6.932 | 6.788 | 6.9995 |
| 3 | 6.7445 | 6.8115 | 6.96 | 7.088 | 6.8115 | 6.8025 | 6.9395 | 6.8765 |
| 4 | 6.514 | 6.9995 | 6.482 | 6.7645 | 6.6815 | 7.0225 | 6.7905 | 6.944 |
| 5 | 6.862 | 6.951 | 6.642 | 6.944 | 6.6305 | 7.0065 | 6.8025 | 6.9205 |
| 6 | 6.7995 | 6.9015 | 6.4 | 7.0345 | 6.7955 | 6.8345 | 6.8505 | 6.9995 |
| 7 | 6.865 | 6.7995 | 6.753 | 6.7995 | 6.8115 | 6.737 | 7.0025 | 6.846 |
| 8 | 6.8695 | 6.8185 | 7.011 | 6.967 | 6.549 | 6.995 | 6.772 | 6.651 |
| 9 | 6.8115 | 6.916 | 6.514 | 6.8155 | 6.533 | 7.0385 | 6.8895 | 6.913 |


| 10 | 6.3885 | 6.8925 | 6.5445 | 7.053 | 6.8155 | 6.976 | 6.9045 | 6.8155 |
| ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 11 | 6.8275 | 7.104 | 7.062 | 6.96 | 6.839 | 6.7765 | 6.702 | 6.654 |
| 12 | 6.8695 | 7.085 | 6.983 | 7.104 | 6.9045 | 6.8155 | 6.642 | 6.721 |
| 13 | 6.948 | 6.983 | 6.8925 | 7.062 | 6.916 | 6.909 | 6.881 | 6.928 |
| 14 | 6.8225 | 6.9365 | 6.913 | 6.9715 | 6.7765 | 7.025 | 6.9045 | 6.7645 |
| 15 | 6.944 | 7.025 | 6.951 | 6.8735 | 6.9015 | 6.862 | 6.7765 | 6.96 |
| 16 | 6.8115 | 6.8415 | 6.8345 | 6.9875 | 6.897 | 6.654 | 6.8415 | 6.967 |
| 17 | 6.788 | 6.8535 | 6.979 | 6.7995 | 6.979 | 7.069 | 6.8225 | 6.8345 |
| 18 | 6.9395 | 6.6815 | 7.0295 | 6.995 | 6.916 | 7.057 | 6.9365 | 6.951 |
| 19 | 6.4395 | 6.7165 | 6.9395 | 6.928 | 6.7765 | 6.925 | 6.862 | 6.9905 |
| 20 | 6.8415 | 7.0505 | 6.865 | 6.925 | 6.6655 | 6.8345 | 6.7675 | 6.9365 |
| 21 | 6.913 | 6.7835 | 6.8155 | 6.964 | 6.925 | 6.9905 | 6.8225 | 6.607 |
| 22 | 6.839 | 6.7675 | 6.8185 | 7.151 | 6.705 | 6.8155 | 6.846 | 6.67 |
| 23 | 6.6185 | 6.897 | 6.8575 | 6.5955 | 6.779 | 7.0225 | 6.642 | 6.881 |
| 24 | 6.7835 | 6.839 | 6.788 | 6.658 | 6.8855 | 6.9045 | 6.7485 | 6.7325 |
| 25 | 6.4075 | 6.9875 | 6.897 | 6.6185 | 6.7675 | 6.865 | 6.7675 | 6.839 |
| 26 | 6.881 | 6.737 | 6.967 | 6.932 | 6.756 | 6.9395 | 6.7285 | 7.057 |
| 27 | 6.721 | 6.7955 | 6.7835 | 6.651 | 6.8185 | 6.8155 | 6.8765 | 6.9365 |
| 28 | 6.8155 | 6.8225 | 6.431 | 6.96 | 6.6785 | 6.9045 | 6.5095 | 6.8895 |
| 29 | 6.2325 | 6.779 | 6.8185 | 6.9995 | 6.7675 | 6.69 | 6.6185 | 7.0185 |
| 30 | 6.9015 | 6.6305 | 6.916 | 6.788 | 6.709 | 6.96 | 6.8115 | 6.8115 |

## IV. Data Analysis:

## Data Collection:

Each tester performed ten tests of each of the samples on three different days. Each tester performed a total of 30 tests for each sample; 120 total test values were recorded for each sample. The sampling allows us to make the assumption that all data points in each data set are independent identically distributed.

## Data Organization:

After we collected all the data we wanted, the data was organized into a spreadsheet. Each property was divided into table showing the results of each tester for samples 1 and 2 (or A and B). Values 1-10, 11-20 \& 21-30 would represent the 3 test events. Further analysis was performed using Minitab.

Data II


Figure.

| Variable | N | Mean | Median | TrMean | StDev | SE Mean |
| :--- | ---: | :---: | :---: | :---: | :---: | :---: |
| 3GPD 1 | 120 | 3.6103 | 3.6110 | 3.6112 | 0.0546 | 0.0050 |
| 3GPD 2 | 120 | 3.5800 | 3.5810 | 3.5807 | 0.0489 | 0.0045 |
|  |  |  |  |  |  |  |
| Variable | Minimum | Maximum | Q1 | Q3 |  |  |
| 3GPD 1 | 3.4790 | 3.7340 | 3.5725 | 3.6548 |  |  |
| 3GPD 2 | 3.4290 | 3.7100 | 3.5493 | 3.6118 |  |  |

Initial observation shows that the Mean, Standard deviation and Median are really all very close.

We also provide all the data points in each sample to show the distribution using box plots.
Figure: Boxplots - \%Strain @ 3GPD in Sample 1

Dotplot for 3 GPD tot 1


Figure: Boxplots - \%Strain @ 3GPD in Sample 2

Dotplot for 3 GPD tot 2


Figure: Graphical Summary for sample 1 in strain

## Descriptive Statistics


Variable: 3GPD 1

| Anderson-Darling | Normality Test |
| :--- | ---: |
| A-Squared: | 0.252 |
| P-Value: | 0.734 |
| Mean | 3.61029 |
| StDev | 0.05457 |
| Variance | $2.98 \mathrm{E}-03$ |
| Skewness | $-2.0 \mathrm{E}-01$ |
| Kurtosis | $-3.1 \mathrm{E}-01$ |
| N | 120 |
|  |  |
| Minimum | 3.47900 |
| 1st Quartile | 3.57250 |
| Median | 3.61100 |
| 3rd Quartile | 3.65475 |
| Maximum | 3.73400 |

95\% Confidence Interval for Mu $3.60043 \quad 3.62016$
95\% Confidence Interval for Sigma
$0.04843 \quad 0.06251$
95\% Confidence Interval for Median
3.596393 .62640

By observation, the sample mean and sample median are very close. Also, as P -value is 0.734 we cannot reject normality.
Figure: Graphical Summary for sample 2 in strain
Descriptive Statistics


Variable: 3GPD 2

| Anderson-Darling | Normality Test |
| :---: | ---: |
| A-Squared: | 0.234 |
| P-Value: | 0.792 |
| Mean | 3.58002 |
| StDev | 0.04885 |
| Variance | $2.39 \mathrm{E}-03$ |
| Skewness | $-2.4 \mathrm{E}-01$ |
| Kurtosis | 0.442121 |
| N | 120 |
| Minimum | 3.42900 |
| 1st Quartile | 3.54925 |
| Median | 3.58100 |
| 3rd Quartile | 3.61175 |
| Maximum | 3.71000 |
| 95\% Confidence Interval for Mu |  |
| 3.57119 | 3.58886 |
| 95\% Confidence Interval for Sigma |  |
| 0.04336 | 0.05596 |
| 95\% Confidence Interval for Median |  |
| 3.56980 | 3.59120 |

By observation, the sample mean and sample median are very close. Also, the $P$ value is 0.792 so we cannot reject normality.
Figure: Descriptive Statistics - \%Strain @ 3GPD by Tester

| Variable | N | Mean | Median | Tr Mean | St Dev | SE Mean | Production line |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tester 1 | 30 | 3.5474 | 3.5490 | 3.5482 | 0.0367 | 0.0067 | A |
| Tester 2 | 30 | 3.6343 | 3.6315 | 3.6351 | 0.0333 | 0.0061 | A |
| Tester 3 | 30 | 3.6473 | 3.6530 | 3.6473 | 0.0410 | 0.0075 | A |
| Tester 4 | 30 | 3.6122 | 3.6080 | 3.6086 | 0.0444 | 0.0081 | A |
| Tester 1 | 30 | 3.5413 | 3.5470 | 3.5420 | 0.0480 | 0.0088 | B |
| Tester 2 | 30 | 3.5965 | 3.5930 | 3.5964 | 0.0374 | 0.0068 | B |
| Tester 3 | 30 | 3.5751 | 3.5760 | 3.5762 | 0.0341 | 0.0062 | B |
| Tester 4 | 30 | 3.6072 | 3.6085 | 3.6082 | 0.0480 | 0.0088 | B |


| Variable | Minimum | Maximum | Q1 | Q3 | Production line |
| :--- | :---: | :--- | :---: | :---: | :---: |
| Tester 1 | 3.4790 | 3.6120 | 3.5300 | 3.5745 | A |
| Tester 2 | 3.5610 | 3.6950 | 3.6085 | 3.6620 | A |
| Tester 3 | 3.5720 | 3.7190 | 3.6228 | 3.6765 | A |
| Tester 4 | 3.5540 | 3.7340 | 3.5765 | 3.6433 | A |
| Tester 1 | 3.4290 | 3.6580 | 3.5113 | 3.5660 | B |
| Tester 2 | 3.5080 | 3.6700 | 3.5665 | 3.6195 | B |
| Tester 3 | 3.4980 | 3.6350 | 3.5520 | 3.5938 | B |
| Tester 4 | 3.4890 | 3.7100 | 3.5843 | 3.6420 | B |

According to the above figure, we can observe that for each tester testing in \%strain @ 3 GPD, the Mean, Median and Standard deviation are very close.

Figure: Graphical Summary for tester 1 test sample 1 in strain

Descriptive Statistics


## Variable: Tester 1A

| Anderson-Darling | Normality Test |
| :--- | ---: |
| A-Squared: | 0.330 |
| P-Value: | 0.502 |
|  |  |
| Mean | 3.54737 |
| StDev | 0.03672 |
| Variance | $1.35 \mathrm{E}-03$ |
| Skewness | $-3.2 \mathrm{E}-01$ |
| Kurtosis | $-4.7 \mathrm{E}-01$ |
| N | 30 |
| Minimum | 3.47900 |
| 1st Quartile | 3.53000 |
| Median | 3.54900 |
| 3rd Quartile | 3.57450 |
| Maximum | 3.61200 |

95\% Confidence Interval for Mu $3.53365 \quad 3.56108$
95\% Confidence Interval for Sigma $0.02925 \quad 0.04937$
95\% Confidence Interval for Median $3.53591 \quad 3.56763$

By observation, we can see that the data is skewed right (sample mean is located below the sample median).Also, P -value is 0.502 so the data is normal.

Figure: Graphical Summary for tester 2 test sample 1 in strain

## Descriptive Statistics



Variable: Tester 2A

| Anderson-Darling | Normality Test |
| :---: | ---: |
| A-Squared: | 0.377 |
| P-Value: | 0.387 |
| Mean | 3.63430 |
| StDev | 0.03329 |
| Variance | $1.11 \mathrm{E}-03$ |
| Skewness | $-1.1 \mathrm{E}-01$ |
| Kurtosis | $-6.0 \mathrm{E}-01$ |
| N | 30 |
| Minimum | 3.56100 |
| 1st Quartile | 3.60850 |
| Median | 3.63150 |
| 3rd Quartile | 3.66200 |
| Maximum | 3.69500 |
| 95\% Confidence Interval for Mu |  |
| 3.62187 | 3.64673 |
| 95\% Confidence Interval for Sigma |  |
| 0.02652 | 0.04476 |
| 95\% Confidence Interval for Median |  |
| 3.61260 | 3.65931 |

By observation, we can see that the data is skewed left (sample median is located below the sample mean). Also, the P -value is 0.387 so we cannot reject normality.

Figure: Graphical Summary for tester 3 test sample 1 in strain

Descriptive Statistics


95\% Confidence Interval for Mu


Variable: Tester 3A

Anderson-Darling Normality Test

| A-Squared: | 0.300 |
| :--- | ---: |
| P-Value: | 0.561 |
| Mean | 3.64730 |
| StDev | 0.04097 |
| Variance | $1.68 \mathrm{E}-03$ |
| Skewness | $-1.4 \mathrm{E}-01$ |
| Kurtosis | $-7.7 \mathrm{E}-01$ |
| N | 30 |
|  |  |
| Minimum | 3.57200 |
| 1st Quartile | 3.62275 |
| Median | 3.65300 |
| 3rd Quartile | 3.67650 |
| Maximum | 3.71900 |

95\% Confidence Interval for Mu
$3.63200 \quad 3.66260$
95\% Confidence Interval for Sigma
0.032630 .05508

95\% Confidence Interval for Median
$3.62969 \quad 3.67040$

By observation, we can see that the data is skewed right (sample mean is located below the sample median) \& the P -value is 0.561 so the data collected is normal.

Figure: Graphical Summary for tester 4 test sample 1 in strain

## Descriptive Statistics



Variable: Tester 4A

Anderson-Darling Normality Test
A-Squared: 0.451
P-Value: 0.257

| Mean | 3.61220 |
| :--- | ---: |
| StDev | 0.04440 |
| Variance | $1.97 \mathrm{E}-03$ |
| Skewness | 0.771577 |
| Kurtosis | 0.560493 |
| N | 30 |
|  |  |
| Minimum | 3.55400 |
| 1st Quartile | 3.57650 |
| Median | 3.60800 |
| 3rd Quartile | 3.64325 |
| Maximum | 3.73400 |

95\% Confidence Interval for Mu
3.595623 .62878

95\% Confidence Interval for Sigma
$0.03536 \quad 0.05969$
95\% Confidence Interval for Median
$3.58269 \quad 3.63263$
By observation, we can see that the data is skewed left (sample median is located below the sample mean) \& the P -value is 0.257 so we cannot reject normality.

## Figure: Graphical Summary for tester 1 test sample 2 in strain

## Descriptive Statistics


Variable: Tester 1B
Anderson-Darling Normality Test

| A-Squared: | 0.288 |
| :--- | ---: |
| P-Value: | 0.593 |
|  |  |
| Mean | 3.54127 |
| StDev | 0.04797 |
| Variance | $2.30 \mathrm{E}-03$ |
| Skewness | $-6.5 \mathrm{E}-02$ |
| Kurtosis | 0.884458 |
| N | 30 |
|  |  |
| Minimum | 3.42900 |
| 1st Quartile | 3.51125 |
| Median | 3.54700 |
| 3rd Quartile | 3.56600 |
| Maximum | 3.65800 |

95\% Confidence Interval for Mu 3.523353 .55918 95\% Confidence Interval for Sigma $0.03820 \quad 0.06449$
95\% Confidence Interval for Median
$3.52200 \quad 3.56177$

By observation, we can see that the data is skewed right (sample mean is located below the sample median). Also, the P-value is 0.593 so we cannot reject normality.

Figure: Graphical Summary for tester 2 test sample 2 in strain
Descriptive Statistics


95\% Confidence Interval for Mu

Variable: Tester 2B
Anderson-Darling Normality Test
A-Squared: 0.22
P-Value:

| Mean | 3.59650 |
| :--- | ---: |
| StDev | 0.03738 |
| Variance | $1.40 \mathrm{E}-03$ |
| Skewness | $1.92 \mathrm{E}-02$ |

Kurtosis $\quad-4.0 \mathrm{E}-02$
N
Minimum
3.50800
1st Quartile
3.56650
3.59300
$\begin{array}{ll}\text { 3rd Quartile } & 3.61950 \\ \text { Maximum } & 3.67000\end{array}$
Maximum $\quad 3.67000$
95\% Confidence Interval for Mu
$3.58254 \quad 3.61046$
95\% Confidence Interval for Sigma
$0.02977 \quad 0.05025$
$95 \%$ Confidence Interval for Median
$3.58423 \quad 3.60854$

By observation, we can see that the data is skewed left (sample median is located below the sample mean). P-value is 0.815 so the data is normal.

Figure: Graphical Summary for tester 3 test sample 2 in strain

Descriptive Statistics


Variable: Tester 3B

|  |  |
| :--- | ---: |
| Anderson-Darling | Normality Test |
| A-Squared: | 0.309 |
| P-Value: | 0.537 |
|  |  |
| Mean | 3.57510 |
| StDev | 0.03414 |
| Variance | $1.17 \mathrm{E}-03$ |
| Skewness | $-1.4 \mathrm{E}-01$ |
| Kurtosis | $8.96 \mathrm{E}-02$ |
| N | 30 |
| Minimum | 3.49800 |
| 1st Quartile | 3.55200 |
| Median | 3.57600 |
| 3rd Quartile | 3.59375 |
| Maximum | 3.63500 |

95\% Confidence Interval for Mu
$3.56235 \quad 3.58785$
95\% Confidence Interval for Sigma
$0.02719 \quad 0.04589$
95\% Confidence Interval for Median
$3.56314 \quad 3.58654$

By observation, we can see that the data is skewed right (sample mean is located below the sample median) \& P-value is 0.537 so the curve follows normality.

Figure: Graphical Summary for tester 4 test sample 2 in strain

## Descriptive Statistics



Variable: Tester 4B

| Anderson-Darling Normality Test |  |
| :---: | :---: |
| A-Squared: | 0.361 |
| P-Value: | 0.424 |
| Mean | 3.60723 |
| StDev | 0.04800 |
| Variance | $2.30 \mathrm{E}-03$ |
| Skewness | $-3.6 \mathrm{E}-01$ |
| Kurtosis | 0.717630 |
| N | 30 |
| Minimum | 3.48900 |
| 1st Quartile | 3.58425 |
| Median | 3.60850 |
| 3rd Quartile | 3.64200 |
| Maximum | 3.71000 |
| 95\% Confidence Interval for Mu |  |
| 3.58931 | 3.62516 |
| 95\% Confidence Interval for Sigma |  |
| 0.03823 | 0.06453 |
| 95\% Confidence Interval for Median |  |
| 3.59246 | 3.63103 |

By observation, we can see that the data is skewed right (sample mean is located below the sample median). Also, the P -value is 0.424 so we cannot reject normality.

## Normality testing (Anderson Darling):

Figure: Normal Probability Plot for tester 1 test sample 1 in strain Normal Probability Plot


By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 2 test sample 1 in strain Normal Probability Plot


Average: 3.6343
StDev: 0.0332940
$\mathrm{N}: 30$

Anderson-Darling Normality Test A-Squared: 0.377 P-Value: 0.387

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 3 test sample 1 in strain

## Normal Probability Plot



By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 4 test sample 1 in strain
Normal Probability Plot


Average: 3.6122
StDev: 0.0443998
$\mathrm{N}: 30$

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 1 test sample 2 in strain

## Normal Probability Plot



By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 2 test sample 2 in strain
Normal Probability Plot


By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 3 test sample 2 in strain

## Normal Probability Plot



Average: 3.5751
StDev: 0.0341360
$\mathrm{N}: 30$
Anderson-Darling Normality Test
A-Squared: 0.309
P-Value: 0.537

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 4 test sample 2 in strain Normal Probability Plot


By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

## P-values and confidence interval of strain test on spool A \& B -

| Tester on spool A | P- values | Confidence interval for <br> mean |
| :---: | :---: | :---: |
| 1 | 0.502 | $3.53<\mathrm{Mu}<3.56$ |
| 2 | 0.387 | $3.62<\mathrm{Mu}<3.64$ |
| 3 | 0.561 | $3.63<\mathrm{Mu}<3.66$ |
| 4 | 0.257 | $3.59<\mathrm{Mu}<3.62$ |
| Tester on spool B |  |  |
| 1 | 0.593 | $3.52<\mathrm{Mu}<3.56$ |
| 2 | 0.815 | $3.58<\mathrm{Mu}<3.61$ |
| 3 | 0.537 | $3.56<\mathrm{Mu}<3.59$ |
| 4 | 0.424 | $3.58<\mathrm{Mu}<3.62$ |

## Tenacity

Figure: Descriptive Statistics: Tenacity @ Break by Sample

| Variable | N | Mean | Median | TrMean | StDev | SE Mean |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| TEN 1 | 120 | 7.2148 | 7.2420 | 7.2257 | 0.1633 | 0.0149 |
| TEN 2 | 120 | 7.3177 | 7.3375 | 7.3191 | 0.1385 | 0.0126 |
|  |  |  |  |  |  |  |
| Variable | Minimum | Maximum | Q1 | Q3 |  |  |
| TEN 1 | 6.6210 | 7.5020 | 7.1660 | 7.3308 |  |  |
| TEN 2 | 7.0070 | 7.6090 | 7.2240 | 7.4230 |  |  |

As what we can observe from this figure, we conclude that the Mean, Standard deviation and Median are really all very close. But the minimum value for sample 1 is slightly smaller than sample 2 .

We also provide all the data points in each sample to show the distribution.

Figure: Boxplots - Tenacity @ Break in Sample 1
Dotplot for Ten tot 1


Figure: Boxplots - Tenacity @ Break in Sample 1

Dotplot for Ten tot 2


Figure: Graphical Summary for sample 1 in tenacity @ break

## Descriptive Statistics



Variable: TEN 1

| Anderson-Darling Normality Test |  |
| :---: | ---: |
| A-Squared: | 3.156 |
| P-Value: | 0.000 |
| Mean | 7.21478 |
| StDev | 0.16328 |
| Variance | $2.67 \mathrm{E}-02$ |
| Skewness | -1.13485 |
| Kurtosis | 1.32145 |
| N | 120 |
| Minimum | 6.62100 |
| 1st Quartile | 7.16600 |
| Median | 7.24200 |
| 3rd Quartile | 7.33075 |
| Maximum | 7.50200 |
| 95\% Confidence Interval for Mu |  |
| 7.18527 | 7.24430 |
| 95\% Confidence Interval for Sigma |  |
| 0.14491 | 0.18703 |
| 95\% Confidence Interval for Median |  |
| 7.21799 | 7.26561 |

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& we observe that the data collected is not normal as the P -value is zero.

Figure: Graphical Summary for sample 2 in tenacity @ break

Descriptive Statistics


Variable: TEN 2

| Anderson-Darling Normality Test |  |
| :---: | ---: |
| A-Squared: | 0.635 |
| P-Value: | 0.095 |
| Mean | 7.31766 |
| StDev | 0.13846 |
| Variance | $1.92 \mathrm{E}-02$ |
| Skewness | $-2.5 \mathrm{E}-01$ |
| Kurtosis | $-5.2 \mathrm{E}-01$ |
| N | 120 |
| Minimum | 7.00700 |
| 1st Quartile | 7.22400 |
| Median | 7.33750 |
| 3rd Quartile | 7.42300 |
| Maximum | 7.60900 |
| 95\% Confidence Interval for Mu |  |
| 7.29263 | 7.34269 |
| 95\% Confidence Interval for Sigma |  |
| 0.12288 | 0.15860 |
| 95\% Confidence Interval for Median |  |
| 7.28818 | 7.36900 |

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median), interestingly the p -value is 0.095 so we say that the data is normal as $\mathrm{P}>\alpha$

Figure: Descriptive Statistics - Tenacity @ Break by Tester

| Variable | N | Mean | Median | TrMean | StDev | SE Mean | Production Line |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: |
| Tester 1 | 30 | 6.7528 | 6.8135 | 6.7719 | 0.1844 | 0.0337 | A |
| Tester 1 | 30 | 6.8747 | 6.8475 | 6.8722 | 0.1323 | 0.0242 | B |
| Tester 2 | 30 | 6.8113 | 6.8613 | 6.8237 | 0.1875 | 0.0342 | A |
| Tester 2 | 30 | 6.9096 | 6.9520 | 6.9139 | 0.1558 | 0.0284 | B |
| Tester 3 | 30 | 6.7940 | 6.8035 | 6.7985 | 0.1156 | 0.0211 | A |
| Tester 3 | 30 | 6.9040 | 6.9170 | 6.9096 | 0.1097 | 0.0200 | B |
| Tester 4 | 30 | 6.8077 | 6.8170 | 6.8122 | 0.1103 | 0.0201 | A |
| Tester 4 | 30 | 6.8647 | 6.8853 | 6.8696 | 0.1201 | 0.0219 | B |
|  |  |  |  |  |  |  |  |
| Variable | Minimum | Maximum |  | Q1 | Production Line |  |  |
| Tester 1 | 6.2325 | 6.9480 | 6.6954 | 6.8695 | A |  |  |
| Tester 1 | 6.6305 | 7.1475 | 6.7824 | 6.9841 | B |  |  |
| Tester 2 | 6.4000 | 7.0620 | 6.7253 | 6.9533 | A |  |  |
| Tester 2 | 6.5955 | 7.1625 | 6.7966 | 7.0083 | B |  |  |
| Tester 3 | 6.5330 | 6.9995 | 6.7080 | 6.8981 | A |  |  |
| Tester 3 | 6.6540 | 7.0690 | 6.8155 | 6.9979 | B |  |  |
| Tester 4 | 6.5095 | 7.0025 | 6.7628 | 6.8831 | A |  |  |
| Tester 4 | 6.6070 | 7.0570 | 6.7998 | 6.9533 | B |  |  |

According to above figure, we can observe that for each tester testing in Tenacity @ Break, the mean and median are larger in sample 1 than sample 2 for each tester.

Figure: Graphical Summary for tester 1 test sample 1 in tenacity @ break

## Descriptive Statistics



Variable: Tester 1 AA

Anderson-Darling Normality Test
A-Squared: 2.099
P-Value: $\quad 0.000$
Mean 6.75275
StDev 0.18439

Variance $\quad 3.40 \mathrm{E}-02$
Skewness -1.42038
Kurtosis 1.25193
N
Minimum 6.23250
1st Quartile $\quad 6.69538$
Median 6.81350
3rd Quartile $\quad 6.86950$
Maximum
6.94800
$95 \%$ Confidence Interval for Mu
$6.68390 \quad 6.82160$
95\% Confidence Interval for Sigma
$0.14685 \quad 0.24788$
95\% Confidence Interval for Median
$6.78003 \quad 6.85731$

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) as P -value is zero the data is not normal.

Figure: Graphical Summary for tester 2 test sample 1 in tenacity @ break

## Descriptive Statistics



Variable: Tester 2 AA

| Anderson-Darling Normality Test |  |
| :--- | ---: |
| A-Squared: | 1.294 |
| P-Value: | 0.002 |
|  |  |
| Mean | 6.81127 |
| StDev | 0.18754 |
| Variance | $3.52 \mathrm{E}-02$ |
| Skewness | $-9.2 \mathrm{E}-01$ |
| Kurtosis | $-2.4 \mathrm{E}-01$ |
| N | 30 |
|  |  |
| Minimum | 6.40000 |
| 1st Quartile | 6.72525 |
| Median | 6.86125 |
| 3rd Quartile | 6.95325 |
| Maximum | 7.06200 |

95\% Confidence Interval for Mu $6.74124 \quad 6.88129$ 95\% Confidence Interval for Sigma
$0.14936 \quad 0.25211$
95\% Confidence Interval for Median 6.794296 .92294

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& the data is not normal as $\mathrm{P}<\alpha$

Figure: Graphical Summary for tester 3 test sample 1 in tenacity @ break

## Descriptive Statistics



Variable: Tester 3 AA

Anderson-Darling Normality Test
A-Squared: 0.314
$P$-Value: $\quad 0.527$

| Mean | 6.79402 |
| :--- | :--- |
| StDev | 0.11557 |

$\begin{array}{ll}\text { Mean } & 6.79402 \\ \text { StDev } & 0.11557\end{array}$
Variance $\quad 1.34 \mathrm{E}-02$
Skewness -4.3E-01
$\begin{array}{ll}\text { Kurtosis } & -4.4 \mathrm{E}-02 \\ \mathrm{~N}\end{array}$
N
Minimum 6.53300
1st Quartile 6.70800
Median 6.80350
3rd Quartile $\quad 6.89813$
Maximum 6.99950
95\% Confidence Interval for Mu
$6.75086 \quad 6.83717$
95\% Confidence Interval for Sigma
$0.09204 \quad 0.15537$
95\% Confidence Interval for Median
6.76750 6.83694

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& P-value is 0.527 so the data is normal.

Figure: Graphical Summary for tester 4 test sample 1 in tenacity @ break
Descriptive Statistics


By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& P-value is 0.515 so data is normal.

Figure: Graphical Summary for tester1 test sample 2 in tenacity @ break

## Descriptive Statistics



95\% Confidence Interval for Median

Variable: Tester 1 BB

Anderson-Darling Normality Test
A-Squared: 0.214
P-Value: $\quad 0.837$
Mean 6.87465
StDev 0.13232
Variance $\quad 1.75 \mathrm{E}-02$
Skewness 0.262836
Kurtosis $\quad-5.8 \mathrm{E}-01$
N
Minimum 6.63050
1st Quartile 6.78238
Median 6.84750
$\begin{array}{ll}\text { 3rd Quartile } & 6.98413 \\ & 7.14750\end{array}$
Maximum $\quad 7.14750$
95\% Confidence Interval for Mu
$6.82524 \quad 6.92406$
95\% Confidence Interval for Sigma
$0.10538 \quad 0.17789$
95\% Confidence Interval for Median
$6.80224 \quad 6.93181$

By observation, we can see that the data is skewed left obviously (sample median is located below the sample mean) \& P-value is 0.837 so the curve follows normality

Figure: Graphical Summary for tester2 test sample 2 in tenacity @ break

## Descriptive Statistics



Variable: Tester 2 BB
Anderson-Darling Normality Test
A-Squared: 0.560
$P$-Value: $\quad 0.135$

| Mean | 6.90963 |
| :--- | ---: |
| StDev | 0.15578 |
| Variance | $2.43 \mathrm{E}-02$ |
| Skewness | $-4.7 \mathrm{E}-01$ |
| Kurtosis | $-5.5 \mathrm{E}-01$ |
| N | 30 |
|  |  |
| Minimum | 6.59550 |
| 1st Quartile | 6.79663 |
| Median | 6.95200 |
| 3rd Quartile | 7.00825 |
| Maximum | 7.16250 |

95\% Confidence Interval for Mu $6.85147 \quad 6.96780$
95\% Confidence Interval for Sigma
0.124060 .20941

95\% Confidence Interval for Median
6.82877
6.98384

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& P-value is 0.135 so we cannot reject normality.

Figure: Graphical Summary for tester3 test sample 2 in tenacity @ break

## Descriptive Statistics



Variable: Tester 3 BB

Anderson-Darling Normality Test
A-Squared: 0.350
P-Value:
0.450

| Mean | 6.90397 |
| :--- | ---: |
| StDev | 0.10970 |
| Variance | $1.20 \mathrm{E}-02$ |
| Skewness | $-4.8 \mathrm{E}-01$ |
| Kurtosis | $-4.4 \mathrm{E}-01$ |
| N | 30 |
| Minimum | 6.65400 |
| 1st Quartile | 6.81550 |
| Median | 6.91700 |
| 3rd Quartile | 6.99788 |
| Maximum | 7.06900 |

95\% Confidence Interval for Mu $6.86300 \quad 6.94493$
95\% Confidence Interval for Sigma $0.08737 \quad 0.14747$
95\% Confidence Interval for Median 6.840796 .9723

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& P-value is 0.45 so we cannot reject normality.

Figure: Graphical Summary for tester4 test sample 2 in tenacity @ break

## Descriptive Statistics



Variable: Tester 4 BB

Anderson-Darling Normality Test

| A-Squared: | 0.572 |
| :--- | ---: |
| P-Value: | 0.126 |
|  |  |
| Mean | 6.86475 |
| StDev | 0.12005 |
| Variance | $1.44 \mathrm{E}-02$ |
| Skewness | $-6.0 \mathrm{E}-01$ |
| Kurtosis | $-4.8 \mathrm{E}-01$ |
| N | 30 |
|  |  |
| Minimum | 6.60700 |
| 1st Quartile | 6.79975 |
| Median | 6.88525 |
| 3rd Quartile | 6.95325 |
| Maximum | 7.05700 |

95\% Confidence Interval for Mu 6.819926 .90958

95\% Confidence Interval for Sigma $0.09561 \quad 0.16139$
95\% Confidence Interval for Median
6.829106 .93650

By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) \& P-value was 0.126 so we cannot reject normality.

## Normality testing (Anderson Darling)

Figure: Normal Probability Plot for tester 1 test sample 1 in tenacity @ break

## Normal Probability Plot



```
Average: 6.75275
StDev: 0.184394
N: 30
Anderson-Darling Normality Test \(\mathrm{N}: 30\)
A-Squared: 2.099
P-Value: 0.000
```

By the graphic, we can conclude that the data is not normal (because P -value $<$ 0.05 ), the reason might be tester error, sample defect or instrument problems.

Figure: Normal Probability Plot for tester 2 test sample 1 in tenacity @ break Normal Probability Plot


By the graphic, we can conclude that the data is not normal (because P -value $<$ 0.05 ), the reason might be tester error, sample defect or instrument problems.

Figure: Normal Probability Plot for tester 3 test sample 1 in tenacity @ break Normal Probability Plot


By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 4 test sample 1 in tenacity @ break Normal Probability Plot


Anderson-Darling Normality Test
StDev. 0.110296
A-Squared: 0.321
$\mathrm{N}: 30$ $P$-Value: 0.515

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 1 test sample 2 in tenacity @ break

## Normal Probability Plot



Average: 6.87465
Anderson-Darling Normality Test
StDev: 0.132324
A-Squared: 0.214
P-Value: 0.837
By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 2 test sample 2 in tenacity @ break
Normal Probability Plot


Average: 6.90963
StDev. 0.155776
$\mathrm{N}: 30$
A-Squared: 0.560
$P$-Value: 0.135

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 3 test sample 2 in tenacity @ break

Normal Probability Plot


Average: 6.90397
StDev: 0.109701
Anderson-Darling Normality Test $\mathrm{N}: 30$ A-Squared: 0.350
P-Value: 0.450

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

Figure: Normal Probability Plot for tester 4 test sample 2 in tenacity @ break Normal Probability Plot


Average: 6.86475
StDev: 0.120053
N: 30

Anderson-Darling Normality Test
A-Squared: 0.572
$P$-Value: 0.126

By the graphic, we can conclude that the data is normal (because P -value $>0.05$ )

## P-values and confidence interval of Tenacity test on spool A \& B -

| Tester on spool A | P- values | Confidence interval for <br> mean |
| :---: | :---: | :---: |
| 1 | 0.000 | $6.68<\mathrm{Mu}<6.82$ |
| 2 | 0.002 | $6.74<\mathrm{Mu}<6.88$ |
| 3 | 0.527 | $6.75<\mathrm{Mu}<6.84$ |
| 4 | 0.515 | $6.77<\mathrm{Mu}<6.85$ |
| Tester on spool B |  |  |
| 1 | 0.837 | $6.83<\mathrm{Mu}<6.92$ |
| 2 | 0.135 | $6.85<\mathrm{Mu}<6.97$ |
| 3 | 0.450 | $6.86<\mathrm{Mu}<6.94$ |
| 4 | 0.126 | $6.82<\mathrm{Mu}<6.91$ |

## Time Series:

To prove that all the data are time independent. There are no time-factor involved in the test.
Figure: Time series plot in sample 1 for \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 1 tests in \%strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 1 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 1 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 1 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 2 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 2 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 2 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 2 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 3 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 3 tests in \% tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 3 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 3 tests in \% tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 4 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 1 for tester 4 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 4 tests in \% strain @ 3GPD


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

Figure: Time series plot in sample 2 for tester 4 tests in tenacity @ break


By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

## V. Hypothesis Testing:

By doing hypothesis test, we want to show that $\mu 1=\mu 2$ for both properties. We assumed that $\mathrm{Ho}: \mu 1=\mu 2, \mathrm{H} 1: \mu 1 \neq \mu 2$ and variances are assumed to be equal based on historical information.

## \% Strain @ 3GPD

Paired T-Test and CI: 3GPD tot 1, 3GPD tot 2
Paired T for 3GPD tot 1 - 3GPD tot 2

|  | N | Mean | StDev | SE Mean |
| :--- | :---: | :---: | :---: | :---: |
| 3GPD tot 1 | 120 | 3.61029 | 0.05457 | 0.00498 |
| 3GPD tot 2 | 120 | 3.58003 | 0.04885 | 0.00446 |
| Difference | 120 | 0.03027 | 0.06007 | 0.00548 |
| 95\% CI for mean difference: | $(0.01941,0.04113)$ |  |  |  |
| T-Test of mean difference $=0$ | $($ vs not $=0):$ T-Value $=5.52$ P-Value $=0.000$ |  |  |  |

As a result, because p -value $(0.0000)<\alpha$, so we have to reject null hypothesis. Therefore, the means of \% strain @ 3GPD for sample 1 and sample 2 are not equal.

## Tenacity @ Break

Paired T-Test and CI: Ten tot 1, Ten tot 2

```
Paired T for Ten tot 1 - Ten tot 2
\begin{tabular}{lcccr} 
& N & Mean & StDev & SE Mean \\
Ten tot 1 & 120 & 6.7914 & 0.1537 & 0.0140 \\
Ten tot 2 & 120 & 6.8883 & 0.1303 & 0.0119 \\
Difference & 120 & -0.0968 & 0.2029 & 0.0185
\end{tabular}
95% CI for mean difference: (-0.1335, -0.0602)
T-Test of mean difference = 0 (vs not = 0) : T-Value = - 5. 23 P-Value = 0.000
```

As a result, because p -value $(0.0000)<\alpha$, so we have to reject null hypothesis. Therefore, the means of \% strain @ 3GPD for sample 1 and sample 2 are not equal.

## VI. Correlation Analysis:

Tenacity is the measure of strength when an object is under tensile stress while strain is the measure of deformation. The relationship between them is inverse proportion or in order words a negative correlation should exist between them.

## Sample 1:

## Correlations: Strain-A, Tenacity-A

Pearson correlation of Strain-A and Tenacity-A $=0.115, \mathrm{P}$-Value $=0.213$


For this graph, we observe that the correlation coefficient $=0.115$ is insignificant since the p -value $>\alpha$. There is still a probability of a relationship existing between the two but it is not a linear one.

## Sample 2:

## Correlations: Strain-B, Tenacity-B



For this graph, we observe that the correlation coefficient $=-0.221$ with a P -value $=0.021$. This shows a weak negative correlation though we expected it to be stronger.

## VII. Modeling: ANOVA and Regression

## ANOVA TESTING

ANOVA testing was performed for each property, \% Strain @ 3 GPD and Tenacity @ Break, for each sample. The mean result for each tester was evaluated to determine if the mean results were the same. Each tester needs to be able to yield results consistent with the other tester before the project can move forward

## Sample 1 "\%Strain @ 3GPD"

Testing for Sample 1, \% Strain @3GPD, shows there is a clear difference in the means between the testers. The p-value is zero and the Tukey's comparison shows differences between tester 1 vs. testers 2,3 \& 4 and between tester 3 vs tester 4.

## One-way ANOVA: 3GPD 1 versus Tester

```
Analysis of Variance for 3GPD 1
\begin{tabular}{lrrrcc} 
Source & DF & SS & \multicolumn{1}{c}{ MS } & F & P \\
Tester & 3 & 0.17728 & 0.05909 & 38.70 & 0.000 \\
Error & 116 & 0.17710 & 0.0015 & & \\
Total & 119 & 0.35438 & & &
\end{tabular}
Individual 95\% CIs For Mean Based on Pooled StDev
```



## 1 <br> 2 <br> 3

$$
\begin{aligned}
2 & -0.11326 \\
& -0.06061
\end{aligned}
$$

$3-0.12626-0.03932$

$$
-0.07361 \quad 0.01332
$$

$$
\begin{array}{llll}
4 & -0.09116 & -0.00422 & 0.00878
\end{array}
$$

$$
\begin{array}{lll}
-0.03851 & 0.04842 & 0.06142
\end{array}
$$

Boxplot for sample 1 for "\%Strain @ 3GPD" shows that the confidence intervals do not overlap for the all the testers as indicated by the ANOVA.

## Boxplots of 3GPD 1 by Tester

(means are indicated by solid circles)


Normality plot of residuals for sample 1 for "\%Strain @ 3GPD" confirms that the data is normally distributed.


Residual plot vs the order of the data for sample 1 for "\%Strain @ 3GPD" confirms that the data independent of time.


## Sample 2-"\%Strain@3GPD"

Testing for Sample 2, \% Strain @3GPD, again shows there is a clear difference in the means between the testers. The p-value is zero and the Tukey's comparison shows differences between tester 1 vs. testers 2, 3 \& 4 and between tester 3 vs tester 4 .

## One-way ANOVA: 3GPD 2 versus Tester

```
Analysis of Variance for 3GPD 2
\begin{tabular}{lrrccc} 
Source & DF & SS & MS & F & P \\
Tester & 3 & 0.07615 & 0.02538 & 14.16 & 0.000 \\
Error & 116 & 0.20786 & 0.00179 & & \\
Total & 119 & 0.28401 & & &
\end{tabular}
Individual 95\% CIs For Mean
Based on Pooled StDev
```



1

$$
\begin{aligned}
2 & -0.08375 \\
& -0.02671
\end{aligned}
$$

$$
3 \quad-0.06235 \quad-0.00712
$$

$$
-0.00531 \quad 0.04992
$$

$$
\begin{array}{llll}
4 & -0.09449 & -0.03925 & -0.06065
\end{array}
$$

$$
-0.03745 \quad 0.01779 \quad-0.00361
$$

Boxplot for sample 2 for "\%Strain @ 3GPD" shows that the confidence intervals do not overlap for the all the testers as indicated by the ANOVA.

## Boxplots of 3GPD 2 by Tester

(means are indicated by solid circles)


Normality plot of residuals for sample 2 for "\%Strain @ 3GPD" confirms that the data is normally distributed.

Normal Probability Plot of the Residuals (response is 3GPD 2)


Residual plot vs the order of the data for sample 2 for " $\%$ Strain @ 3GPD" confirms that the data independent of time.


## Summary - "\%Strain @ 3GPD"

For both samples, ANOVA shows a difference between testers. This difference is contributing to the difference that was seen between samples and led to the rejection of the means being equal.

## Sample 1-"Tenacity @ Break"

Testing for Sample 1, Tenacity @ Break, shows there is no difference in the means between the testers. The $p$-value is 0.497 , which is greater than $\alpha=0.05$, for $95 \%$ confidence interval. Tukey's comparison shows agreement, each interval crosses zero.

## One-way ANOVA: TEN 1 versus Tester

```
Analysis of Variance for TEN 1
\begin{tabular}{lrrccc} 
Source & DF & SS & MS & F & P \\
Tester & 3 & 0.0731 & 0.0244 & 0.91 & 0.437 \\
Error & 116 & 3.0995 & 0.0267 & & \\
Total & 119 & 3.1726 & & &
\end{tabular}
Individual 95\% CIs For Mean
Based on Pooled StDev
\begin{tabular}{llrl} 
Level & N & Mean & StDev \\
1 & 30 & 7.1737 & 0.1959
\end{tabular}
```

1
2
3

## 2

$$
\begin{array}{r}
-0.1723 \\
0.0480
\end{array}
$$

3

| -0.1540 | -0.0918 |
| :---: | :---: |
| 0.0663 | 0.1285 |

4

$$
\begin{array}{ccc}
-0.1685 & -0.1063 & -0.1246 \\
0.0518 & 0.1140 & 0.0956
\end{array}
$$

Boxplot for sample 1 for "Tenacity @ Break" shows that the confidence intervals do overlap for the all the testers as indicated by the ANOVA. You could easily draw one straight line through all the boxes.

## Boxplots of TEN 1 by Tester

(means are indicated by solid circles)


Normality plot of residuals for sample 1 for "Tenacity @ Break" confirms that the data is normally distributed.

Normal Probability Plot of the Residuals
(response is TEN 1 )


## Sample 2-"Tenacity @ Break"

Testing for Sample 2, Tenacity @ Break, shows there is no difference in the means between the testers. The p-value is 0.471 , which is greater than $\square=0.05$, for $95 \%$ confidence interval. Tukey's comparison shows agreement, each interval crosses zero.

## One-way ANOVA: TEN 2 versus Tester

Analysis of Variance for TEN 2

| Source | DF | SS |  | MS |  | F |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | P

Individual 95\% CIs For Mean
Based on Pooled StDev

| Level | N | Mean | StDev | ----------+------------------+------ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 30 | 7.3032 | 0.1406 | (-----------*------------ |  |  |
| 2 | 30 | 7.3404 | 0.1655 | (----------*------------ |  |  |
| 3 | 30 | 7.3344 | 0.1165 | (-----------*-----------) |  |  |
| 4 | 30 | 7.2927 | 0.1275 | --* |  |  |
| Pooled |  | 0.1387 |  | 7.280 | 7.320 | 7.360 |

Tukey's pairwise comparisons
Family error rate $=0.0500$
Individual error rate $=0.0103$
Critical value $=3.69$
Intervals for (column level mean) - (row level mean)

|  | 1 | 2 | 3 |
| :---: | :---: | :---: | :---: |
| 2 | -0.1306 |  |  |
|  | 0.0563 |  |  |
|  |  |  |  |
| 3 | -0.1246 | -0.0875 |  |
|  | 0.0623 | 0.0995 |  |
|  |  |  |  |
| 4 | -0.0830 | -0.0458 | -0.0518 |
|  | 0.1040 | 0.1411 | 0.1351 |

Boxplot for sample 1 for "Tenacity @ Break" shows that the confidence intervals do overlap for the all the testers as indicated by the ANOVA. You could easily draw one straight line through all the boxes.

## Boxplots of TEN 2 by Tester

(means are indicated by solid circles)


Normality plot of residuals for sample 1 for "Tenacity @ Break" confirms that the data is normally distributed.

Normal Probability Plot of the Residuals
(response is TEN 2)


## Summary - "Tenacity @ Break"

For both samples, ANOVA shows no differences between testers. Hypothesis testing showed a difference between samples 1 and 2 with respect to this property, but all the tester show consistency

## Tester 1 -Sample 1 "\%Strain @ 3GPD"

Tester 1 consistently had results that were different than all the other testers for both samples for this property. ANOVA of only tester 1 shows there is a difference in means within the three testing events for samples 1 and 2

For sample 1, testing event \#2 shares values with the other 2 testing events, and the Tukey's analysis shows agreement. Dot plots of this data confirm the differences and the normality plot of the residuals does not show very good normality with some points high and low, but the plot is not scattered.

One-way ANOVA: 3GPD 1 versus Event

Analysis of Variance for 3GPD 1

| Source | DF | SS | MS |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Event | 2 | 0.00891 | 0.00445 | 3.98 | 0.031 |
| Error | 27 | 0.03020 | 0.00112 |  |  |
| Total | 29 | 0.03911 |  |  |  |

Individual 95\% CIs For Mean Based on Pooled StDev


Tukey's pairwise comparisons
Family error rate $=0.0500$
Individual error rate $=0.0196$
Critical value $=3.51$
Intervals for (column level mean) - (row level mean)

1
2
$2-0.05902$
0.01522
$3 \quad-0.07932 \quad-0.05742$
$-0.00508 \quad 0.01682$

## Normal Probability Plot of the Residuals

(response is 3GPD 1)


Dotplots of 3GPD 1 by Event
(group means are indicated by lines)


## Tester 1 - Sample 2 "\%Strain @ 3GPD"

For sample 2, testing event \#1 is different from the other 2 events; this is confirmed through the Tukey's comparison. Dot plots of this data confirm the differences and the normality plot of the residuals does not show very good normality with some points high and low, but the plot is not scattered.

Removal of testing event \#1 may show that the means would be the same for both samples for tester 1.

One-way ANOVA: 3GPD 2 versus Event

Analysis of Variance for 3GPD 2

| Source | DF | SS |  | MS | F | P |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Event | 2 | 0.02505 | 0.01253 | 8.12 | 0.002 |  |
| Error | 27 | 0.04168 | 0.00154 |  |  |  |
| Total | 29 | 0.06673 |  |  |  |  |
|  |  |  |  |  |  |  |

Individual 95\% CIs For Mean
Based on Pooled StDev


Tukey's pairwise comparisons
Family error rate $=0.0500$
Individual error rate $=0.0196$
Critical value $=3.51$
Intervals for (column level mean) - (row level mean)

| 3 | -0.10461 | -0.04301 |
| :---: | :---: | :---: |
|  | -0.01739 | 0.04421 |



## Summary - Tester 1

While some error may be attributed exclusively to tester \#1, it may be that the initial event for tester \#1 is creating most of the error.

## Hypothesis Testing Confirmation

ANOVA analysis was performed for each property to compare sample 1 to sample 2. The results confirm the hypothesis test results and the determination that the means were different for both properties.

## One-way ANOVA: 3GPD 1, 3GPD 2

Analysis of Variance

| Source | DF | SS |  | MS | F | P |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Factor | 1 | 0.05496 | 0.05496 | 20.49 | 0.000 |  |
| Error | 238 | 0.63839 | 0.00268 |  |  |  |
| Total | 239 | 0.69335 |  |  |  |  |

Based on Pooled StDev


## One-way ANOVA: TEN 1, TEN 2

Analysis of Variance

| Source | DF | SS |  | MS |  |
| :--- | ---: | ---: | ---: | ---: | :--- | F | P |
| :--- |
| Factor |

alal CIs For Mean
Based on Pooled StDev


## Regression Analysis:

To continue in the analysis of the data, a regression analysis must be performed. Initially a linear regression equation will be applied to the pooled experimental strength data. To determine the validity of the regression, residual analysis of the data will also be performed to validate or reject the regression equation and verify the assumed normality of the residuals.

## \% Strain @ 3GPD:

- Regression Analysis: Tester 1 A versus Tester 2 A, Tester 3 A, ...
- The regression equation is
- Tester $1 \mathrm{~A}=1.63+0.265$ Tester $2 \mathrm{~A}+0.003$ Tester $3 \mathrm{~A}+0.260$ Tester 4 A
- Predictor Coef SE Coef T P
$\begin{array}{lllll}\text { - } & \text { Constant } & 1.6337 & 0.7694 & 2.12\end{array}$
$\begin{array}{lllll}\text { - } & \begin{array}{lll}\text { Tester } 2 & 0.2653 & 0.2758\end{array} 0.96 & 0.345\end{array}$
$\begin{array}{lllll}\text { - } & \text { Tester } 3 & 0.0026 & 0.2218 & 0.01\end{array}$
$\begin{array}{lllll}\text { - } & \begin{array}{lll}\text { Tester } 4 & 0.2601 & 0.1535\end{array} & 1.69 & 0.102\end{array}$
- $\mathrm{S}=0.03452 \quad \mathrm{R}-\mathrm{Sq}=20.8 \% \quad \mathrm{R}-\mathrm{Sq}(\mathrm{adj})=11.6 \%$
- Analysis of Variance

| - | Source | DF | SS | MS | F |
| :--- | ---: | :---: | :---: | :---: | ---: | P

- Source DF Seq SS
- Tester 210.004665
- $\begin{array}{ccc}\text { Tester } 3 & 1 & 0.000039\end{array}$
- $\begin{array}{ccc}\text { Tester } 4 & 1 & 0.003422\end{array}$
- 
- Unusual Observations

| - | Obs | Tester 2 | Tester 1 | Fit | SE Fit | Residual | St Resid |
| :--- | ---: | ---: | :--- | :---: | :---: | :---: | :---: |
| - | 20 | 3.66 | 3.48000 | 3.54727 | 0.01332 | -0.06727 | -2.11 R |
| - | 28 | 3.64 | 3.47900 | 3.54945 | 0.01166 | -0.07045 | -2.17 R |

- R denotes an observation with a large standardized residual


## Tenacity @ Break:

- Regression Analysis: Tester 1 B versus Tester 2 B, Tester 3 B, ...
- The regression equation is
- Tester $1 \mathrm{~B}=2.55-0.136$ Tester $2 \mathrm{~B}+0.379$ Tester $3 \mathrm{~B}+0.033$ Tester 4 B
- Predictor
- Constant 2.555

| SE Coef | T | $P$ |
| :--- | ---: | ---: |

$\begin{array}{lllll}\text { - } & \text { Tester } 2 & -0.1358 & 0.2420 & -0.56\end{array} 0.580$
$\begin{array}{lllll}\text { - } & \begin{array}{llll}\text { Tester } 3 & 0.3791 & 0.2715 & 1.40\end{array} 0.174\end{array}$
$\begin{array}{lllll}\text { - } & \begin{array}{llll}\text { Tester } 4 & 0.0331 & 0.1931 & 0.17\end{array} 0.865\end{array}$

- $\quad \mathrm{S}=0.04813$
$\mathrm{R}-\mathrm{Sq}=9.7 \%$
$\mathrm{R}-\mathrm{Sq}(\mathrm{adj})=0.0 \%$
- Analysis of Variance

| - Source | DF | SS | MS | F | P |
| :--- | :---: | ---: | :---: | ---: | ---: |
| - | Regression | 3 | 0.006496 | 0.002165 | 0.93 |
| - | Residual Error | 26 | 0.060234 | 0.002317 |  |
| - | Total | 29 | 0.066730 |  |  |

- Source DF Seq SS
- Tester 210.001363
- Tester $3 \quad 1 \quad 0.005066$
- $\begin{array}{lll}\text { Tester } 4 & 1 & 0.000068\end{array}$
- Unusual Observations

| - | Obs | Tester 2 | Tester 1 | Fit | SE Fit | Residual | St Resid |
| :--- | ---: | ---: | :--- | :---: | :---: | :---: | :---: |
| - | 10 | 3.55 | 3.42900 | 3.53121 | 0.01893 | -0.10221 | -2.31 R |
| - | 11 | 3.51 | 3.65800 | 3.57473 | 0.02760 | 0.08327 | 2.11 R |

- R denotes an observation with a large standardized residual

The results show low regression coefficients, low R-sq values and high p-values for both the samples, we can conclude that there is a little or in fact no regression between the testers. Hence, the testers are not biased with each other and work independently.

## VIII. Conclusions:

The mean result for "\%Strain @ 3 GPD" for samples 1 and 2 have a statistical differences. The values only differ by 0.03 units; 3.58 vs. 3.61 , but that amount of error is significant enough to cause quality issues for the customer. It is possible that the samples are more alike than the testing will allow us to show. The statistical differences between the mean values may be primarily caused by the error that is introduced by the tester.

The test method has been designed to reduce tester error, but the tester must interact with the sample during the test. Each testers interaction will add a level of error to the measurement. Additionally, the test being performed is a destructive test - each portion of filament that is tested is destroyed and only tested once. Another portion of the larger sample would be used for each ensuing test. In this case, we assume that all portion are identical as long as they come from the same sample. This may also contribute to the difference that was seen.
It is possible to improve the test method and achieve the desired result - to mix lots from different production lines, but this should not be done at this time for this product.

## Recommendation

The experiment should be repeated using additionally filament from the same samples previously tested. Each tester should be re-trained to perform the desired testing and the engineer should verify the test method being used and the technique of each tester. Additionally, the samples should be guarded more closely to ensure that the tester is selecting the correct sample each time and is not interchanging sample 1 results with sample 2 results. Using this verification and re-training, we should be able to show that a statistical difference between samples 1 and 2 does not exist.

