ECS526

Final Project Paper
Group 1
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Evaluation of Monofilament Testing for Product Mixing

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

Section: **Page**

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	3.622	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 I

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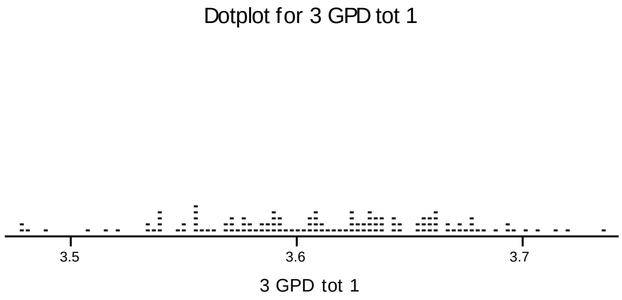


Figure. Descriptive Statistics: 3GPD 1, 3GPD 2

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

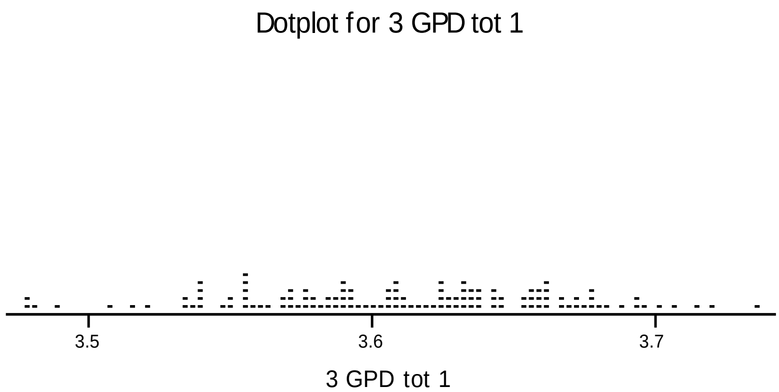


Figure: Boxplots - %Strain @ 3GPD in Sample 2

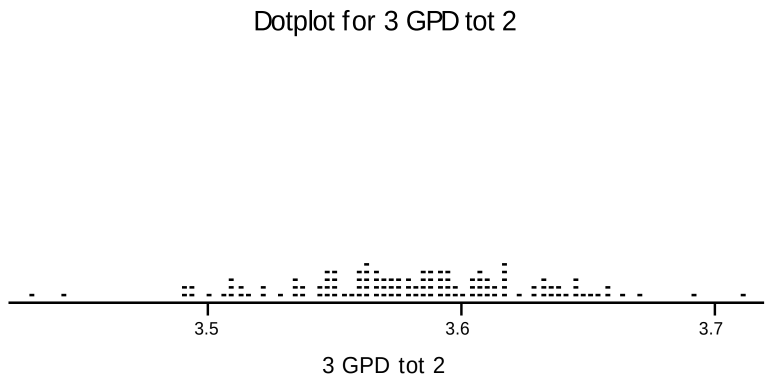
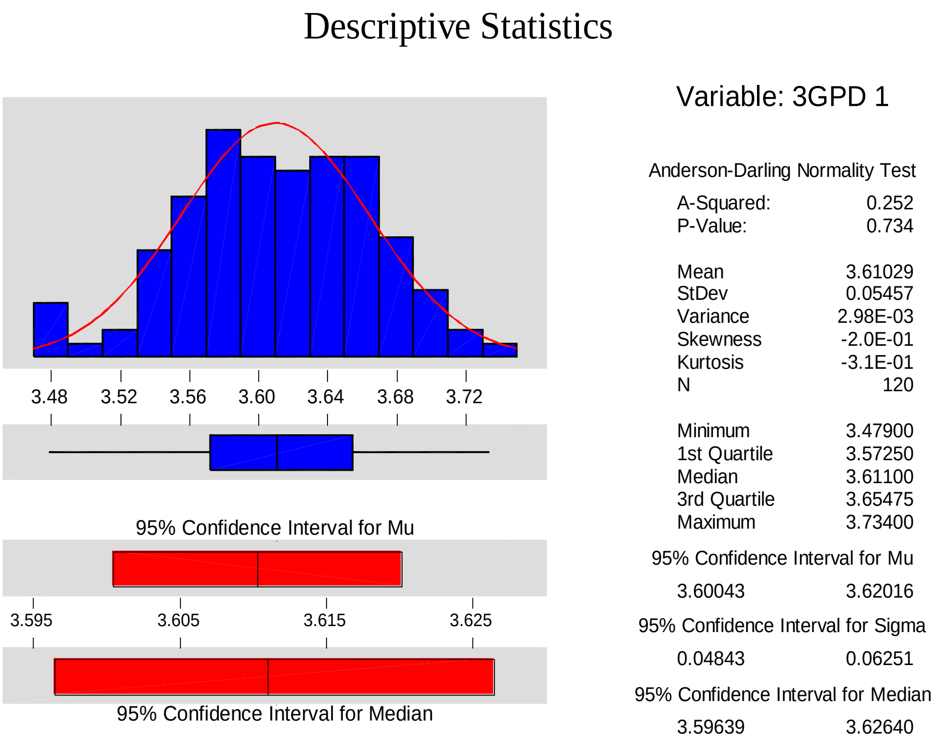
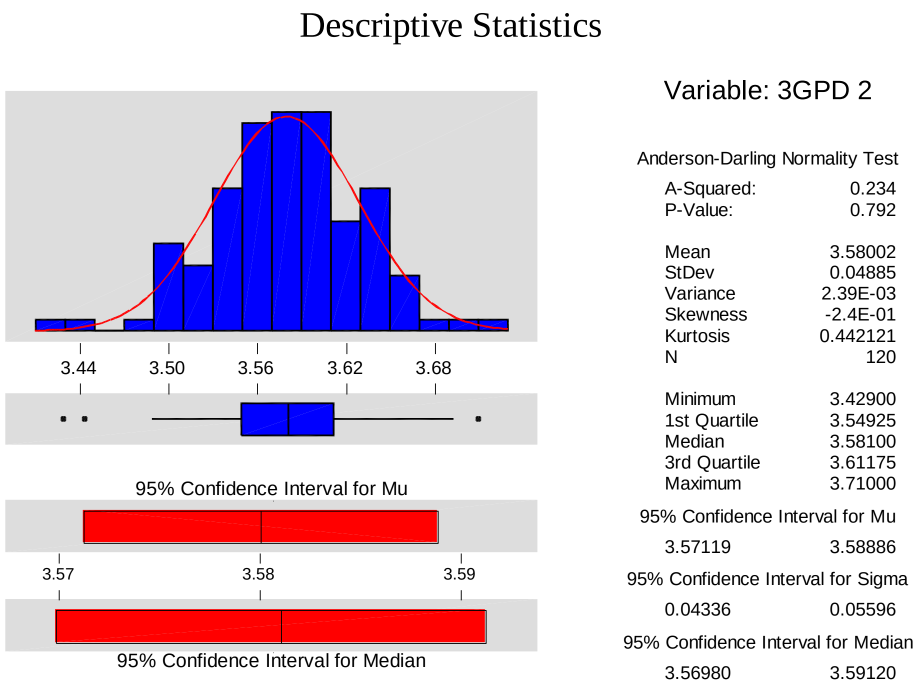


Figure: Graphical Summary for sample 1 in strain



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



By observation, the sample mean and sample median are very close. Also, the P value is 0.792 so we cannot reject normality.

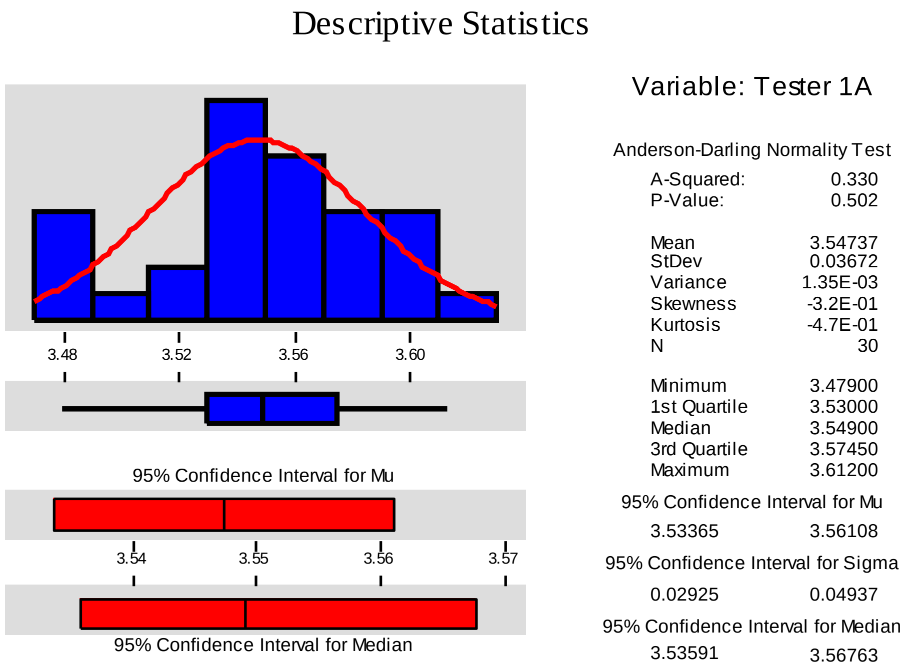
Figure: Descriptive Statistics – %Strain @ 3GPD by Tester

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

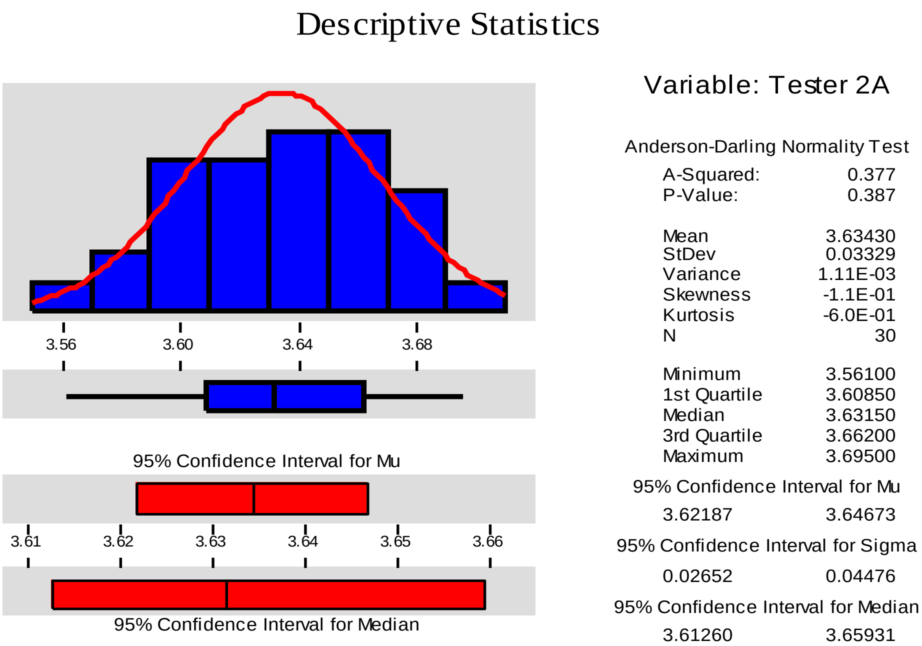
According to the above figure, we can observe that for each tester testing in %strain @ 3 GPD, the Mean, Median and Standard deviation are very close.

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



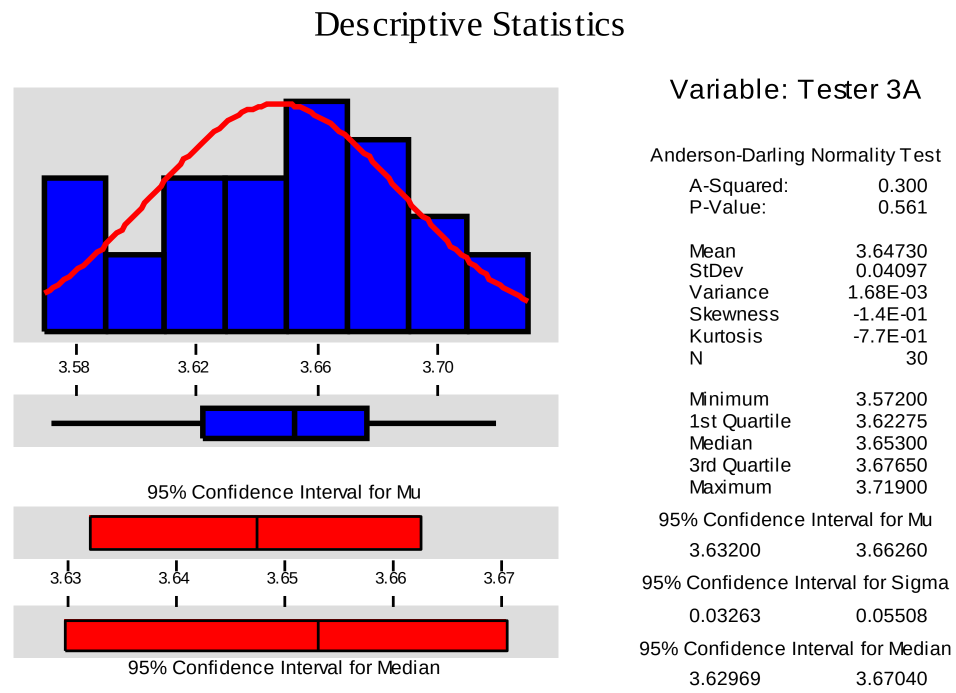
By observation, we can see that the data is skewed right (sample mean is located below the sample median).Also, P-value is 0.502 so the data is normal.

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



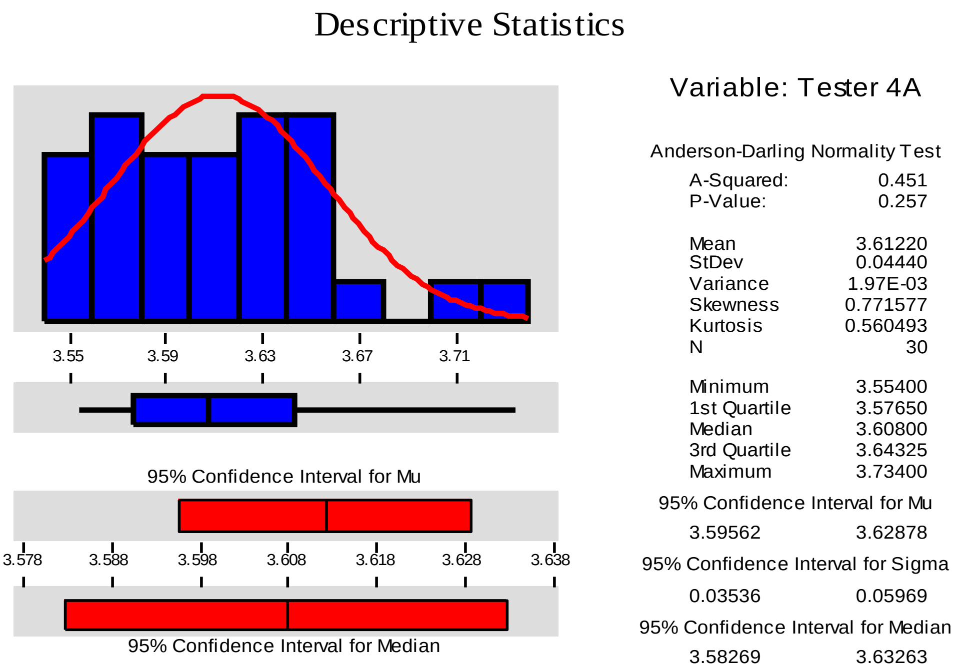
By observation, we can see that the data is skewed left (sample median is located below the sample mean). Also, the P-value is 0.387 so we cannot reject normality.

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



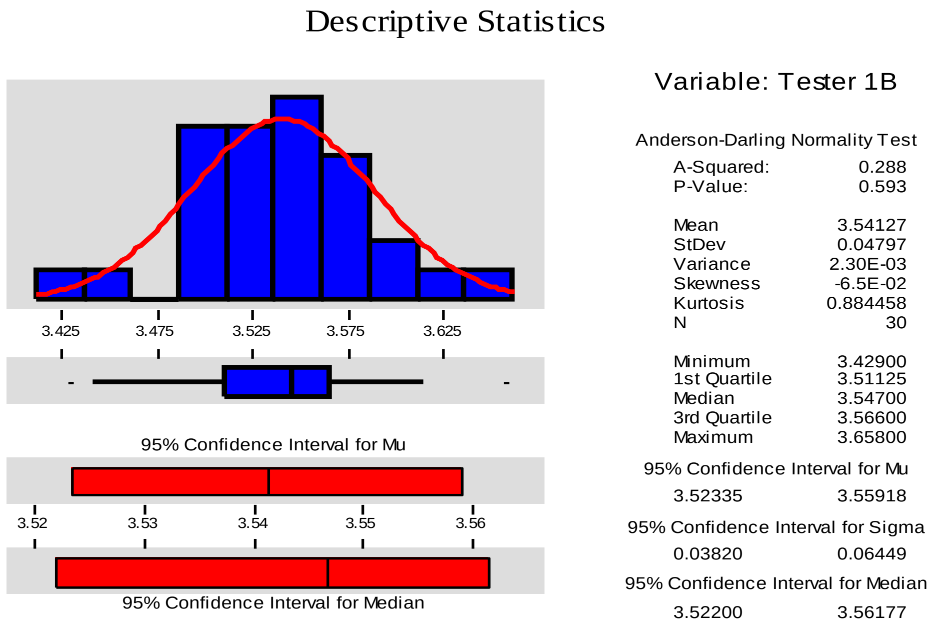
By observation, we can see that the data is skewed right (sample mean is located below the sample median) & the P-value is 0.561 so the data collected is normal.

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



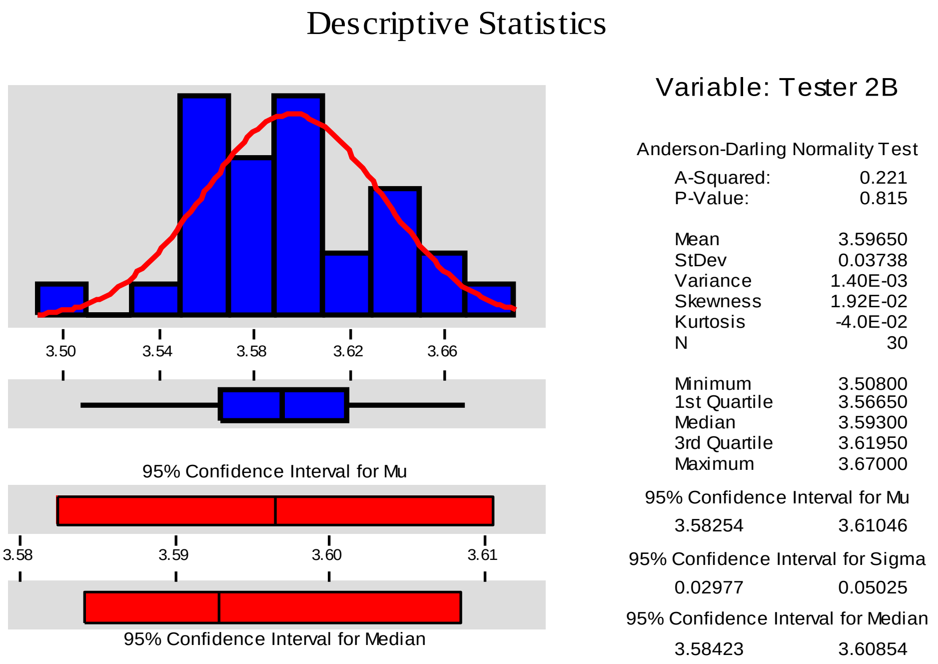
By observation, we can see that the data is skewed left (sample median is located below the sample mean) & the P-value is 0.257 so we cannot reject normality.

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



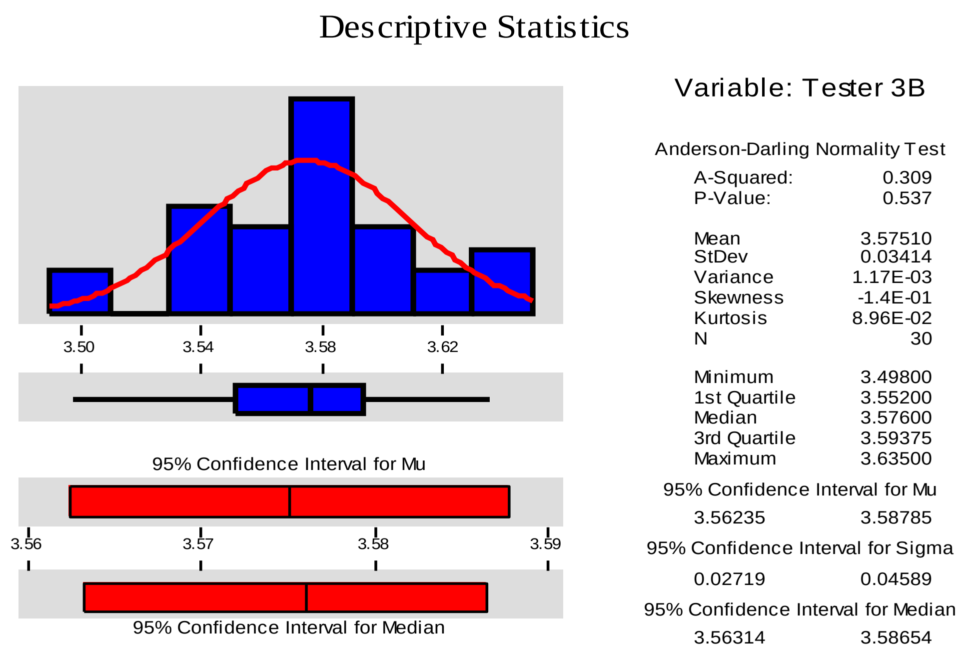
By observation, we can see that the data is skewed right (sample mean is located below the sample median). Also, the P-value is 0.593 so we cannot reject normality.

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



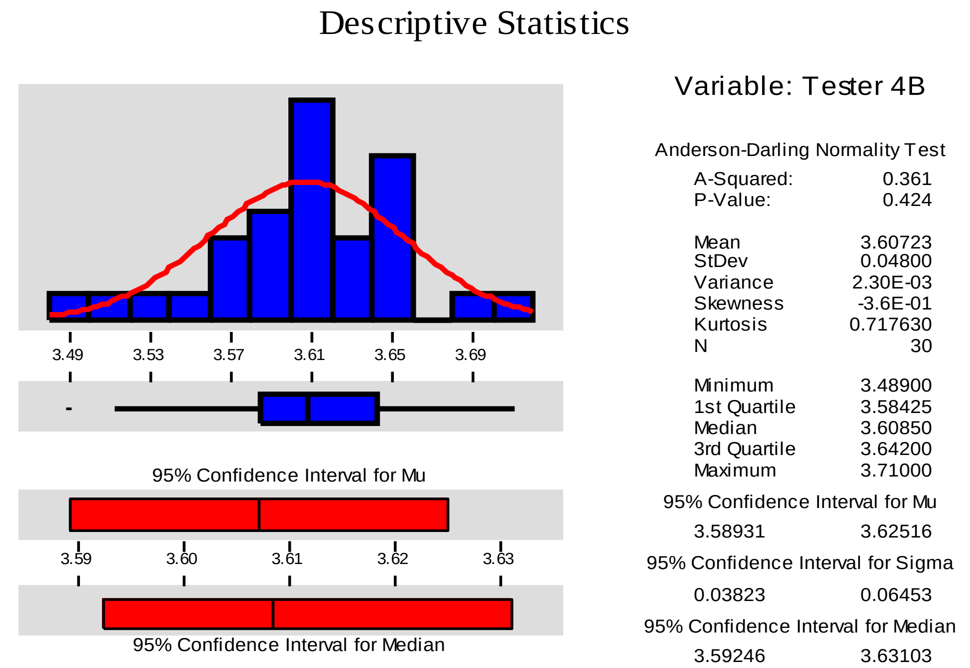
By observation, we can see that the data is skewed left (sample median is located below the sample mean). P-value is 0.815 so the data is normal.

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



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.

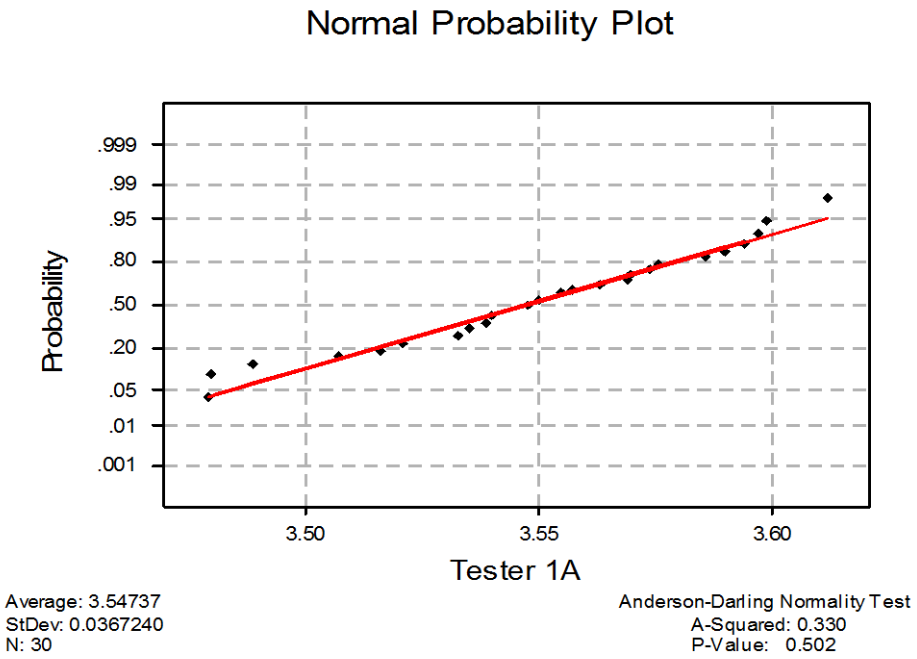
Figure: Graphical Summary for tester 4 test sample 2 in strain



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.

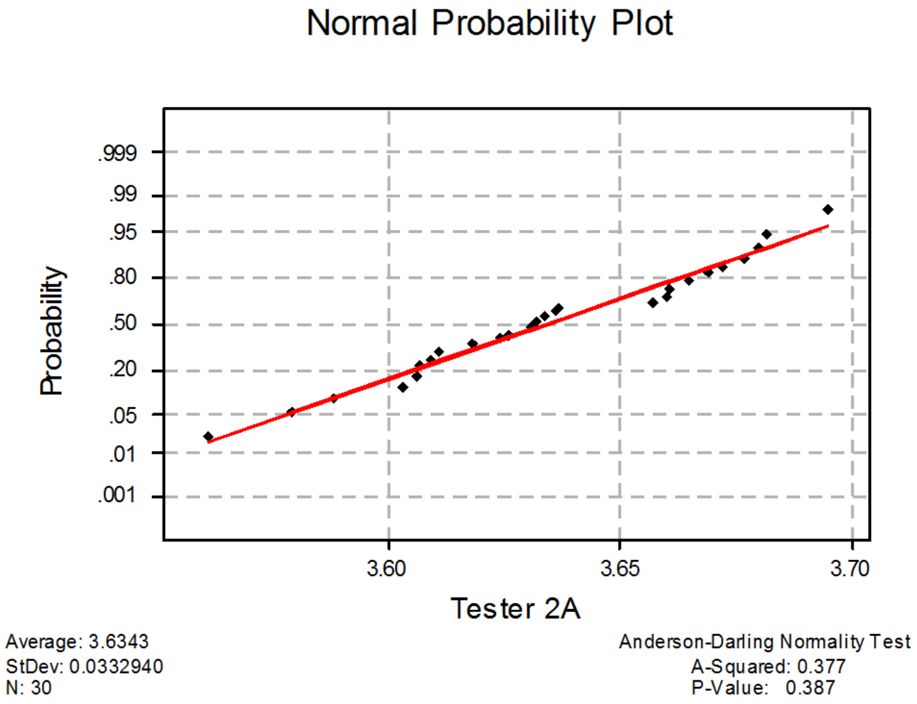
Normality testing (Anderson Darling):

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



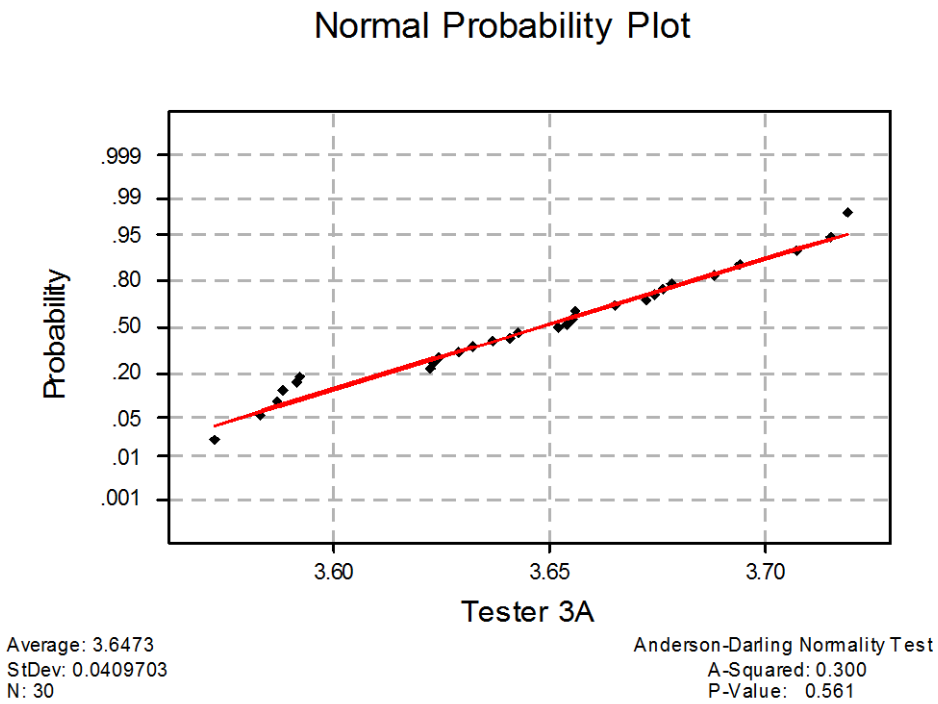
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



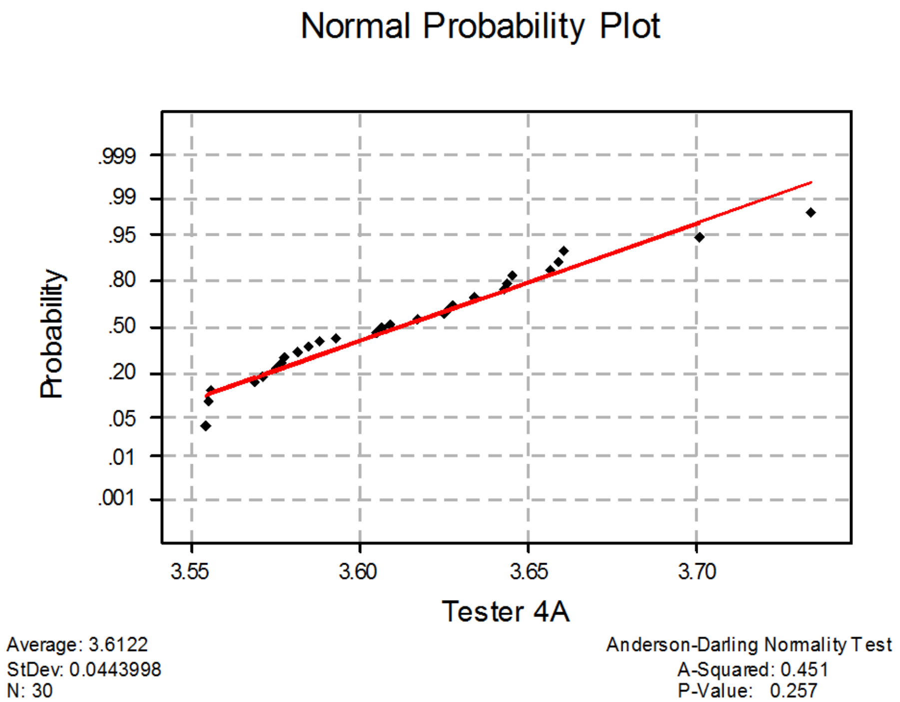
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



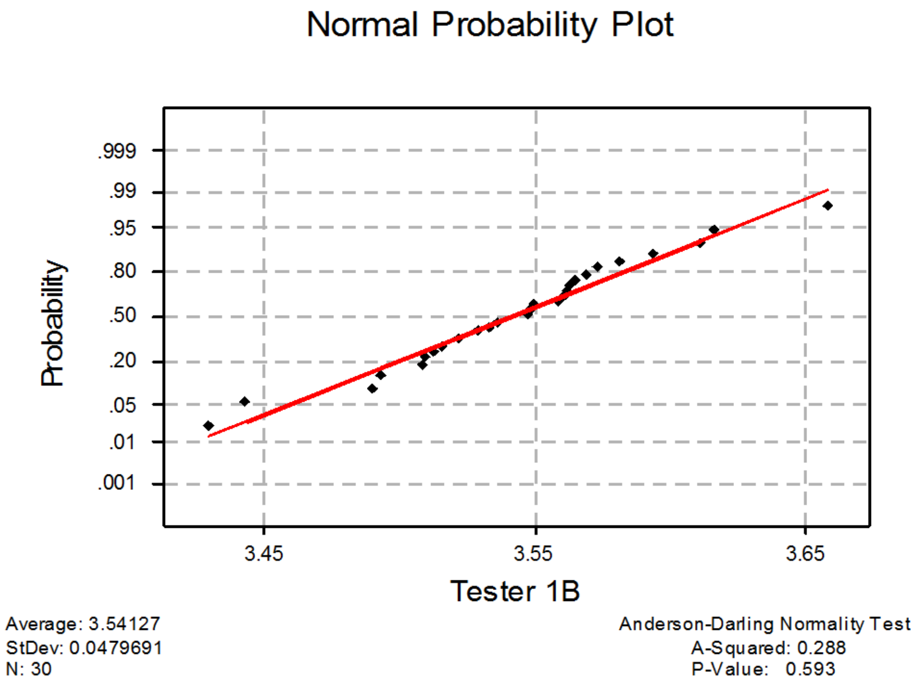
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



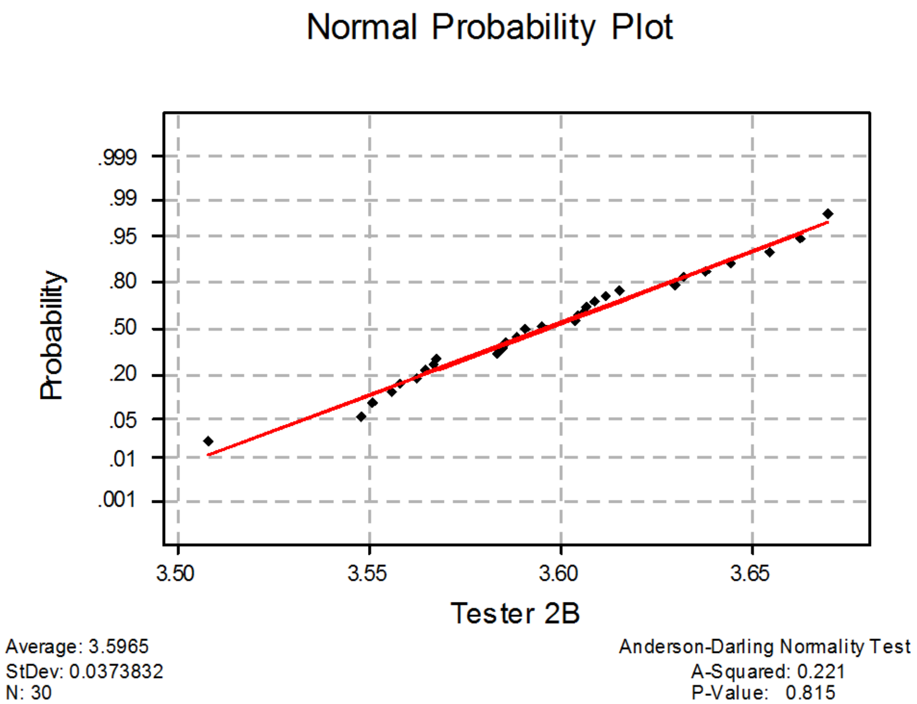
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



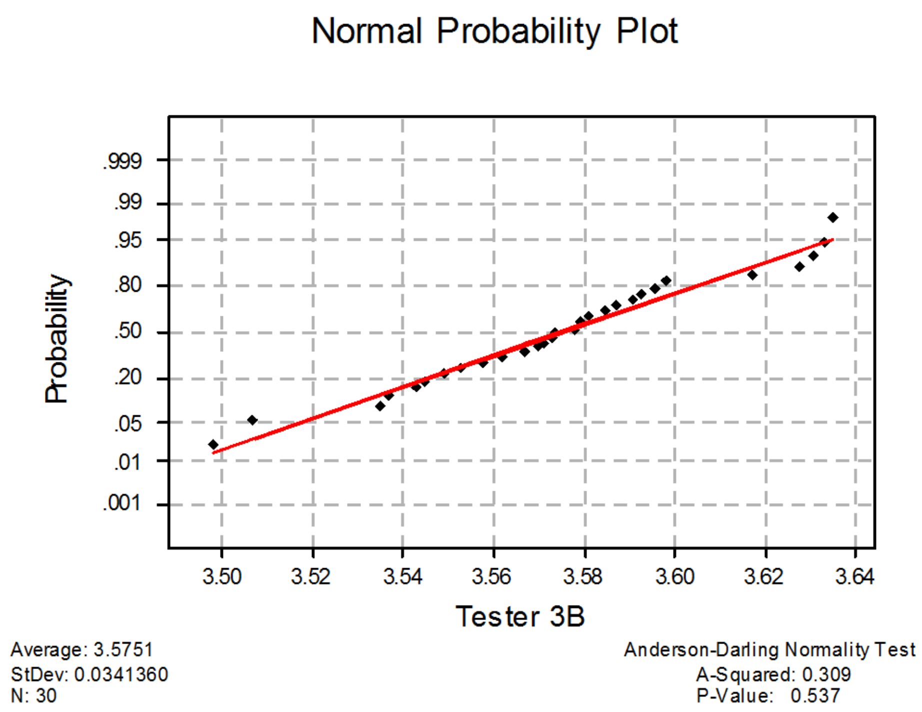
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



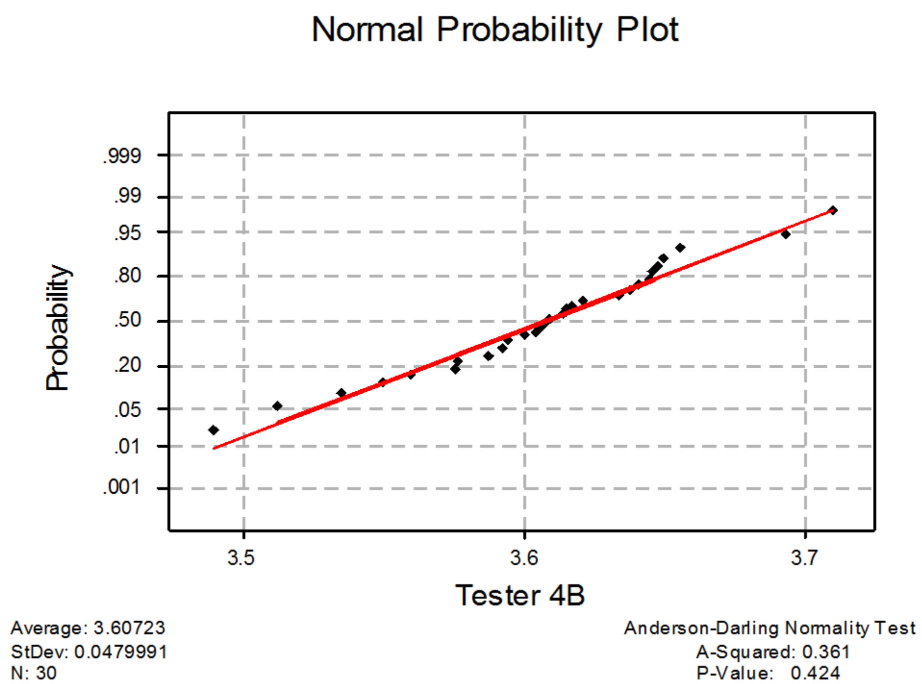
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



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



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 mean
1	0.502	3.53< Mu <3.56
2	0.387	3.62< Mu <3.64
3	0.561	3.63< Mu <3.66
4	0.257	3.59< Mu <3.62
Tester on spool B		
1	0.593	3.52< Mu <3.56
2	0.815	3.58< Mu <3.61
3	0.537	3.56< Mu <3.59
4	0.424	3.58< 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

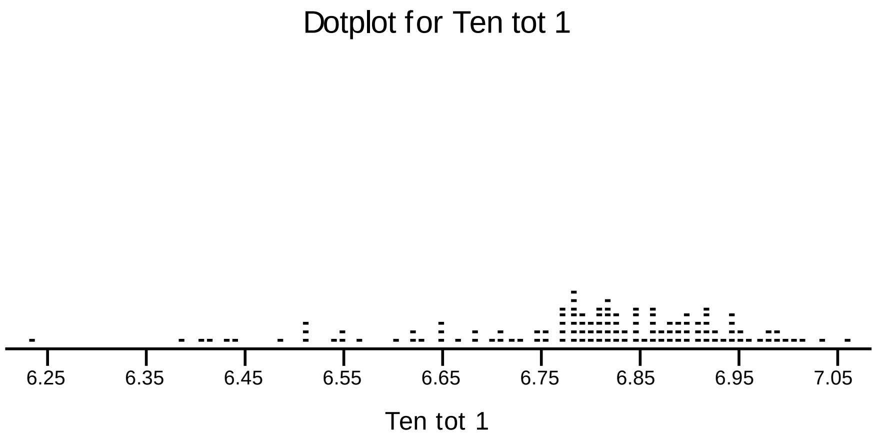


Figure: Boxplots – Tenacity @ Break in Sample 1

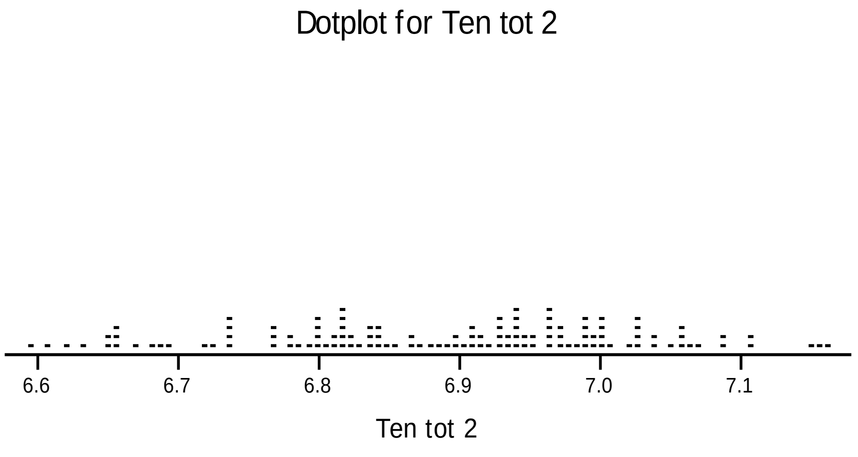
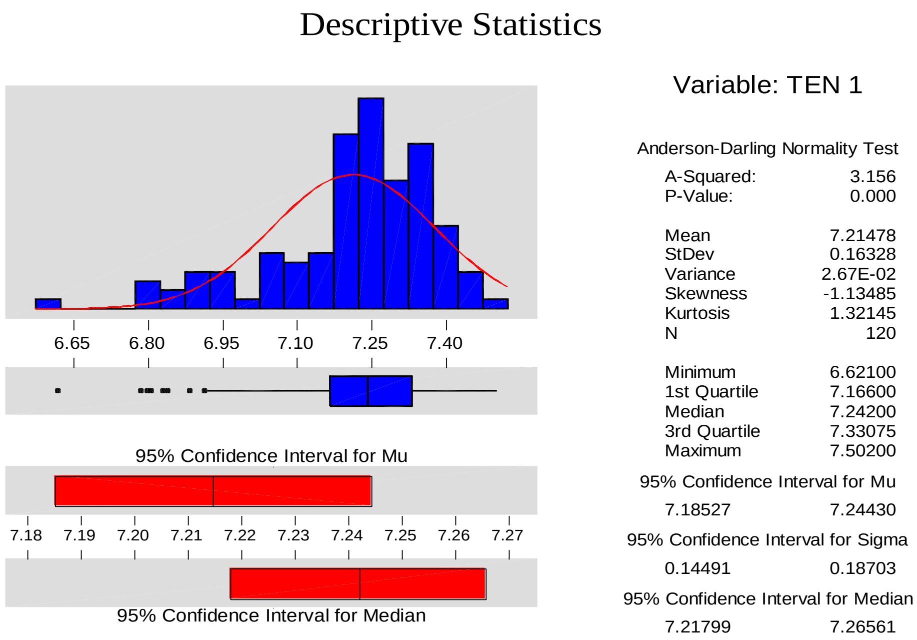
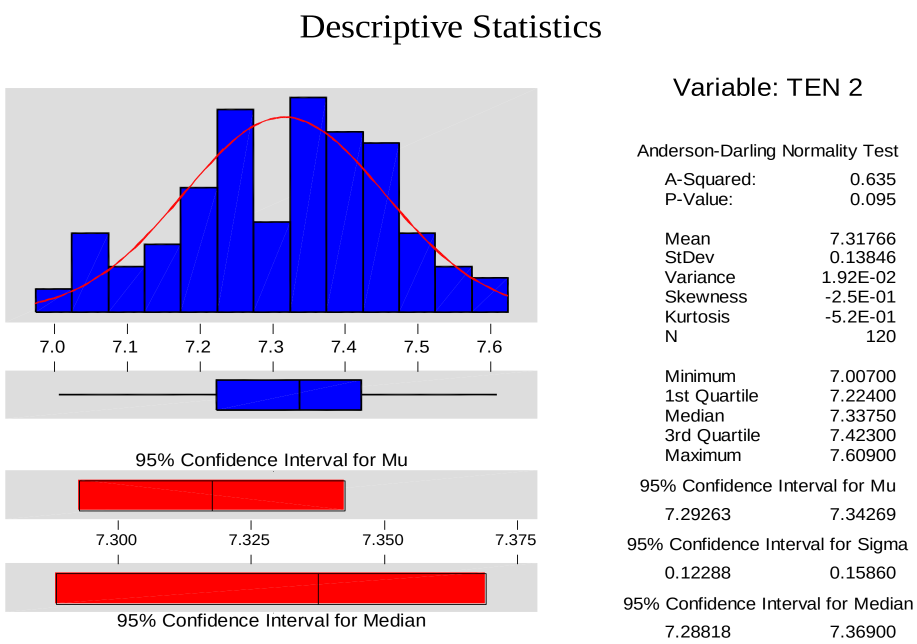


Figure: Graphical Summary for sample 1 in tenacity @ break



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



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 P > α

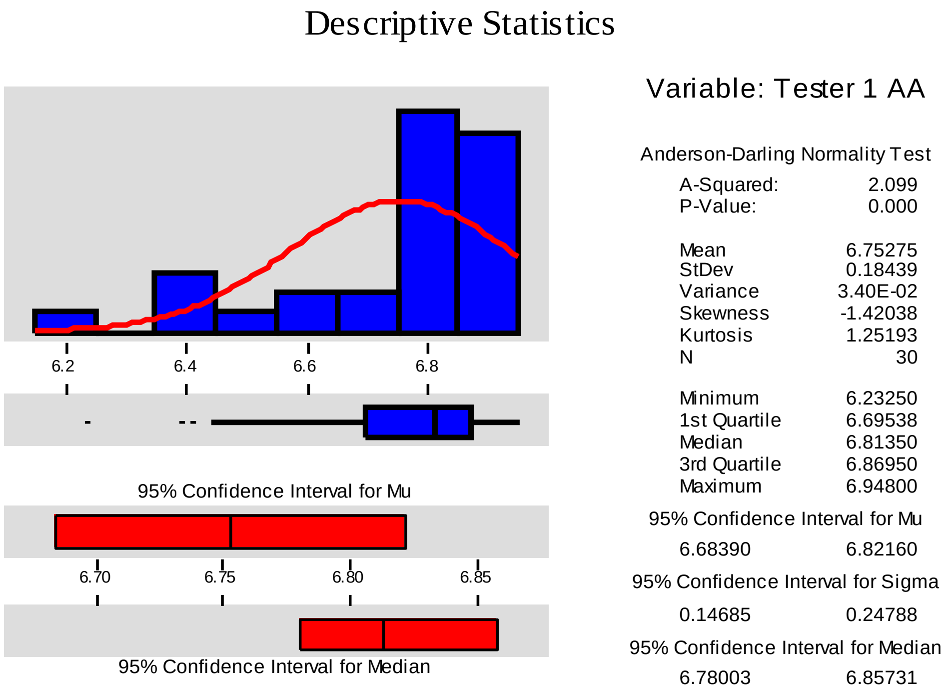
Figure: Descriptive Statistics – Tenacity @ Break by Tester

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	Q3	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

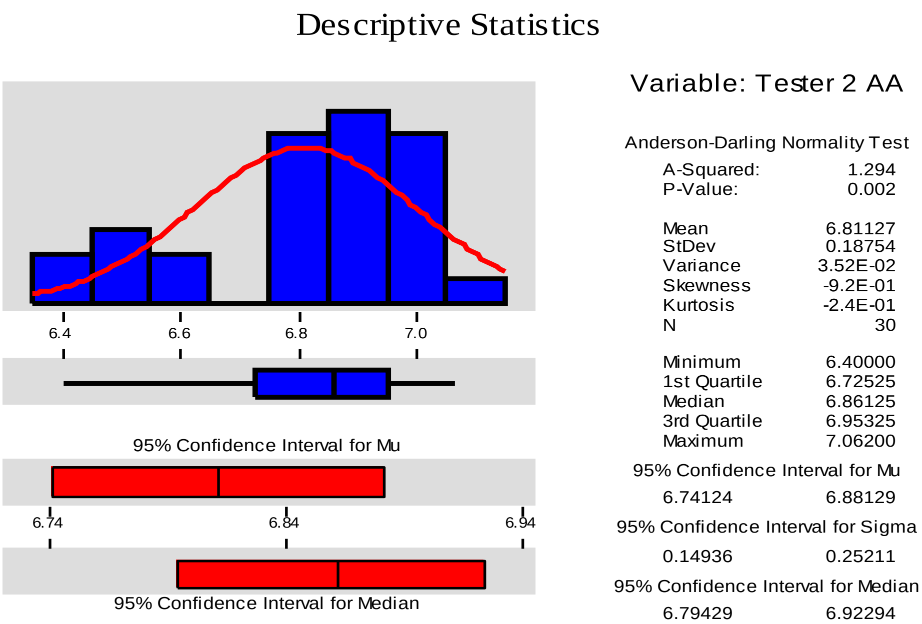
According to above figure, we can observe that for each tester testing in Tenacity @ Break, the mean and median are larger in sample 1 than sample 2 for each tester.

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



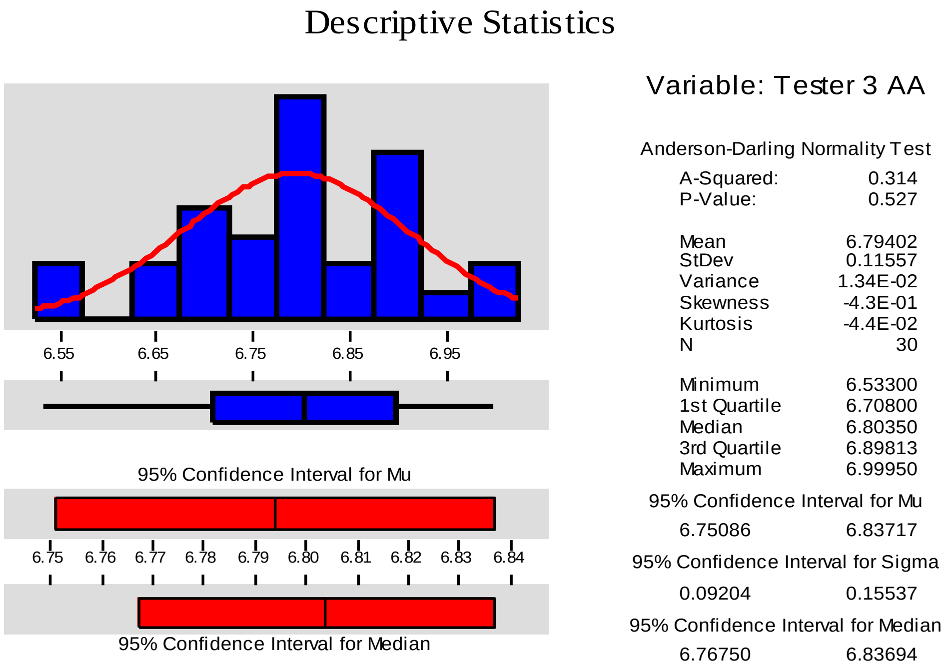
By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) as P-value is zero the data is not normal.

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



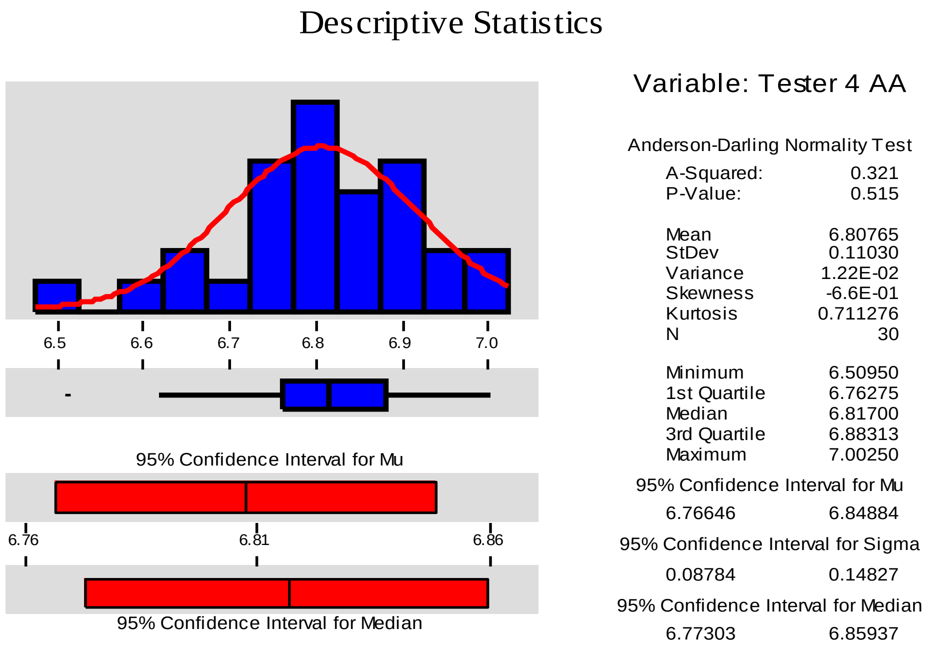
By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) & the data is not normal as $P < \alpha$

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



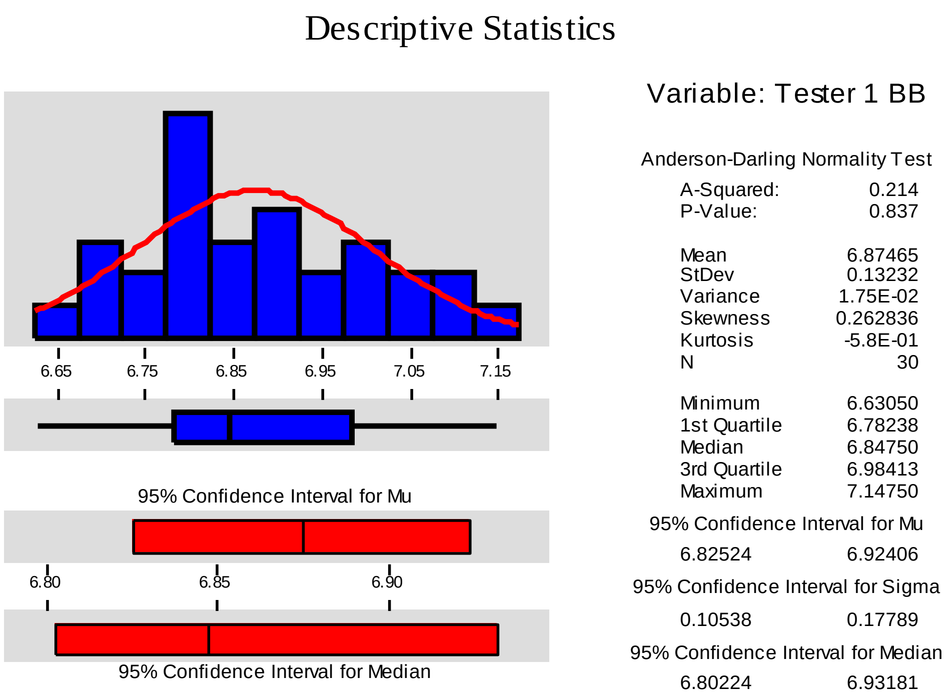
By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) & P-value is 0.527 so the data is normal.

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



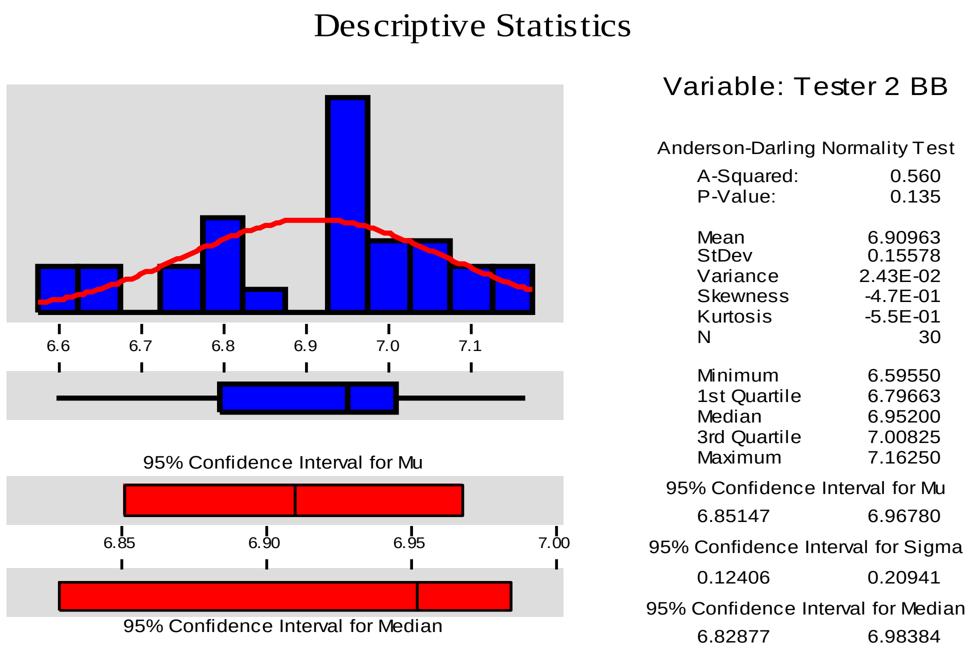
By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) & P-value is 0.515 so data is normal.

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



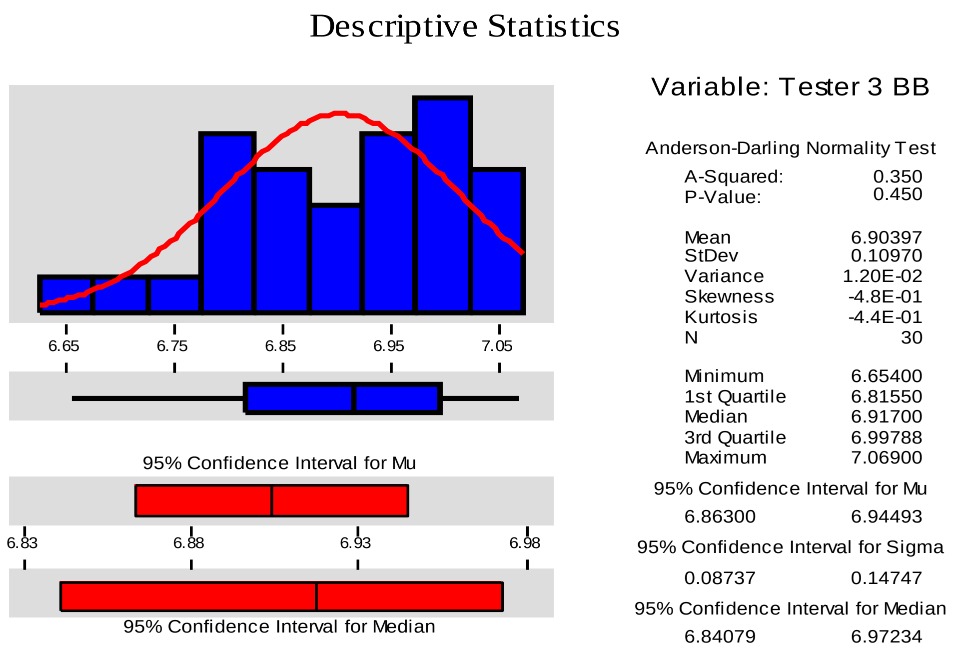
By observation, we can see that the data is skewed left obviously (sample median is located below the sample mean) & P-value is 0.837 so the curve follows normality

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



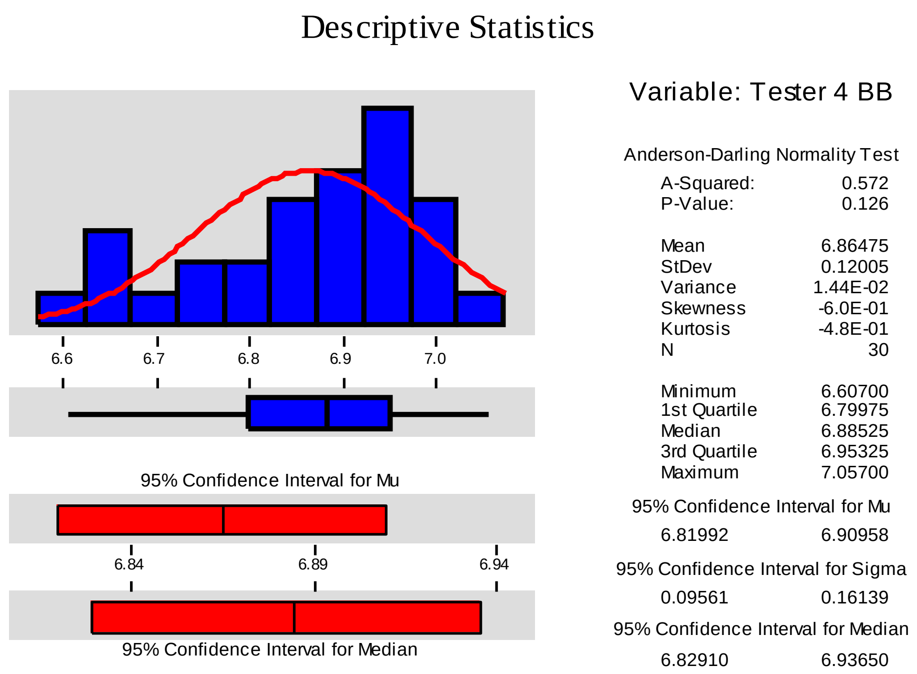
By observation, we can see that the data is skewed right obviously (sample mean is located below the sample median) & P-value is 0.135 so we cannot reject normality.

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



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.

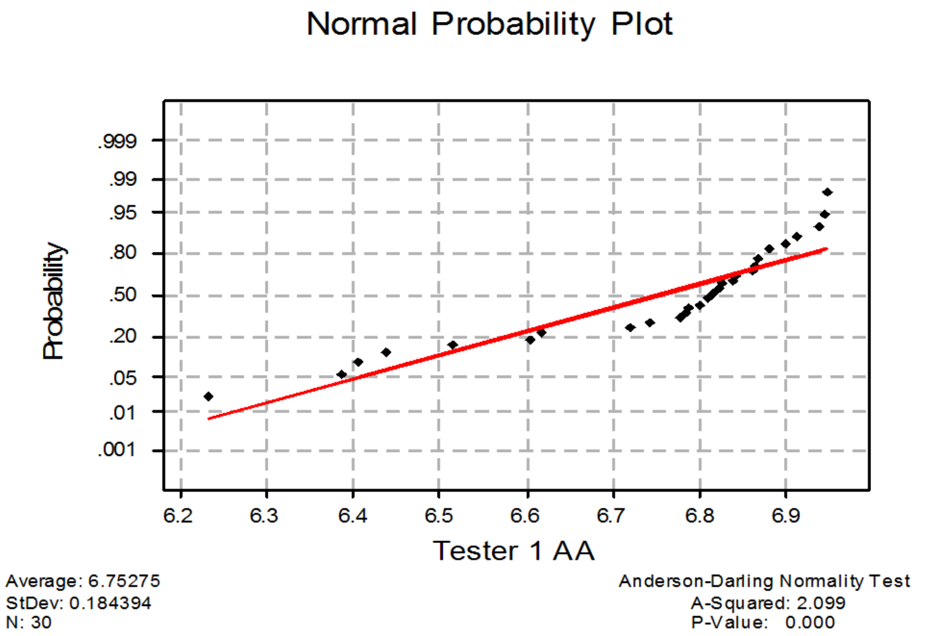
Figure: Graphical Summary for tester4 test sample 2 in tenacity @ break



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.

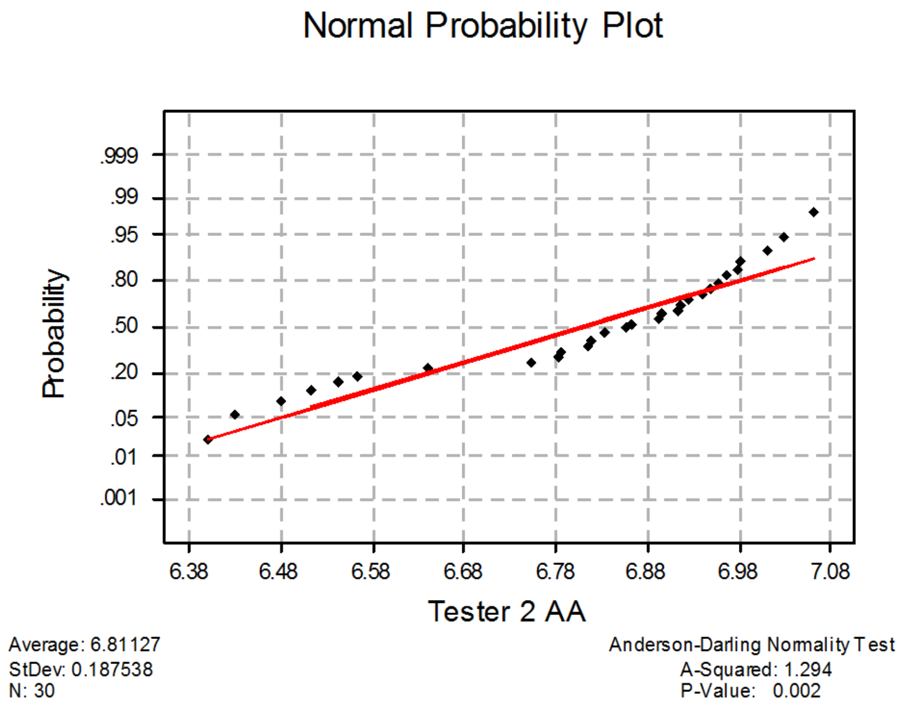
Normality testing (Anderson Darling)

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



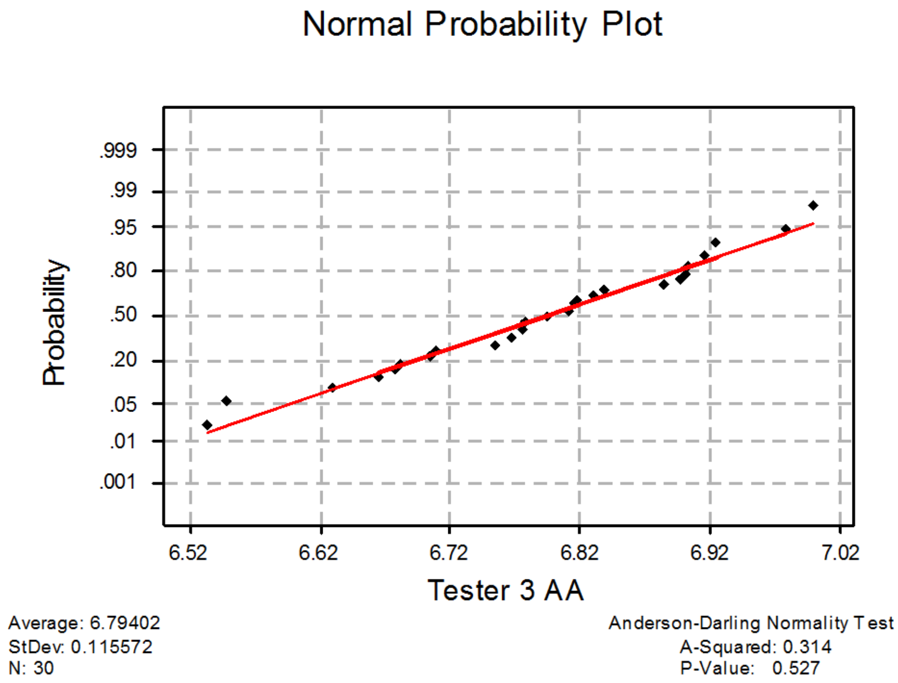
By the graphic, we can conclude that the data is not normal (because P-value < 0.05), the reason might be tester error, sample defect or instrument problems.

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



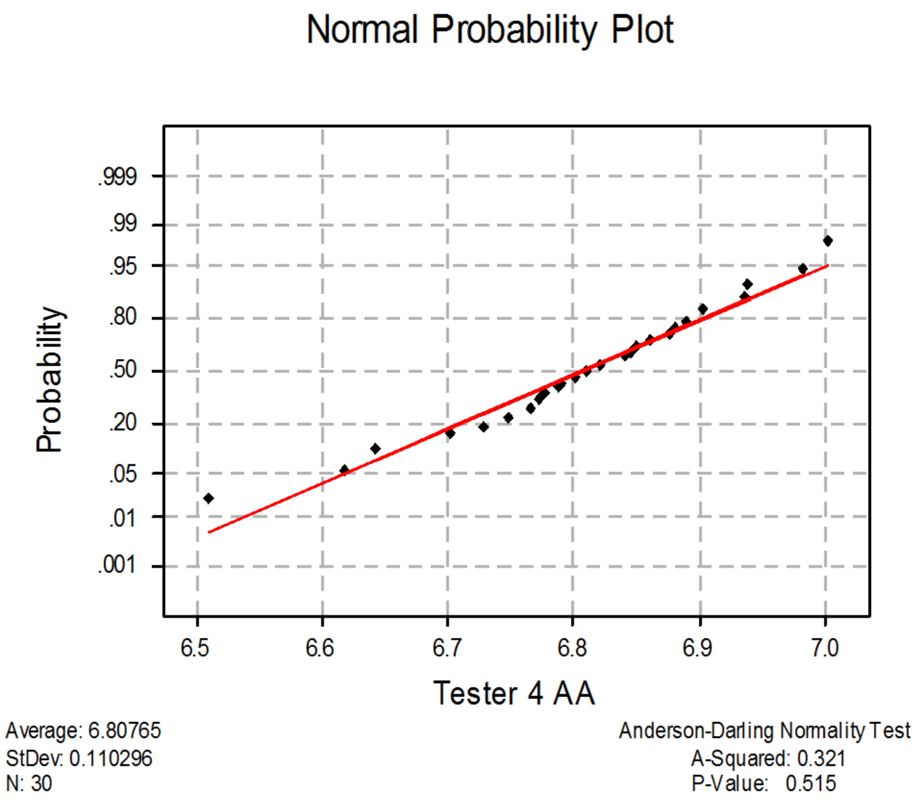
By the graphic, we can conclude that the data is not normal (because P-value < 0.05), the reason might be tester error, sample defect or instrument problems.

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



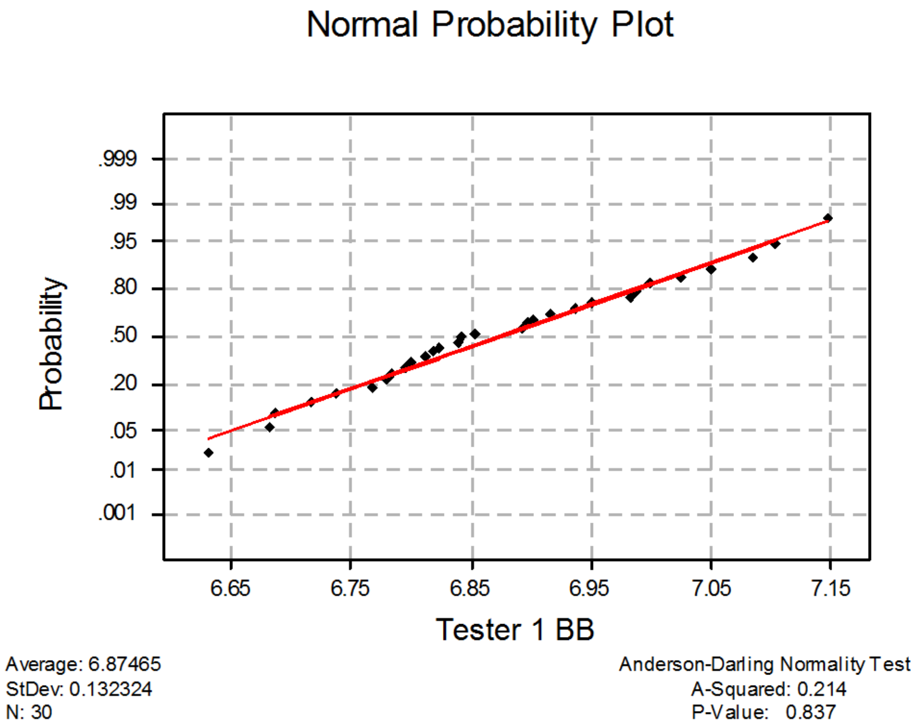
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



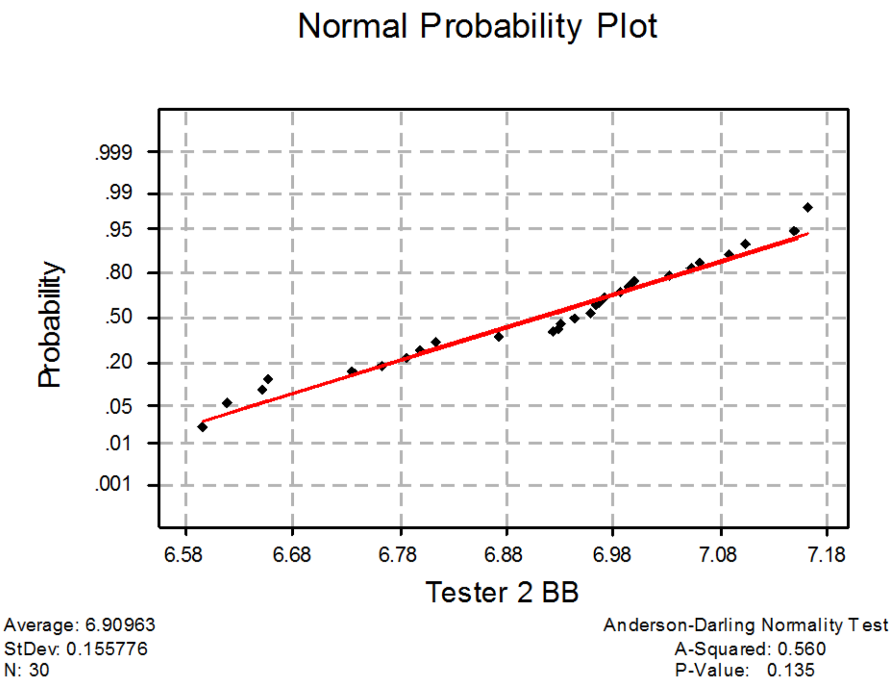
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



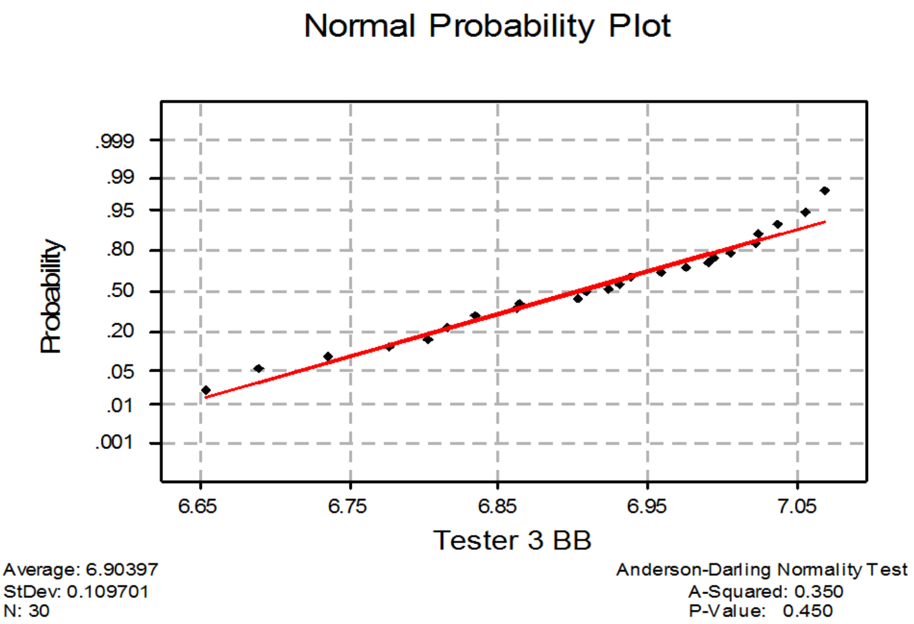
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



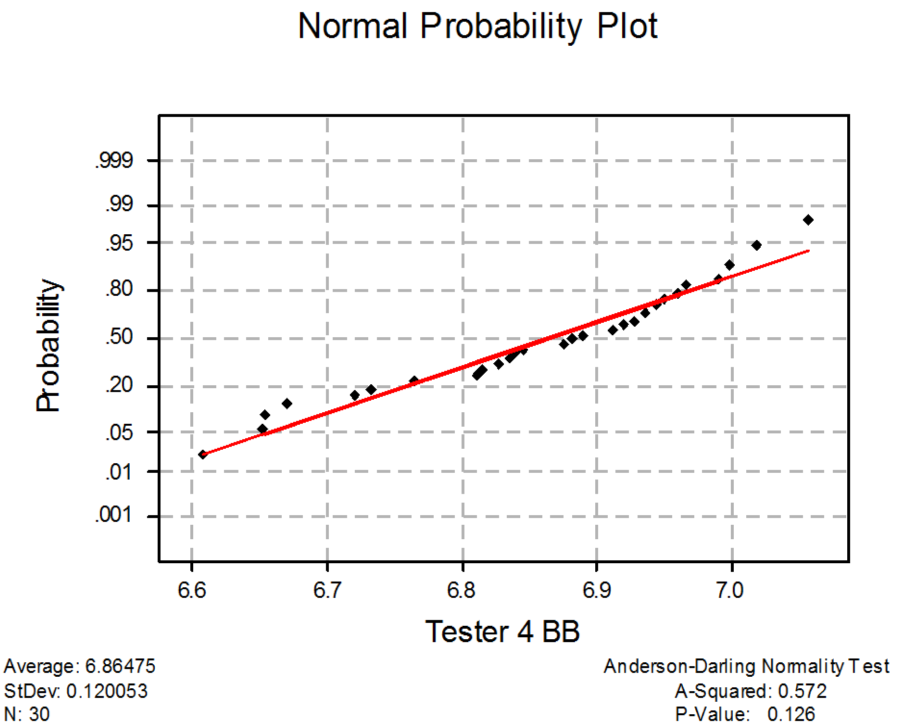
By the graphic, we can conclude that the data is normal (because P-value > 0.05)

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



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



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

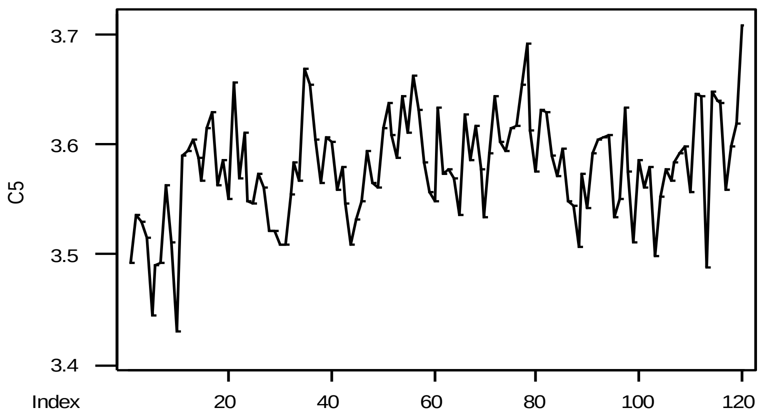
P-values and confidence interval of Tenacity test on spool A & B –

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

Time Series:

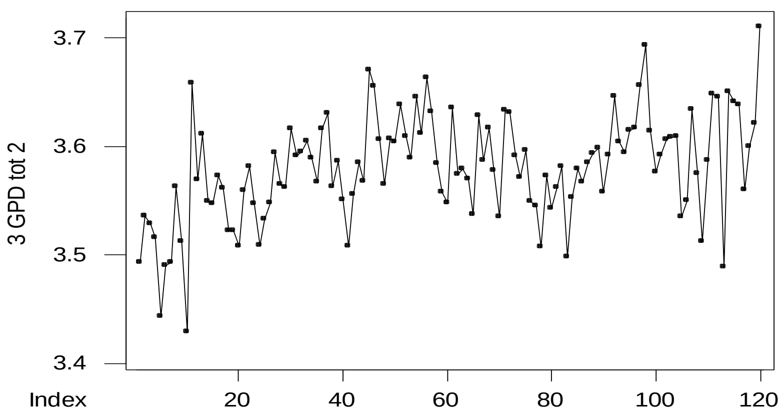
To prove that all the data are time independent. There are no time-factor involved in the test.

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



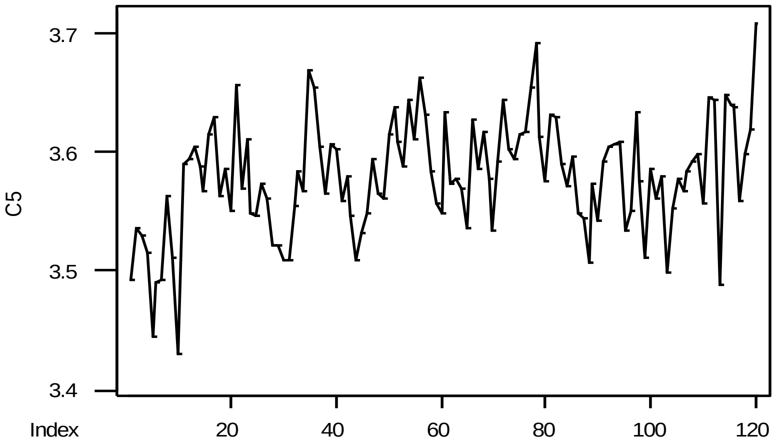
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



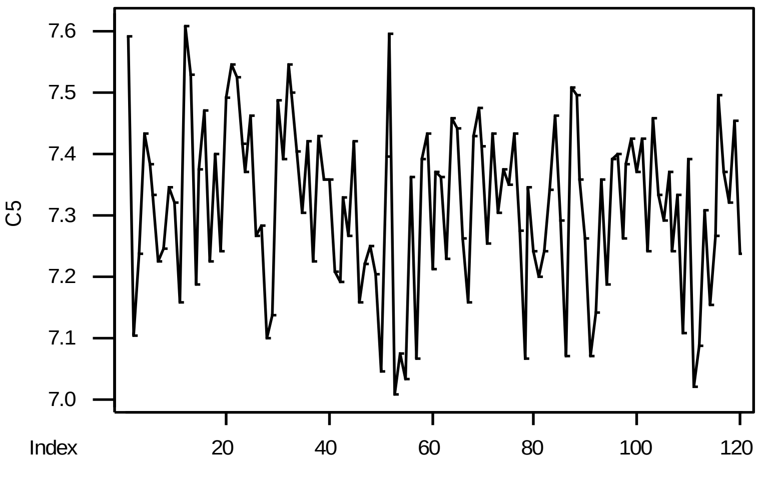
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



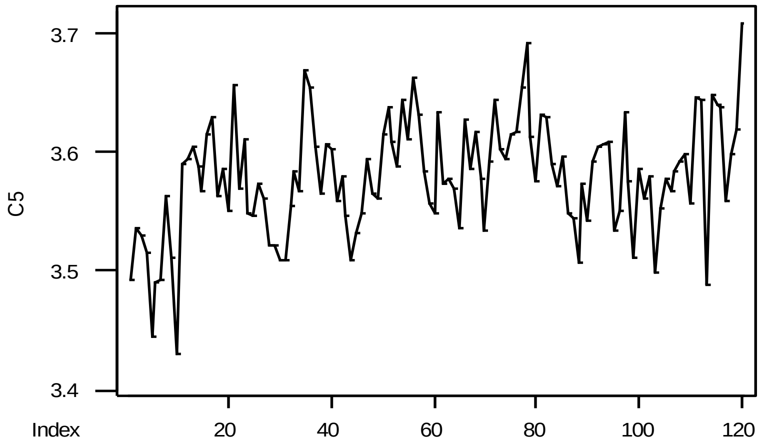
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



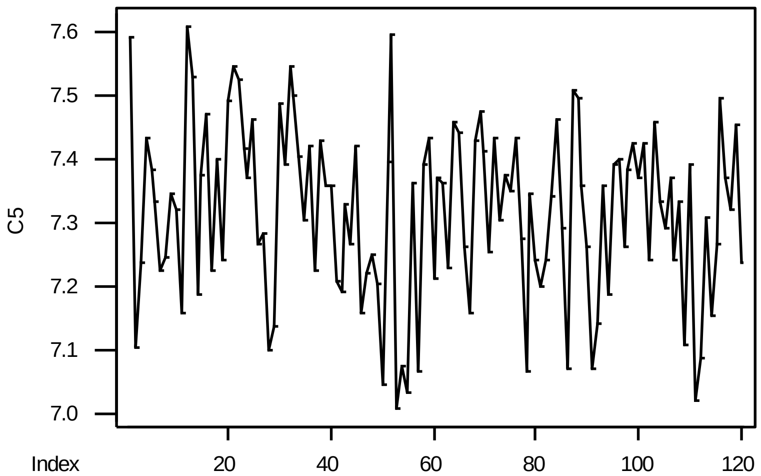
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



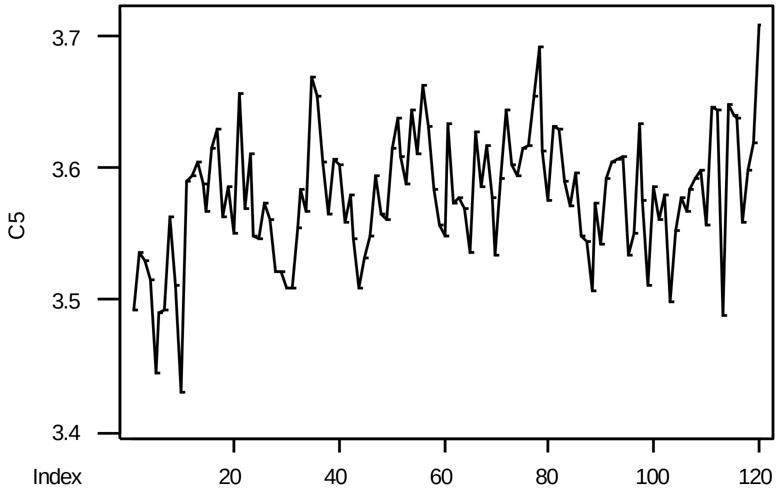
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



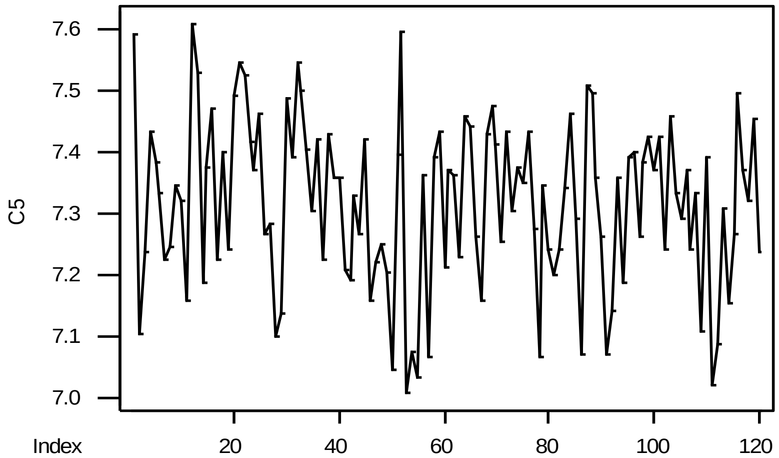
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



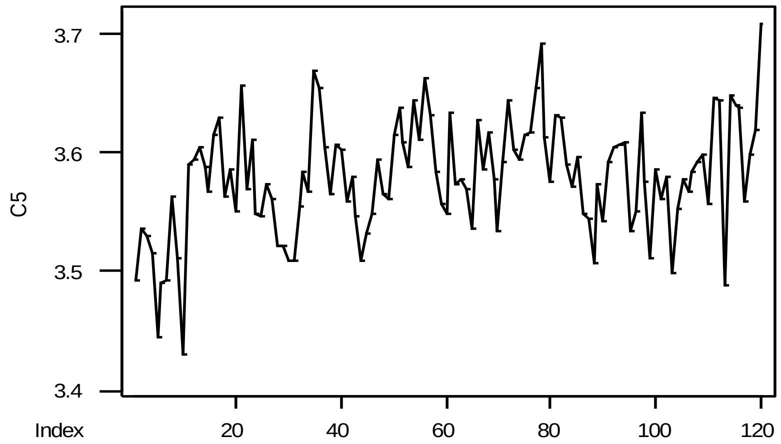
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



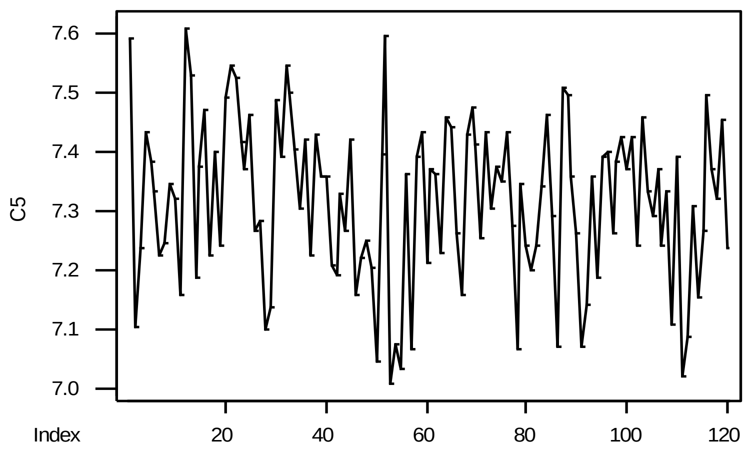
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



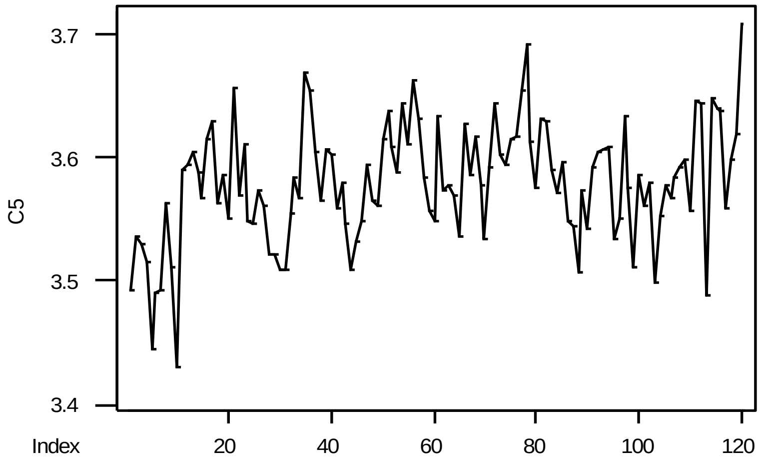
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



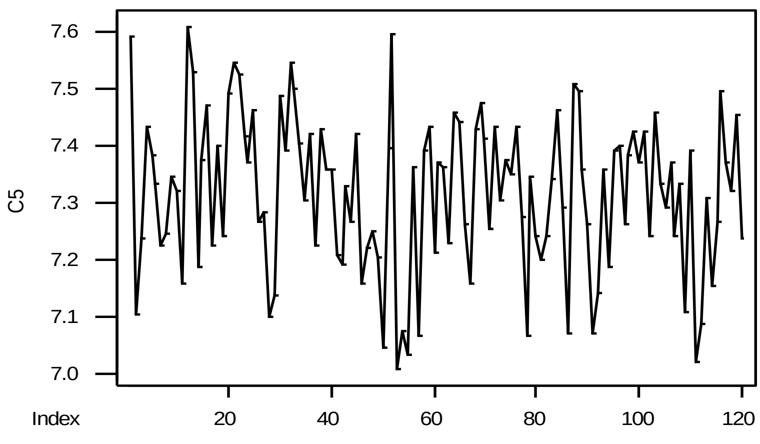
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



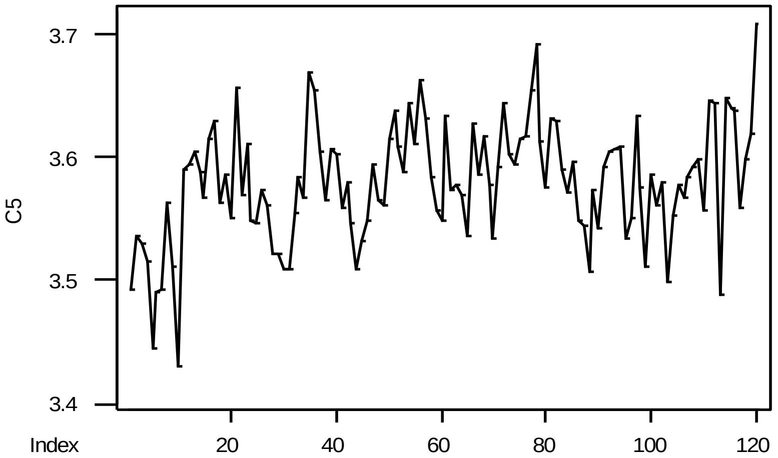
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



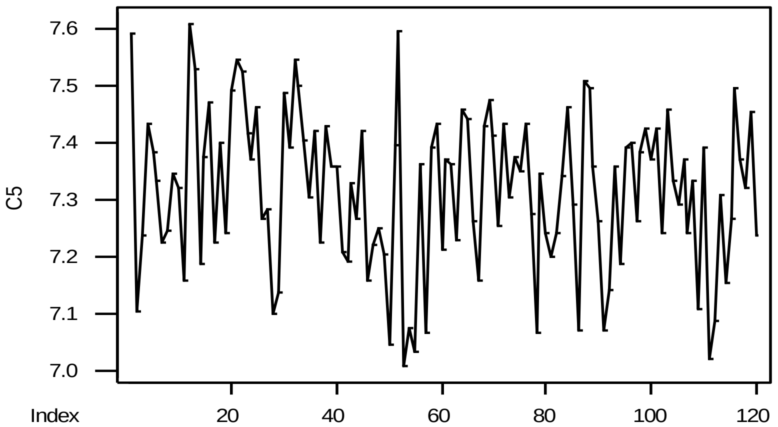
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



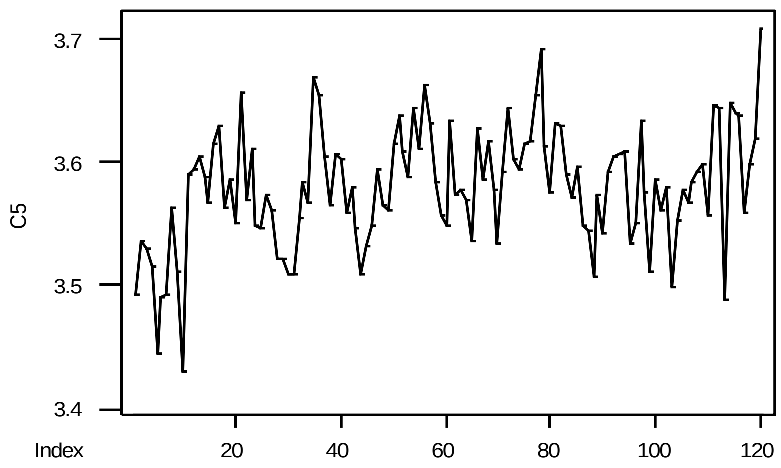
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



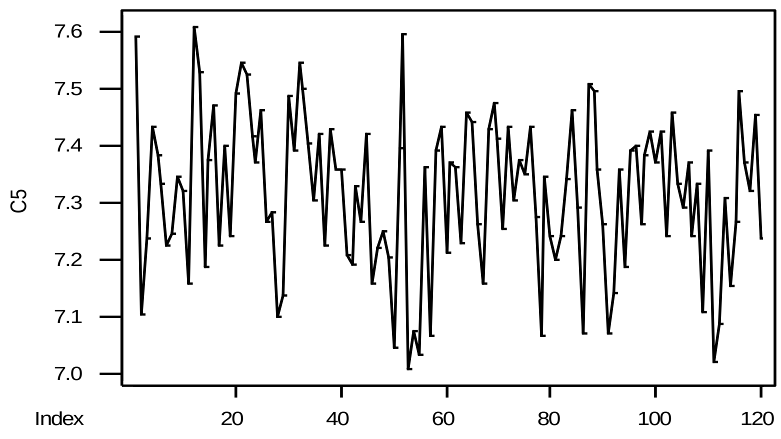
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



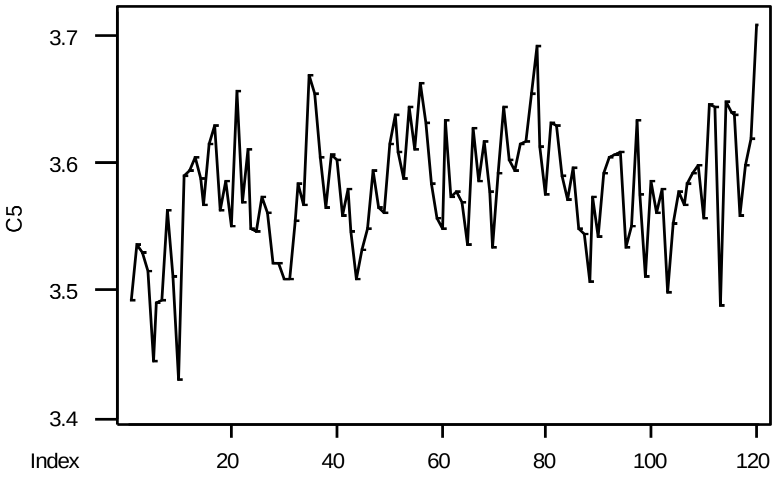
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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



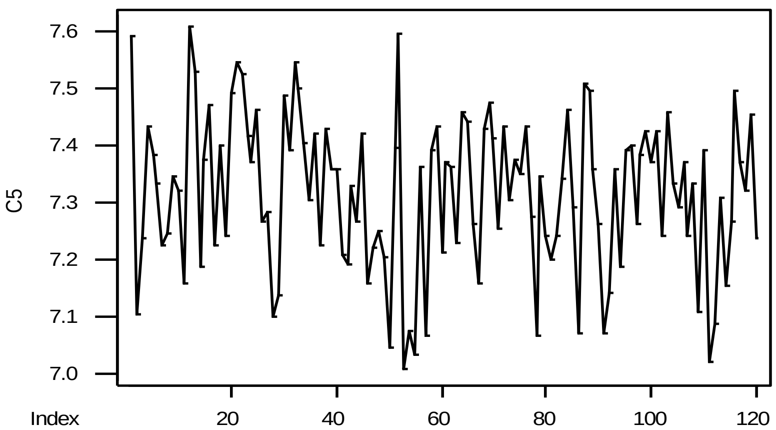
By the graphic, we can make the conclusion that because there is no pattern in this graphic; it means that all the data are time independent. Material tested is stable and properties should not change over time.

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 Ho: $\mu 1 = \mu 2$, H1: $\mu 1 \neq \mu 2$ 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) < α, 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

	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

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) < α, so we have to reject null hypothesis. Therefore, the means of % strain @ 3GPD for sample 1 and sample 2 are not equal.

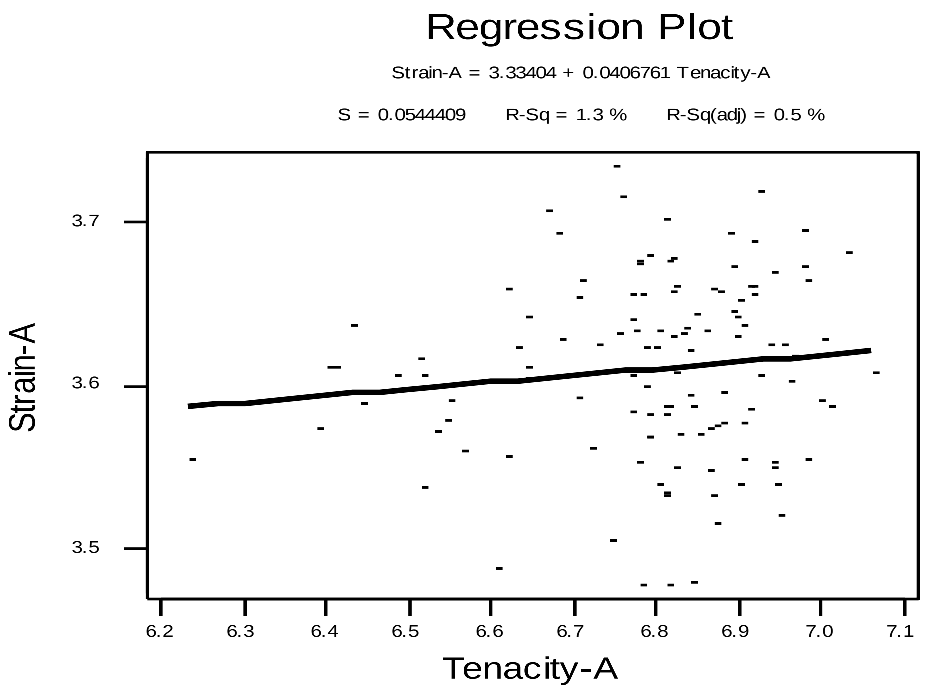
VI. Correlation Analysis:

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

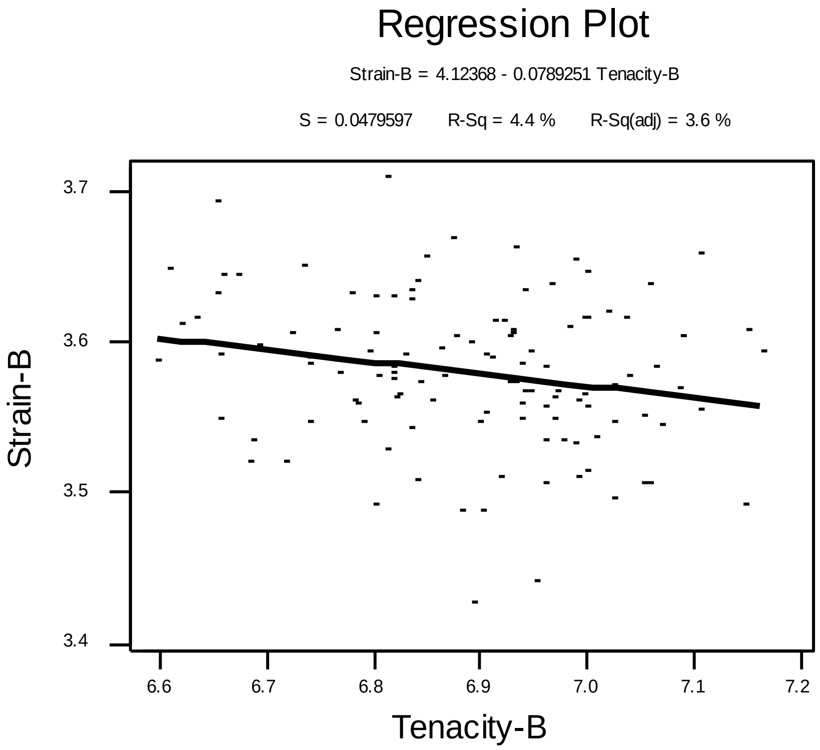
Pearson correlation of Strain-A and Tenacity-A = 0.115, P-Value = 0.213



For this graph, we observe that the correlation coefficient = 0.115 is insignificant since the p-value > α. 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

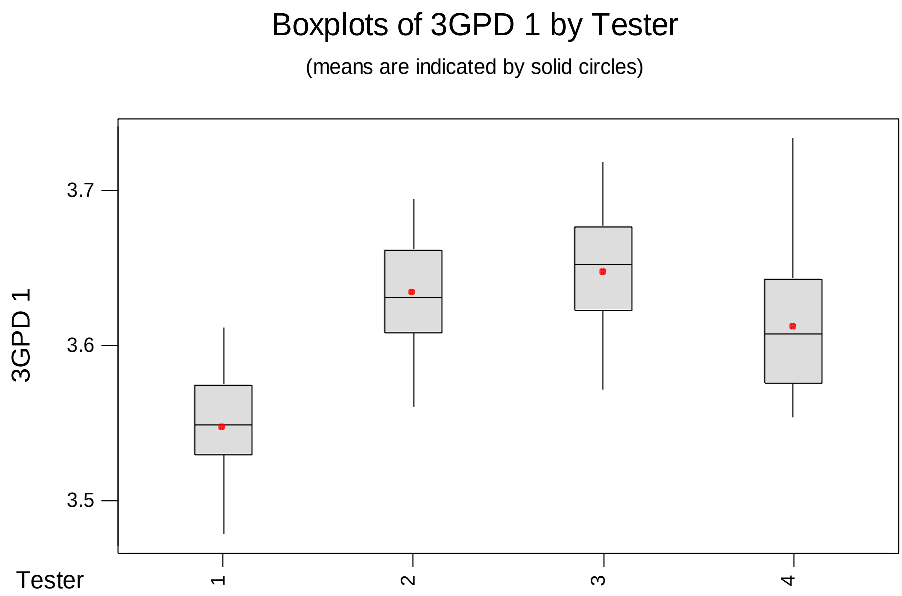
Sample 1 “%Strain @ 3GPD”

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.

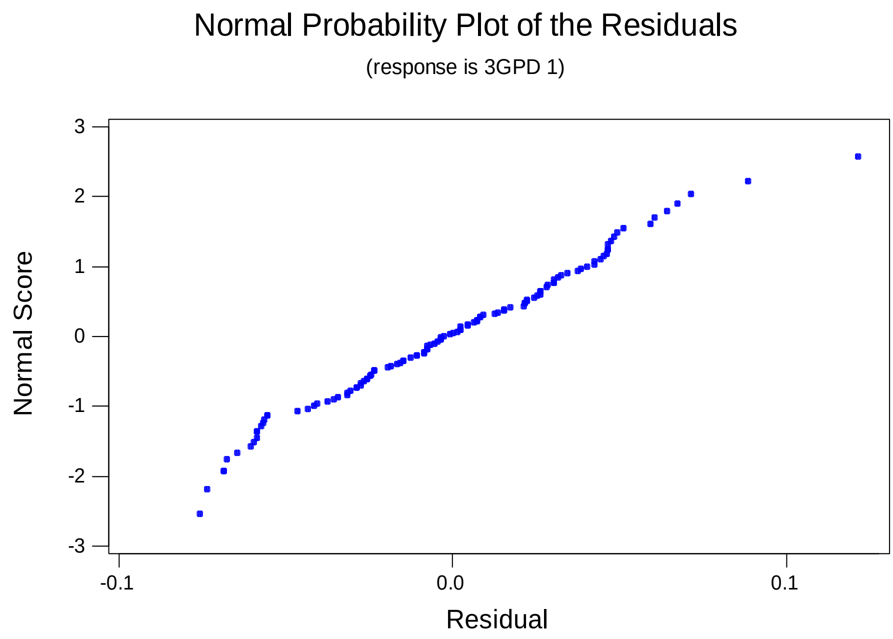
One-way ANOVA: 3GPD 1 versus Tester

```
Analysis of Variance for 3GPD 1
Source     DF        SS        MS        F        P
Tester      3   0.17728   0.05909    38.70    0.000
Error     116   0.17710   0.0015
Total     119   0.35438
                              Individual 95% CIs For Mean
                              Based on Pooled Stdev
Level       N      Mean    StDev  -+---------+---------+---------+-----
1          30    3.5474   0.0367  (----*---)
2          30    3.6343   0.0333                    (---*---)
3          30    3.6473   0.0410                       (---*---)
4          30    3.6122   0.0444               (---*---)
                              -+---------+---------+---------+-----
Pooled StDev =   0.0391         3.535    3.570    3.605    3.640
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   -0.11326
          -0.06061

      3   -0.12626   -0.03932
          -0.07361    0.01332

      4   -0.09116   -0.00422    0.00878
          -0.03851    0.04842    0.06142
```

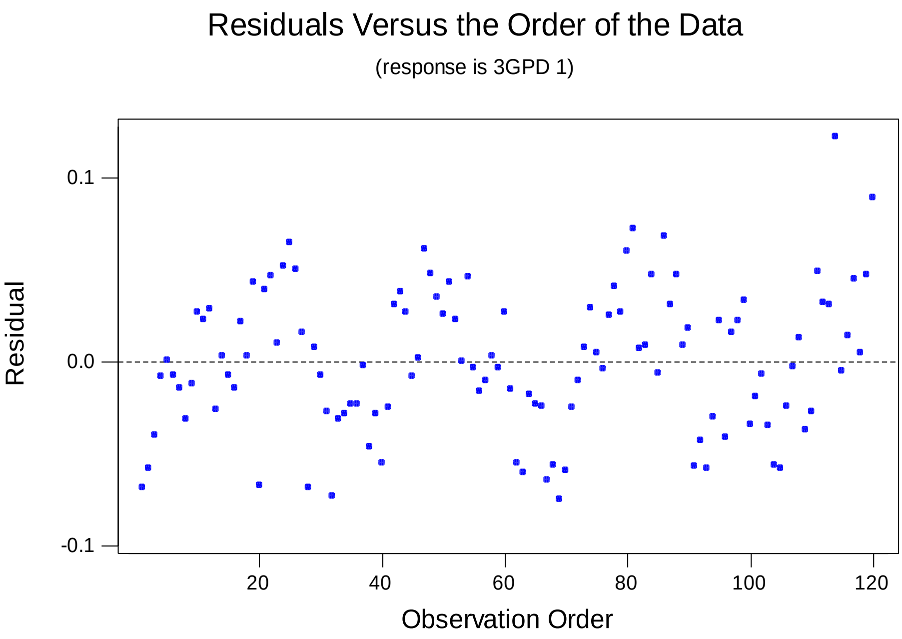
Boxplot for sample 1 for "%Strain @ 3GPD" shows that the confidence intervals do not overlap for the all the testers as indicated by the ANOVA.



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.



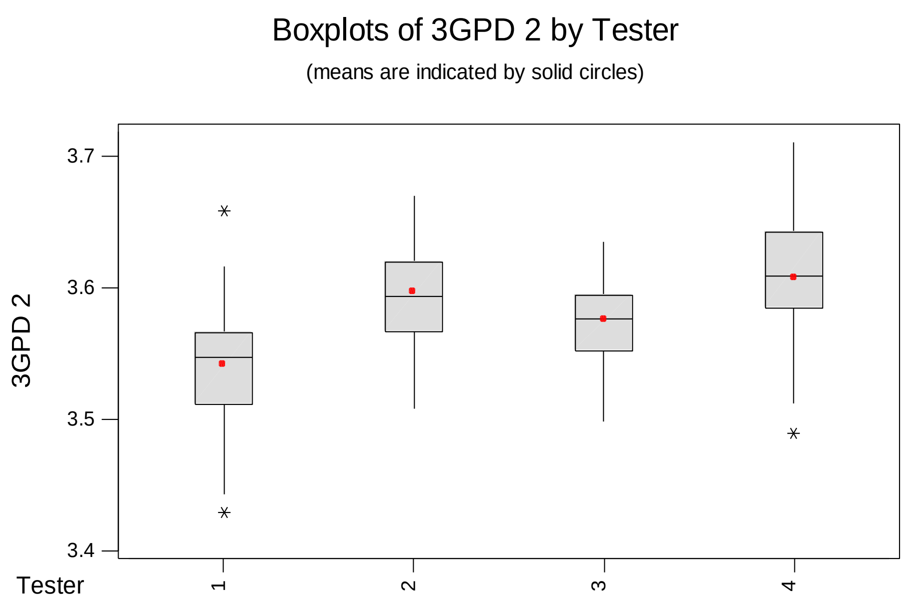
Sample 2 - "%Strain @ 3GPD"

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.

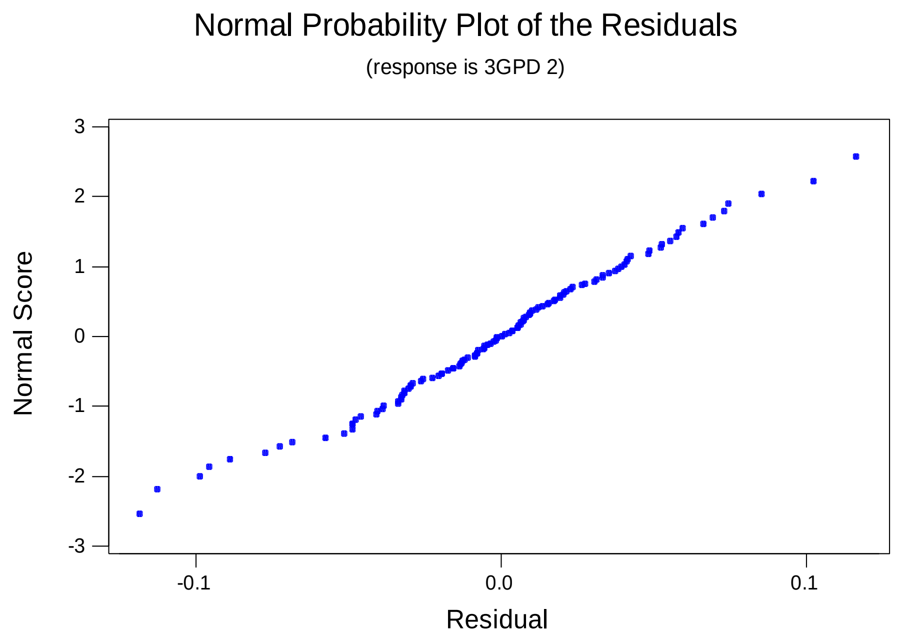
One-way ANOVA: 3GPD 2 versus Tester

```
Analysis of Variance for 3GPD 2
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
                              Individual 95% CIs For Mean
                              Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
1          30    3.5413    0.0480  (----*-----)
2          30    3.5965    0.0374                 (----*----)
3          30    3.5751    0.0341           (----*----)
4          30    3.6072    0.0480                    (----*-----)
                                   -----+---------+---------+---------+-
Pooled StDev =   0.0423              3.540     3.570     3.600     3.630
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   -0.08375
          -0.02671

      3   -0.06235   -0.00712
          -0.00531    0.04992

      4   -0.09449   -0.03925   -0.06065
          -0.03745    0.01779   -0.00361
```

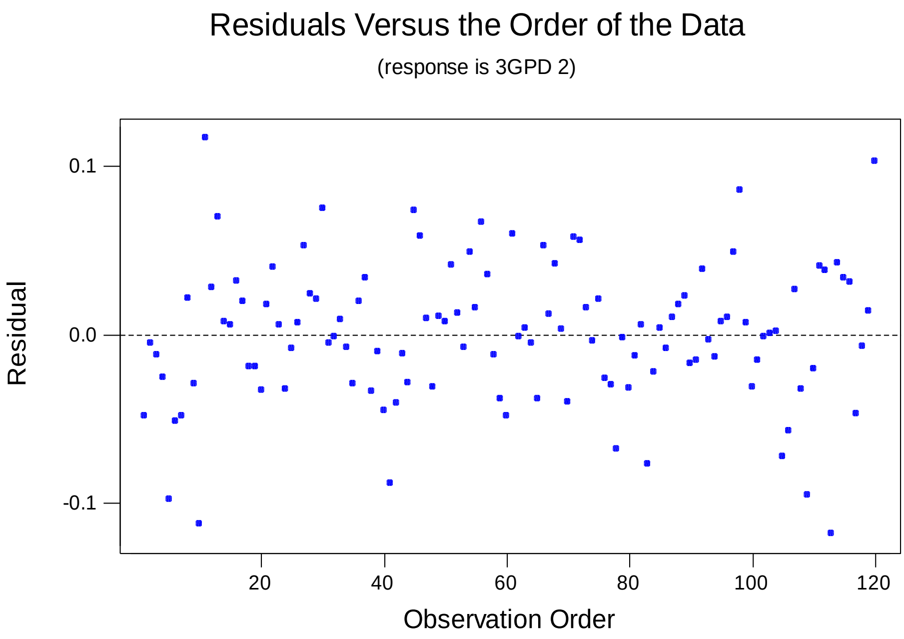
Boxplot for sample 2 for "%Strain @ 3GPD" shows that the confidence intervals do not overlap for the all the testers as indicated by the ANOVA.



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



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.

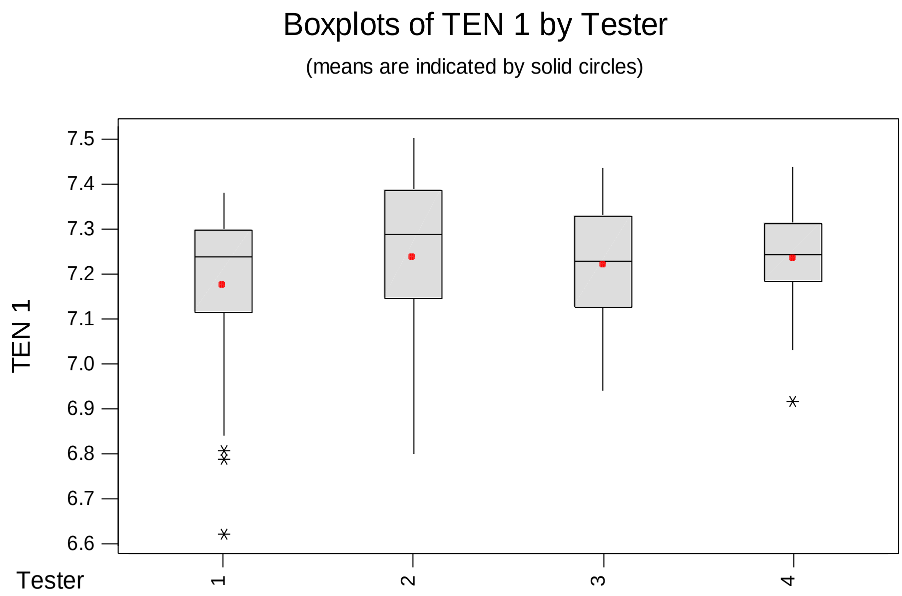
Sample 1 - "Tenacity @ Break"

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 α = 0.05, for 95% confidence interval. Tukey's comparison shows agreement, each interval crosses zero.

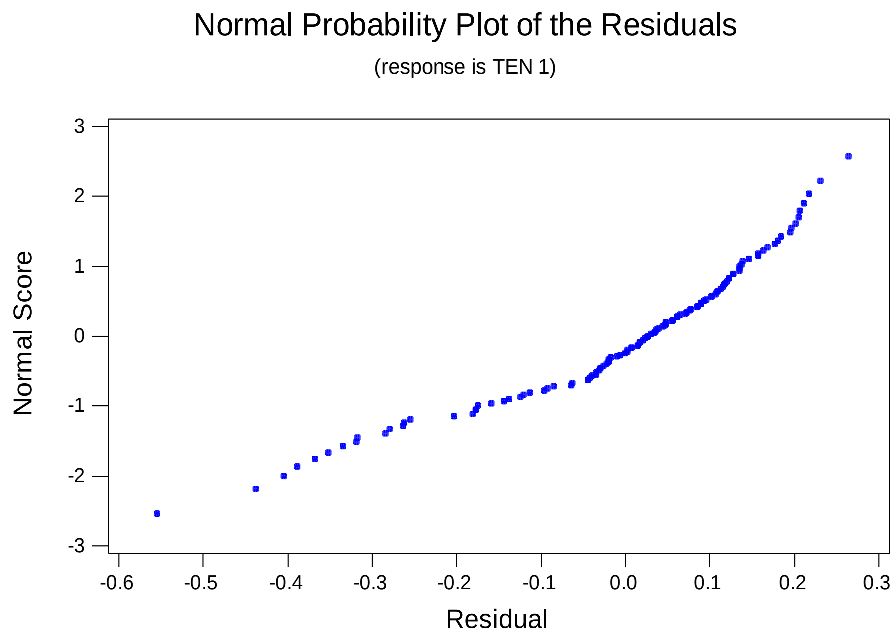
One-way ANOVA: TEN 1 versus Tester

```
Analysis of Variance for TEN 1
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
                             Individual 95% CIs For Mean
                             Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1          30    7.1737    0.1959   (-----------*-----------)
2          30    7.2359    0.1992            (-----------*-----------)
3          30    7.2175    0.1228          (-----------*----------)
4          30    7.2320    0.1172            (----------*-----------)
                                   --------+---------+---------+--------
Pooled StDev =   0.1635                 7.150     7.200     7.250
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    -0.1723
            0.0480

      3    -0.1540    -0.0918
            0.0663     0.1285

      4    -0.1685    -0.1063    -0.1246
            0.0518     0.1140     0.0956
```

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.



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



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 α = 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
Tester	3	0.0488	0.0163	0.85	0.472
Error	116	2.2326	0.0192		
Total	119	2.2814			

```
                                    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 StDev =    0.1387                  7.280      7.320      7.360
```

Tukey's pairwise comparisons

Family error rate = 0.0500

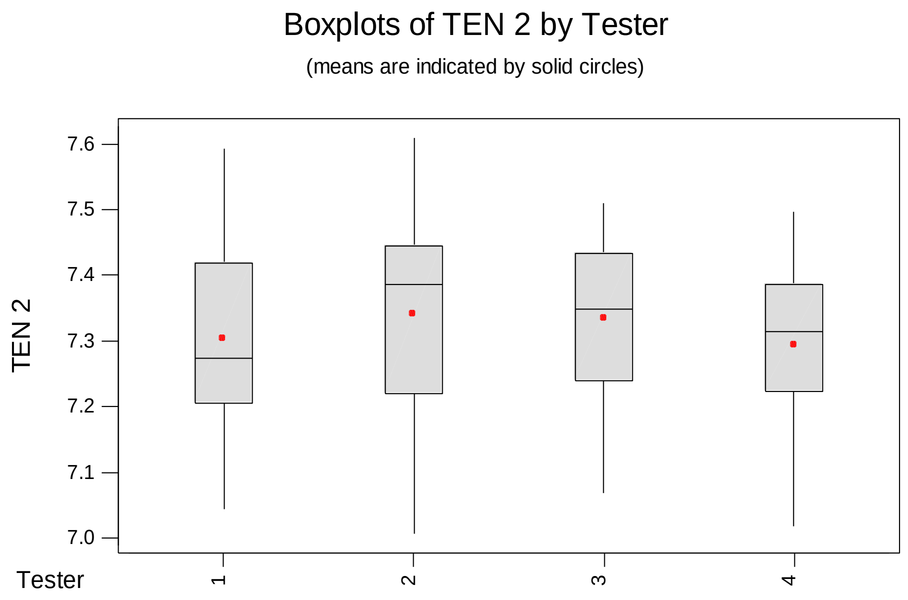
Individual error rate = 0.0103

Critical value = 3.69

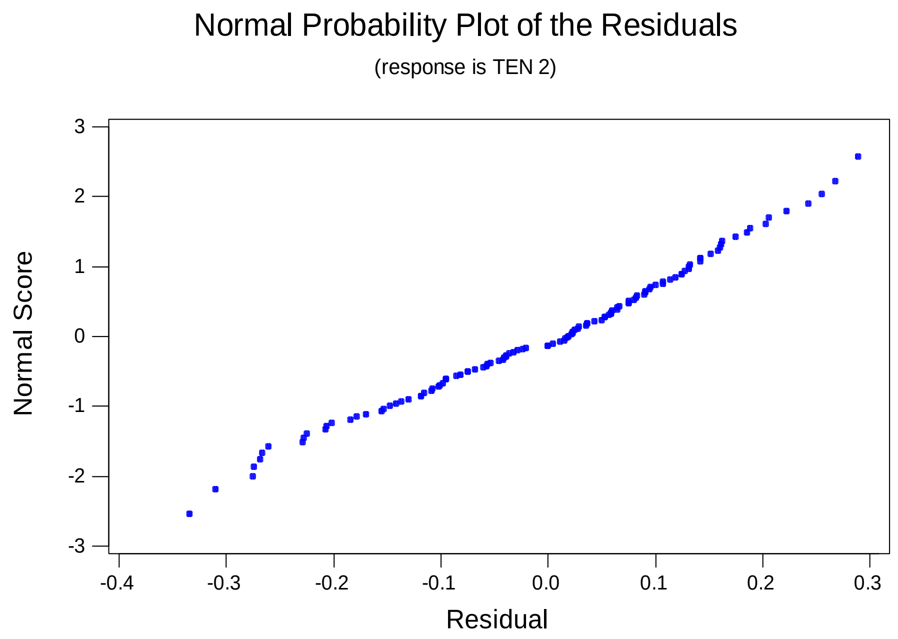
Intervals for (column level mean) - (row level mean)

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



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



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	F	P
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
Level      N      Mean     StDev    ---------+---------+---------+-------
1         10    3.5260    0.0285    (-------*--------)
2         10    3.5479    0.0318             (--------*--------)
3         10    3.5682    0.0391                        (-------*--------)
                                    ---------+---------+---------+-------
Pooled StDev =  0.0334                   3.525     3.550     3.575
```

Tukey's pairwise comparisons

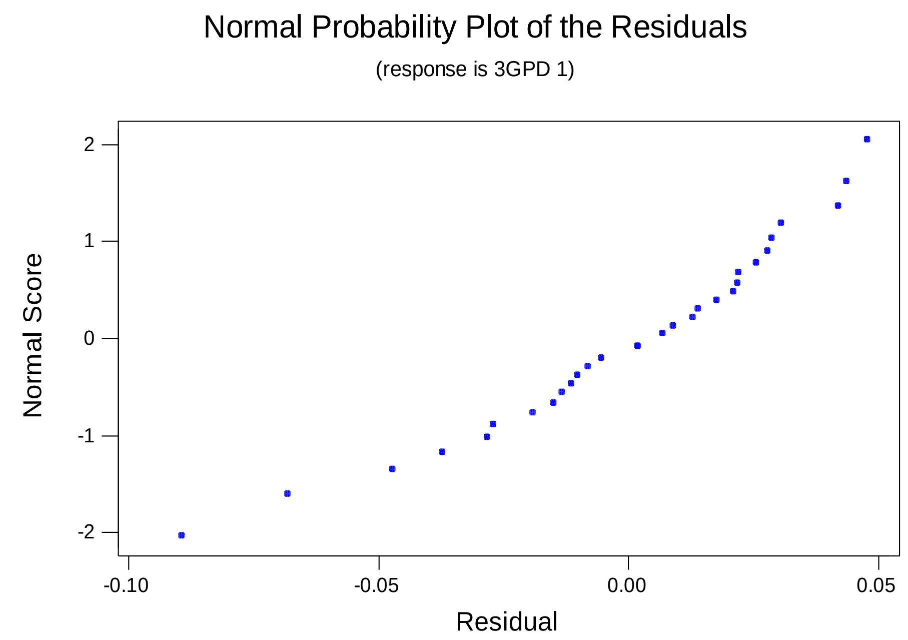
Family error rate = 0.0500

Individual error rate = 0.0196

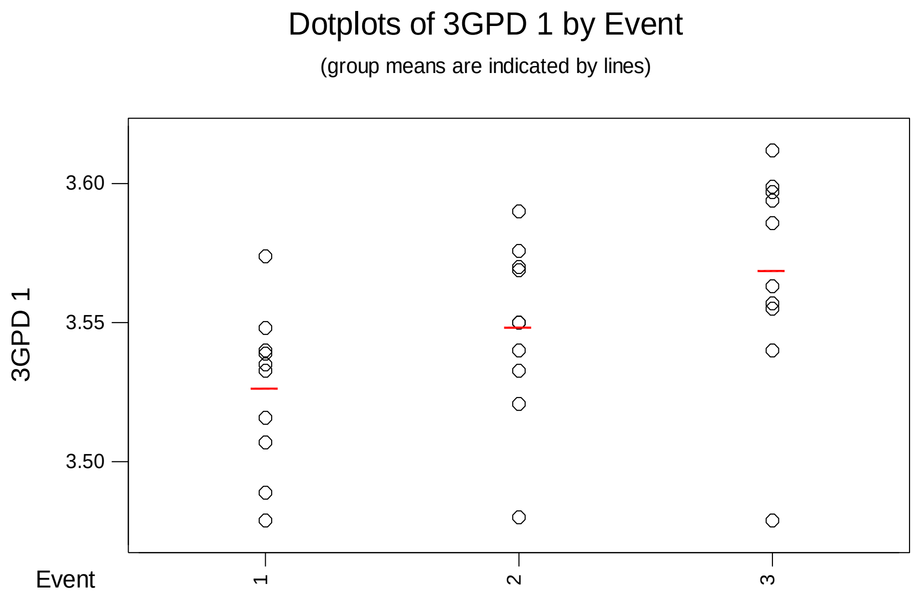
Critical value = 3.51

Intervals for (column level mean) - (row level mean)

	1	2
2	-0.05902 0.01522	
3	-0.07932 -0.00508	-0.05742 0.01682



Normal Probability Plot of the Residuals
(response is 3GPD 1)
Normal Score
2
1
0
-1
-2
-0.10
-0.05
0.00
0.05
Residual



Dotplots of 3GPD 1 by Event
(group means are indicated by lines)
3GPD 1
3.60
3.55
3.50
Event
1
2
3

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
Level        N       Mean       StDev    --------+---------+---------+--------
1           10     3.5004      0.0408    (------*------)
2           10     3.5620      0.0451                        (-------*------)
3           10     3.5614      0.0305                        (-------*------)
                                         --------+---------+---------+--------
Pooled StDev =    0.0393                      3.500     3.535     3.570
```

Tukey's pairwise comparisons

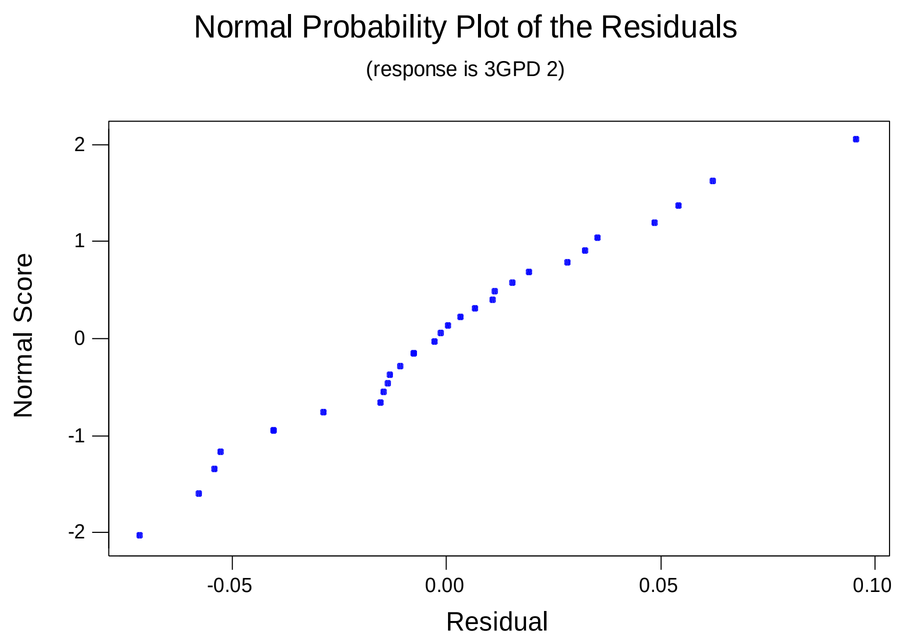
Family error rate = 0.0500

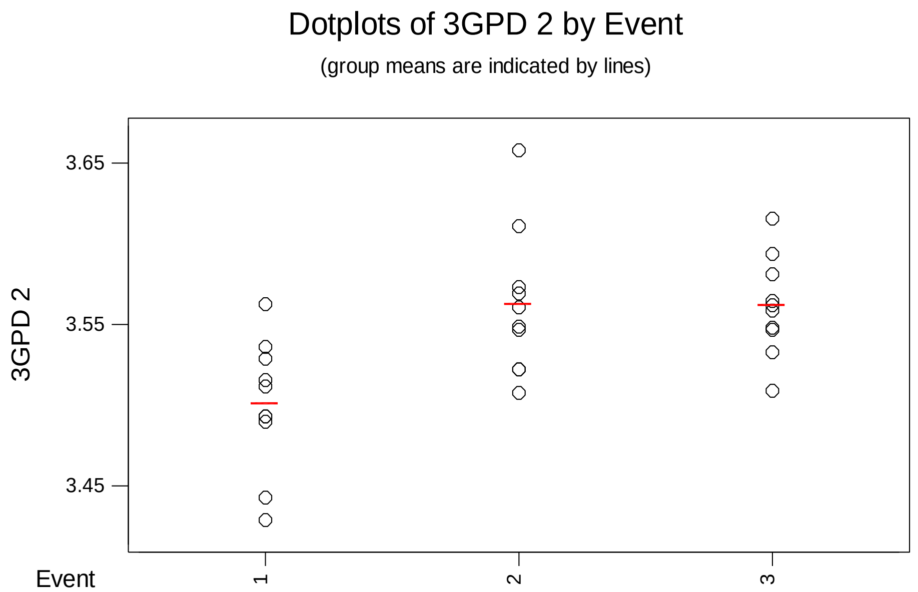
Individual error rate = 0.0196

Critical value = 3.51

Intervals for (column level mean) - (row level mean)

	1	2
2	-0.10521 -0.01799	
3	-0.10461 -0.01739	-0.04301 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			

```
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level      N     Mean     StDev    ----------+---------+---------+------
3GPD 1   120   3.6103    0.0546                         (-----*-----)
3GPD 2   120   3.5800    0.0489   (------*-----)
                                   ----------+---------+---------+------
Pooled StDev =  0.0518                     3.585     3.600     3.615
```

One-way ANOVA: TEN 1, TEN 2

Analysis of Variance

Source	DF	SS	MS	F	P
Factor	1	0.6350	0.6350	27.71	0.000
Error	238	5.4540	0.0229		
Total	239	6.0890			

```
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level      N     Mean     StDev    ---+---------+---------+---------+---
TEN 1    120   7.2148    0.1633    (----*----)
TEN 2    120   7.3177    0.1385                          (-----*----)
                                   ---+---------+---------+---------+---
Pooled StDev =  0.1514            7.200     7.250     7.300     7.350
```

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 A = 1.63 + 0.265 Tester 2 A + 0.003 Tester 3 A + 0.260 Tester 4 A

Predictor	Coef	SE Coef	T	P
Constant	1.6337	0.7694	2.12	0.043
Tester 2	0.2653	0.2758	0.96	0.345
Tester 3	0.0026	0.2218	0.01	0.991
Tester 4	0.2601	0.1535	1.69	0.102

- S = 0.03452 R-Sq = 20.8% R-Sq(adj) = 11.6%

- Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.008126	0.002709	2.27	0.104
Residual Error	26	0.030985	0.001192		
Total	29	0.039111			

Source	DF	Seq SS
Tester 2	1	0.004665
Tester 3	1	0.000039
Tester 4	1	0.003422

- Unusual Observations

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

- 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 B = 2.55 - 0.136 Tester 2 B + 0.379 Tester 3 B + 0.033 Tester 4 B

Predictor	Coef	SE Coef	T	P
Constant	2.555	1.465	1.74	0.093
Tester 2	-0.1358	0.2420	-0.56	0.580
Tester 3	0.3791	0.2715	1.40	0.174
Tester 4	0.0331	0.1931	0.17	0.865

- S = 0.04813   R-Sq = 9.7%   R-Sq(adj) = 0.0%

- Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.006496	0.002165	0.93	0.438
Residual Error	26	0.060234	0.002317		
Total	29	0.066730			

Source	DF	Seq SS
Tester 2	1	0.001363
Tester 3	1	0.005066
Tester 4	1	0.000068

- Unusual Observations

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

- 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.