

ANALYSIS OF 17-4 AND 15-5 ALLOY DATA FROM INVESTMENT CASTING TRIALS

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ABSTRACT:

Investment castings have a penalty in design parameters vis-à-vis wrought products for aerospace applications. An extensive study with over 1000 specimens from 14 investment casters in 17-4 PH and 15-5 PH was conducted. Tensile properties were analyzed for comparison between producers from a benchmarking point of view.

MOTIVATION:

This study is a benchmarking study to compare potential capabilities of alloys produced by different foundries using an existing data set. Two areas were looked at: Average performance and variability within foundries.

SPECIMEN PREPARATION AND TESTING PROCEDURE:

The tensile specimens were made by one injection house and sent to 14 participating foundries. The specimens originated from plate and externally cast bars. Foundries produced molds according to their practice and materials and followed their internal melting and pouring procedures as well. The heat treatment was performed at one heat treatment house and the tensile testing at one laboratory following the ASTM E8 standard.

DATA ANALYSIS PROCEDURE:

A subset of the entire data set was analyzed for this purpose. The alloys were 15-5 PH aged at 935 F and 1000 F and 17-4 PH aged at 1000 F and 1100 F. The properties reviewed were Ultimate Tensile Strength, Yield Strength, Percent Elongation and Percent Reduction in Area.

Averages and standard deviations for each foundry/alloy/aging treatment/property were calculated. Then probability plots for each of these averages and standard deviations were made to identify outliers on the top side and pand 17-4 1000 F potentially look at best practices.

Table 1: Foundries and number of specimens tested per condition.

Foundry	15-5 PH 935 F	15-5 PH 1000 F	17-4 PH 1000 F	17-4 PH 1100 F
A	11	10	-	-
B	14	11	14	11
D	7	13	8	10
E	14	13	14	12
H	10	12	6	11
J	12	9	15	12

K	-	9	11	8
L	11	7	11	8
M	11	9	11	12
P	9	9	9	10
R	11	9	10	9
S	10	8	10	8
T	12	9	11	8
U	10	13	12	7
Total	142	141	142	126

RESULTS AND DISCUSSION SUMMARY:

This section is organized by looking at each property in turn for all alloys. That is, UTS for all alloys, followed by yield strength for all alloys, etc. In each alloy/property combination four plots were generated. General comments on the properties and representative plots of the characteristics in question will be presented. All of the charts are available in the appendix.

Ultimate Tensile Strength (UTS):

For the most part, the UTS values were above the standard minimums. However, the 15-5 935 F and 17-4 1000 F had several instances below the standard (figure 1). Foundry “B” also had data points that went below standard values in other alloys, though this appears to be a variability issue as the average was clearly above the minimum. In terms of some foundries performing significantly better than others, the normal probability plots for UTS indicate that the variation can be explained by normal variation. However, the variability of results (standard deviation) it can be seen that some foundries have significant larger variation as indicated by the point outside of the normal range (figure 2).

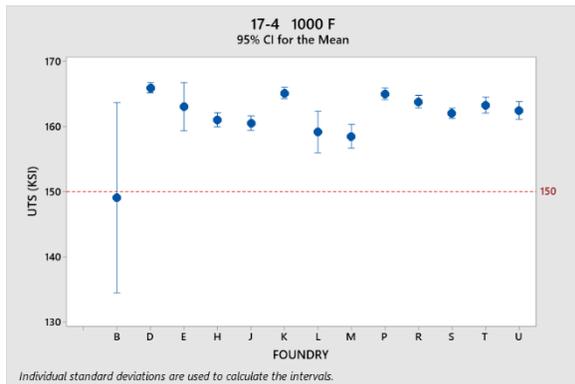


Figure 1A: UTS Confidence intervals. Note some intervals going below the minimum limit.

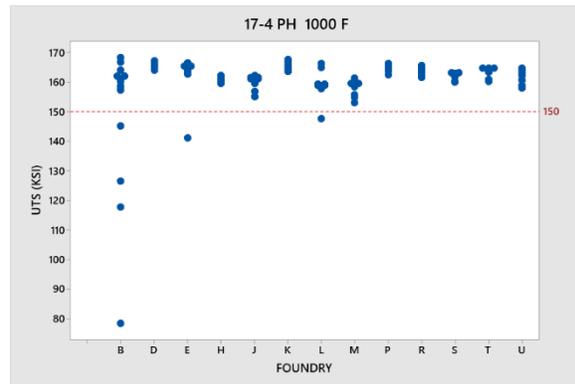


Figure 1B: UTS Individual data plot. Note that generally the values below the specification appear to be outliers, except for foundry B, where large variation is present.

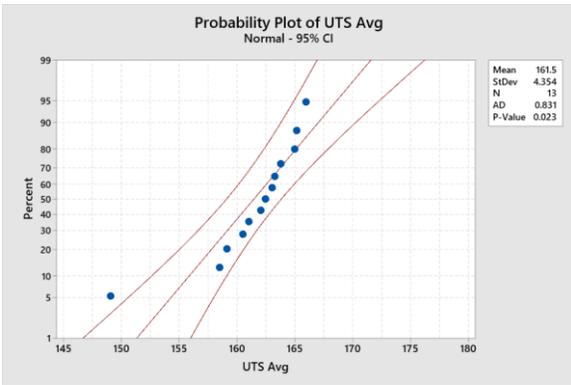


Figure 2A: Probability plot of UTS averages for each foundry 17-4, 1000 F. One significant outliers beyond normal variation, however, below desired value.

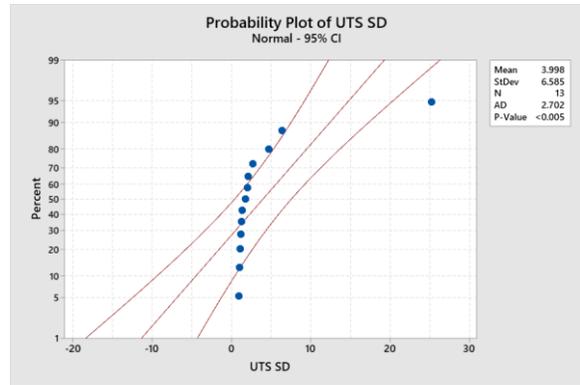


Figure 2B: Probability plot of UTS standard deviations by foundry 17-4, 1000 F. One significant outliers beyond normal variation indicating one instance with more variation between foundries than anticipated.

Yield Strength (YS):

Only two data points were below the minimum value for the entire data set of over 120 points. Thus, the YS minimums were easily met. In terms of variability, the yield strengths were more consistent from foundry to foundry than the UTS. In figure 3 this can be seen.

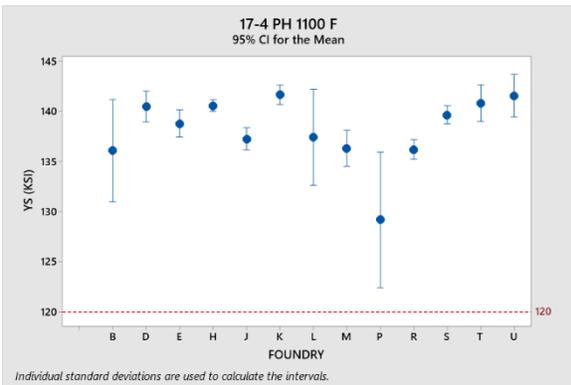


Figure 3A: Yield strength confidence intervals.

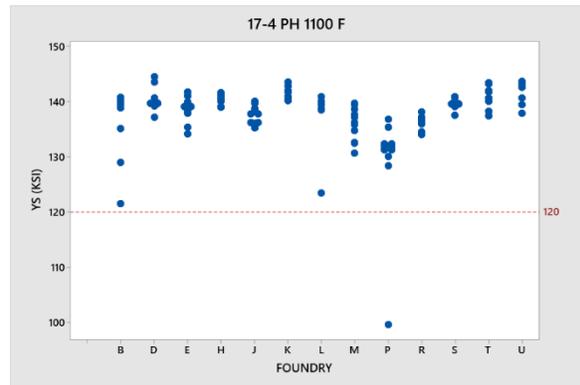


Figure 3B: Yield strength individual plot.

Percent Elongation (%EL):

The percent elongation data for each alloy shows that average values meet the minimum requirements. The variability though typically results in the confidence interval for several (1 to 4 per alloy) foundries extending below the minimum limit. However, looking at the individual data plot in all instance at least 8 foundries had points below the minimum (figure 4). Also note the wide variability in the data, this is one area where results can be obtained, but reducing the variability would provide the best benefit.

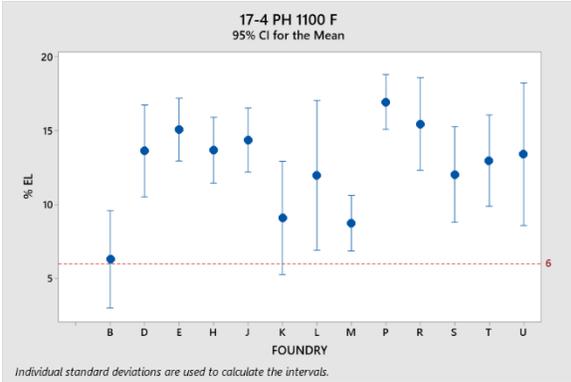


Figure 4A: Percent elongation confidence intervals. Note some intervals going below the minimum limit.

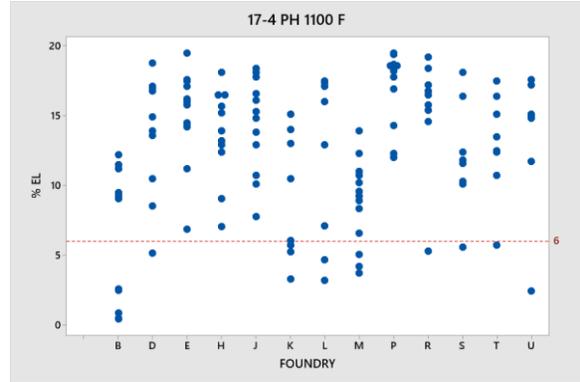


Figure 4B: Percent elongation individual plot. Note many data points below standard.

Percent Reduction in area (%RA):

The %RA follows similar but improved characteristics as the %EL. That is, the averages are significantly higher than the minimum requirements, though some confidence intervals extend below the minimum requirement. High variability is the issue here. See figure 5.

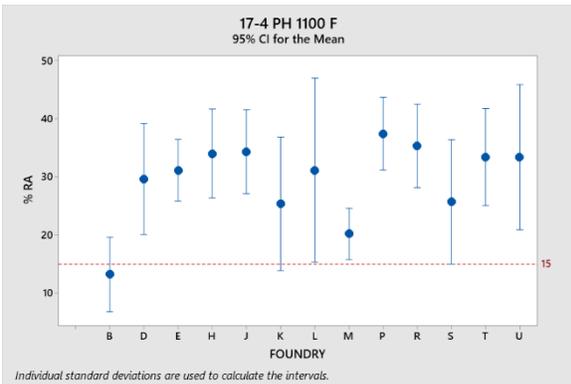


Figure 5A: Percent reduction in area confidence intervals. Note some intervals going below the minimum limit.

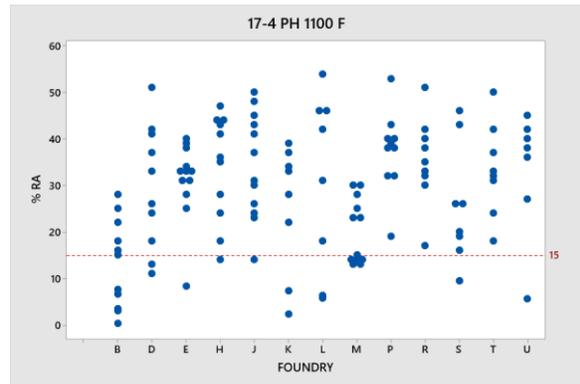


Figure 5B: Percent reduction in area individual plot. Note many data points below standard.

CONCLUSIONS:

Generally, the average UTS, YS, %EL and %RA are well above the minimum requirements. In the case of %EL and %RA high variability can lead to individual values below the minimum requirements. In terms of looking for difference between foundries from a benchmarking standpoint, most of the results can be explained by anticipated normal variation between foundries. The exception to this would be that some foundries perform worse (lower averages and/or more variability). However, on the top end for higher averages and/or less variability there were no clear differences.

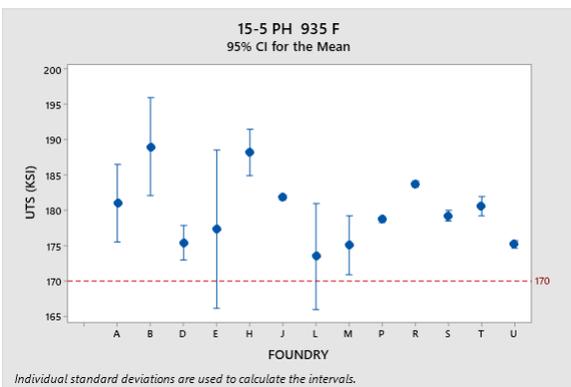
This does not mean that there are no improvements to be made. Foundries can strive to improve their processes to attain the top range of values and lower variability if they are not already there.

APPENDIX

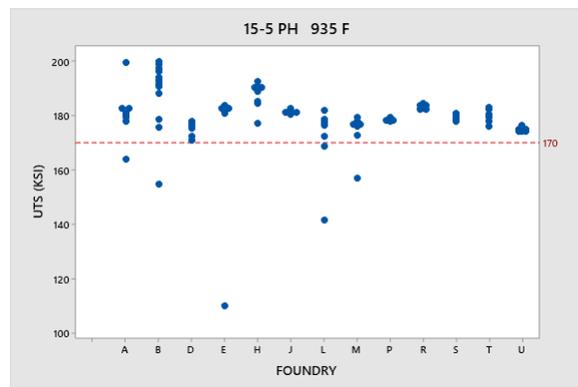
This section is written to be read in the following manner:

Each alloy and treatment are done separately. Then each mechanical property is presented with four graphs. The first graph shows the 95% confidence interval of the property by foundry. The objective here is to present statistical soundness to the analysis. However, as this may mask some features of the data, the second plot is the raw data points by foundry. In both of these plots, it is possible to benchmark differences in values and variation. In order to further identify significant differences between foundries in both mean and standard deviation values, normal probability plots were used on the foundry averages for mean and standard deviations. The interpretation here is to find the outliers with higher properties (top of average/mean chart) and lower variability (bottom of standard deviation chart).

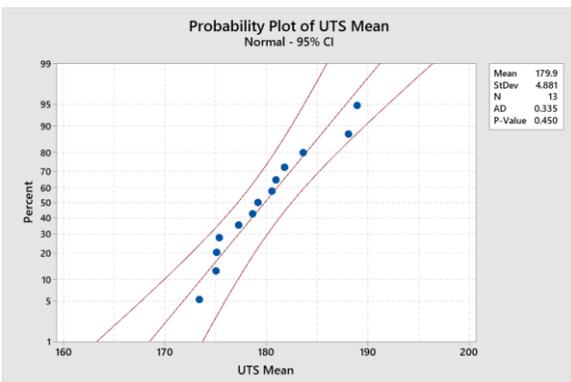
Figures 1A-P: 15-5 PH, 935 F Age Confidence intervals, individual data plots, and normal probability plots for average and standard deviation of properties for each UTS, yield strength, percent elongation and percent reduction in area.



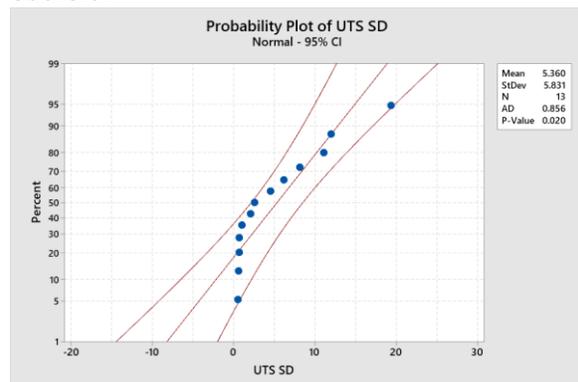
A: UTS Confidence intervals. Note some intervals going below the minimum limit.



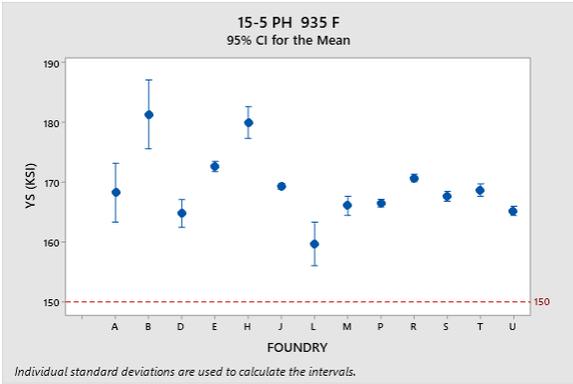
B: UTS Individual data plot. Note that generally the values below the specification appear to be outliers.



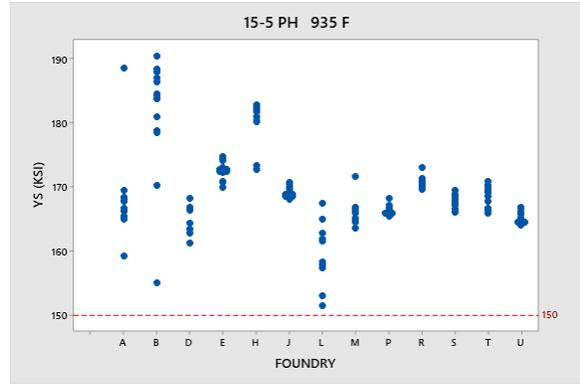
C: Probability plot of UTS averages for each foundry. No significant outliers beyond normal variation.



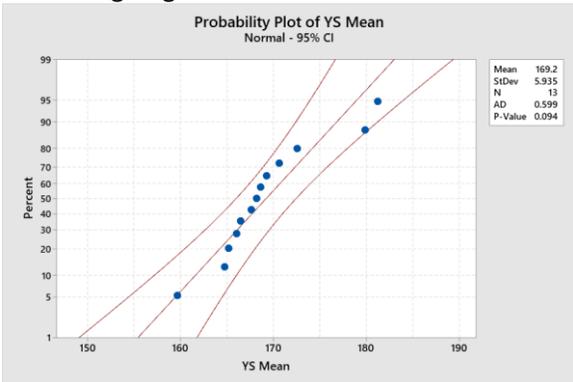
D: Probability plot of UTS standard deviations by foundry. No significant outliers beyond normal variation. The skewness is anomalous.



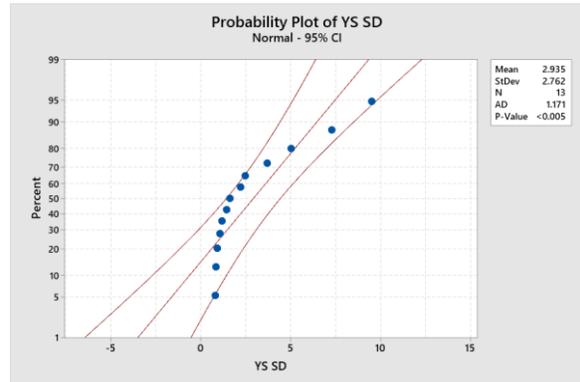
E: Yield strength confidence intervals. Note some intervals going below the minimum limit.



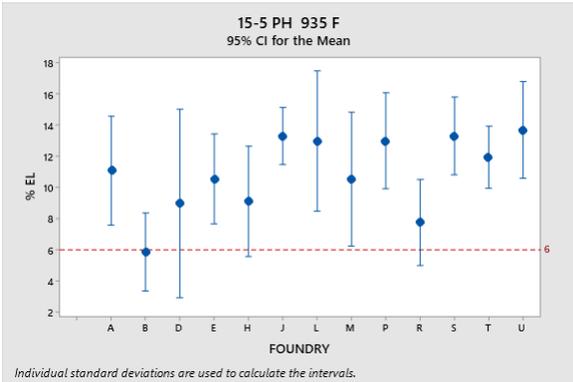
F: Yield strength individual plot. Note differences in variation.



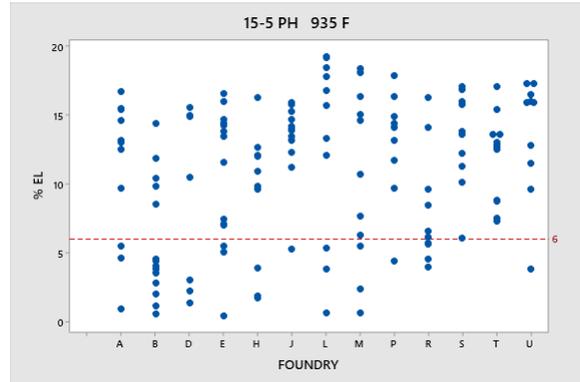
G: Probability plot of yield strength averages for each foundry. No significant outliers beyond normal variation.



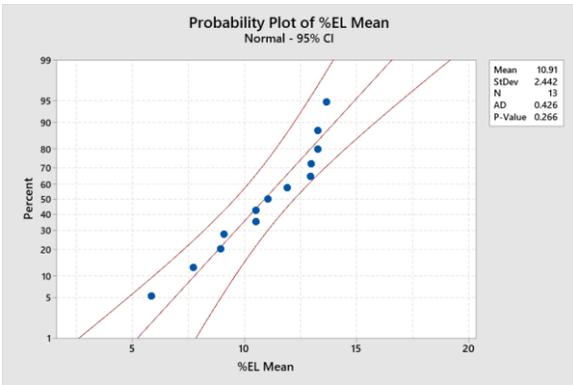
H: Probability plot of yield strength standard deviations by foundry. No significant outliers beyond normal variation. The skewness is anomalous.



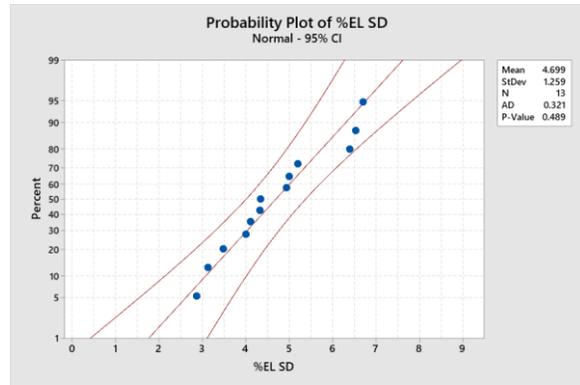
I: Percent elongation confidence intervals. Note some intervals going below the minimum limit.



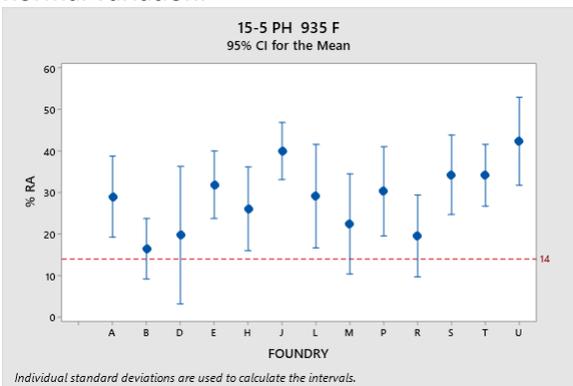
J: Percent elongation individual plot. Note many data points below standard.



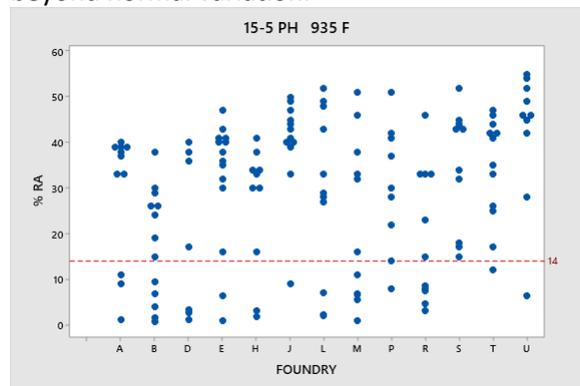
K: Probability plot of percent elongation averages for each foundry. No significant outliers beyond normal variation.



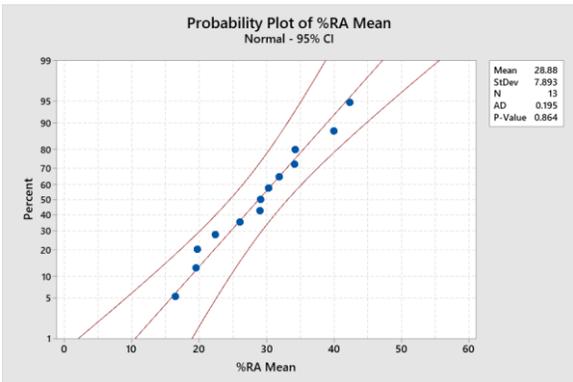
L: Probability plot of percent elongation standard deviations by foundry. No significant outliers beyond normal variation.



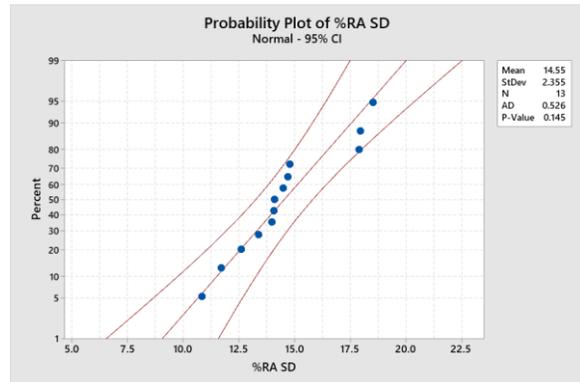
I: Percent reduction in area confidence intervals. Note some intervals going below the minimum limit.



J: Percent reduction in area individual plot. Note many data points below standard.

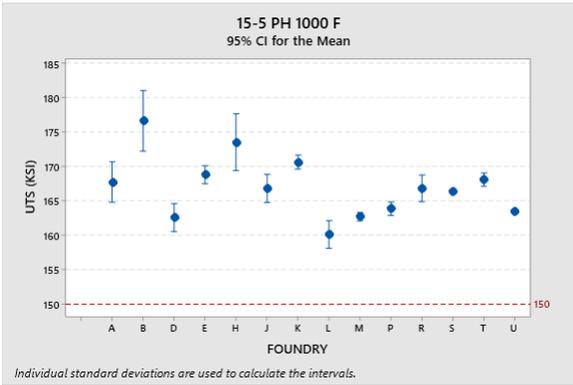


K: Probability plot of percent reduction in area averages for each foundry. No significant outliers beyond normal variation.

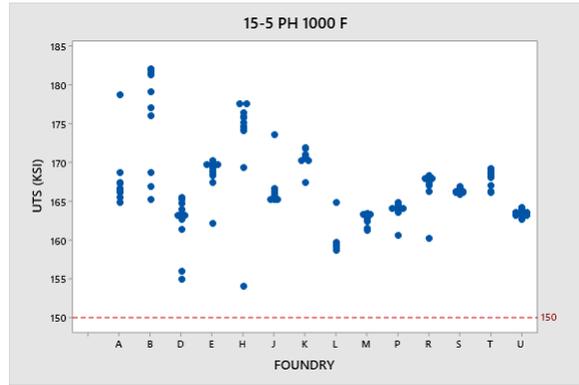


L: Probability plot of percent reduction in area standard deviations by foundry. No significant outliers beyond normal variation.

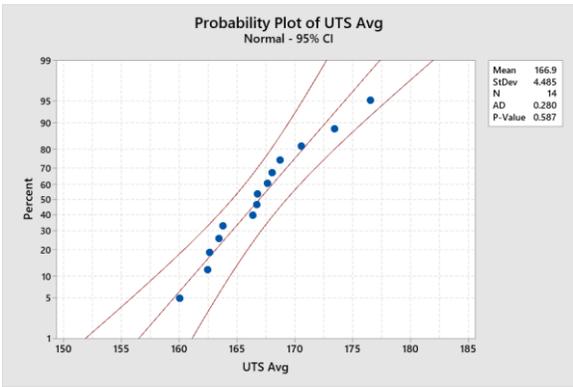
Figures 2A-P: 15-5 PH, 1000 F Age Confidence intervals, individual data plots, and normal probability plots for average and standard deviation of properties for each UTS, yield strength, percent elongation and percent reduction in area.



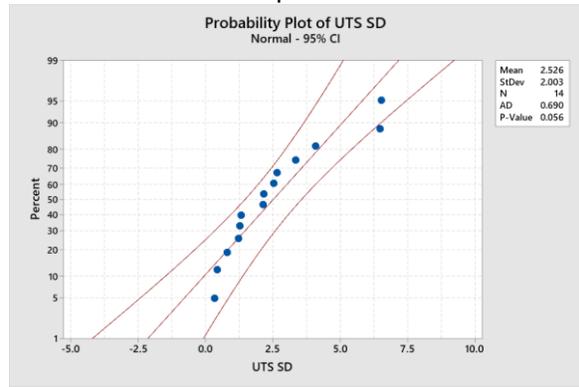
A: UTS Confidence intervals.



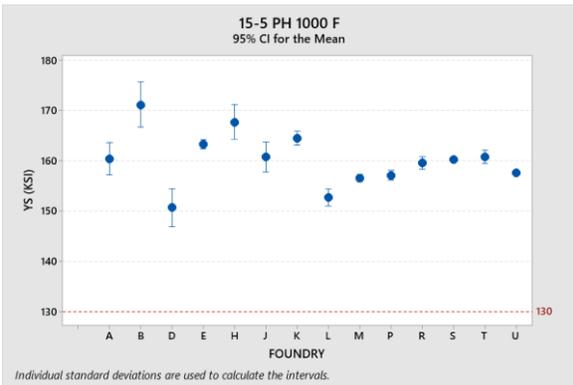
B: UTS Individual data plot.



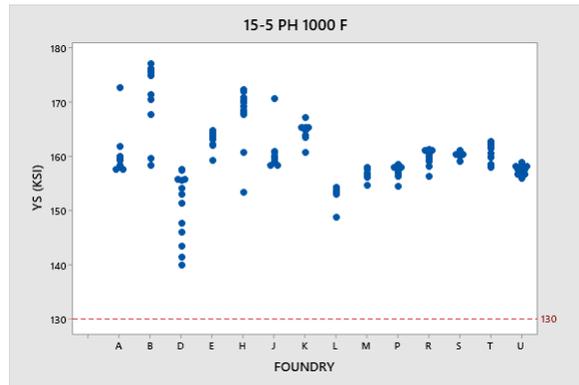
C: Probability plot of UTS averages for each foundry. No significant outliers beyond normal variation.



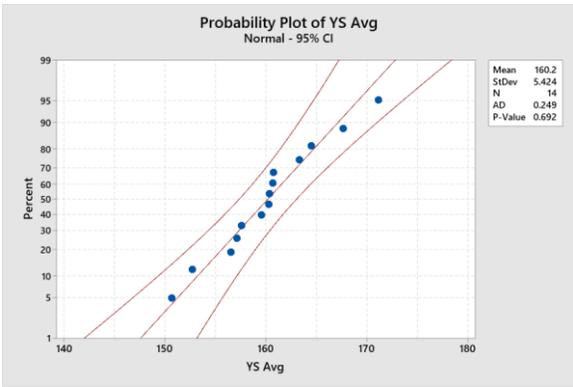
D: Probability plot of UTS standard deviations by foundry. No significant outliers beyond normal variation. The skewness is anomalous.



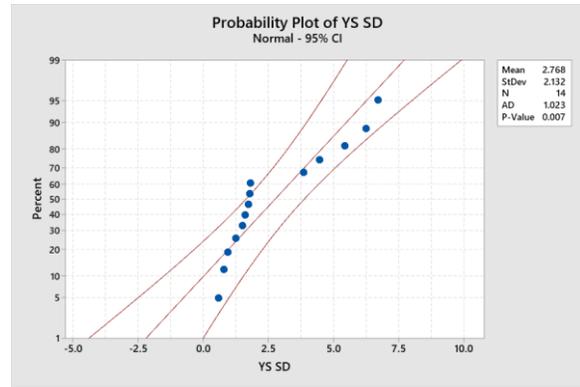
E: Yield strength confidence intervals.



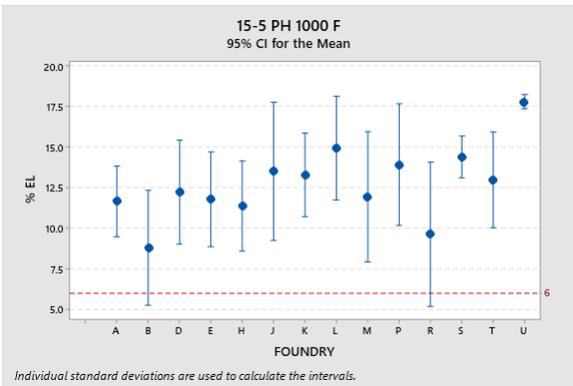
F: Yield strength individual plot. Note differences in variation.



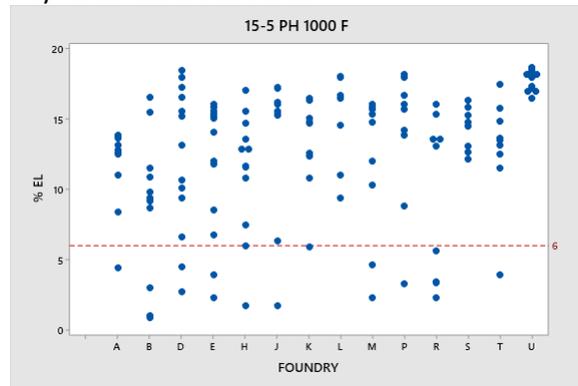
G: Probability plot of yield strength averages for each foundry. No significant outliers beyond normal variation. The skewness is anomalous.



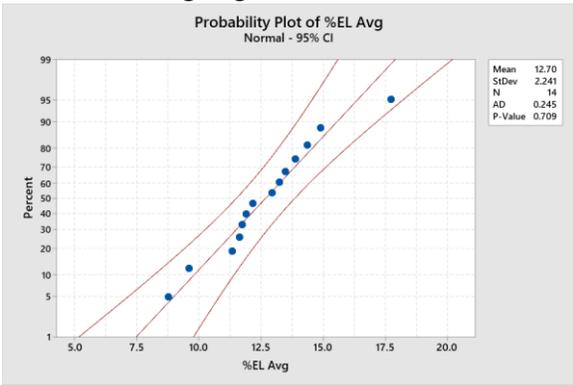
H: Probability plot of yield strength standard deviations by foundry. No significant outliers beyond normal variation.



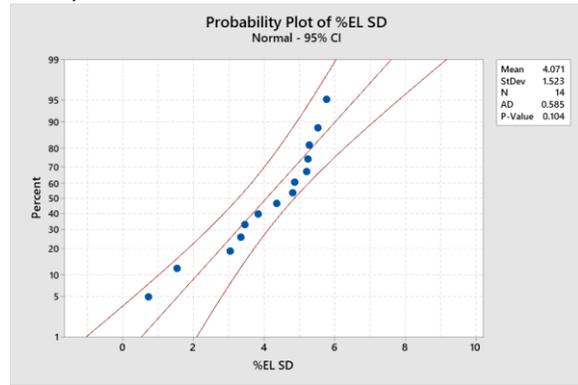
I: Percent elongation confidence intervals. Note some intervals going below the minimum limit.



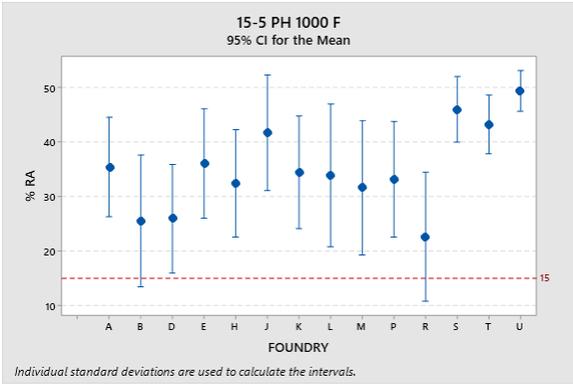
J: Percent elongation individual plot. Note many data points below standard.



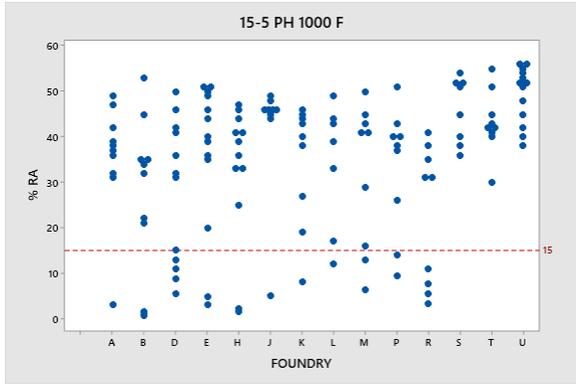
K: Probability plot of percent elongation averages for each foundry. No significant outliers beyond normal variation.



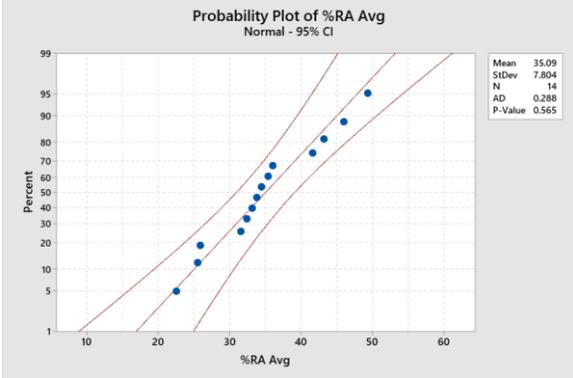
L: Probability plot of percent elongation standard deviations by foundry. No significant outliers beyond normal variation.



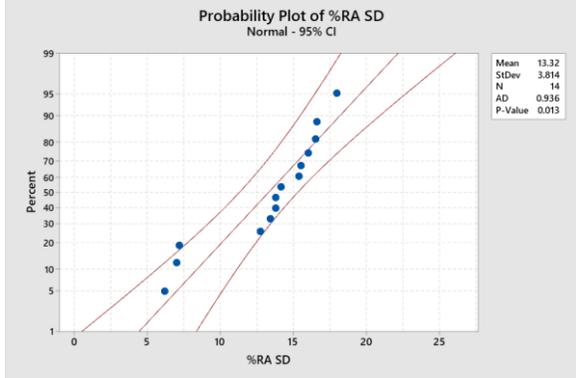
I: Percent reduction in area confidence intervals. Note some intervals going below the minimum limit.



J: Percent reduction in area individual plot. Note many data points below standard.

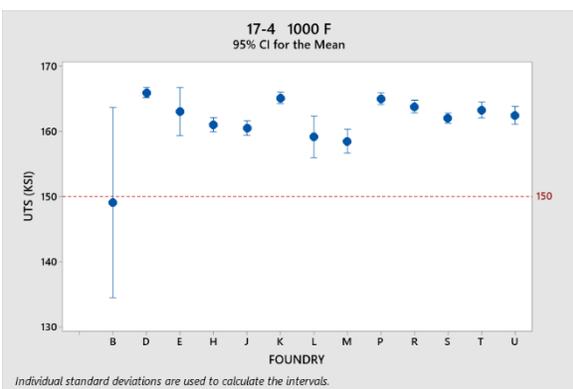


K: Probability plot of percent reduction in area averages for each foundry. No significant outliers beyond normal variation.

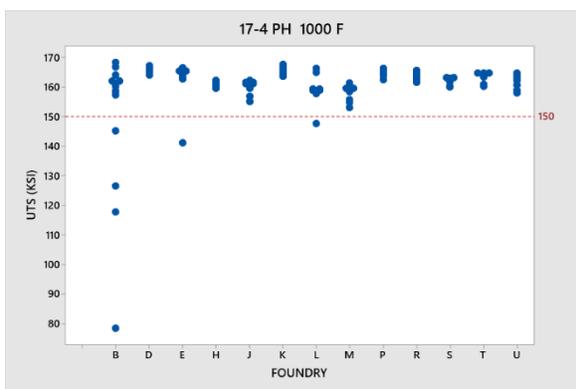


L: Probability plot of percent reduction in area standard deviations by foundry. Data is skewed, but no useful identifiable outliers.

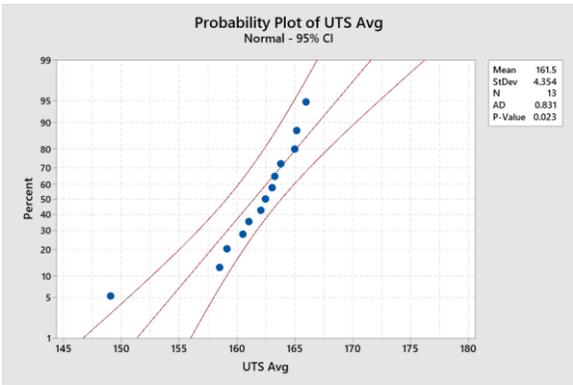
Figures 3A-P: 17-4 PH, 1000 F Age Confidence intervals, individual data plots, and normal probability plots for average and standard deviation of properties for each UTS, yield strength, percent elongation and percent reduction in area.



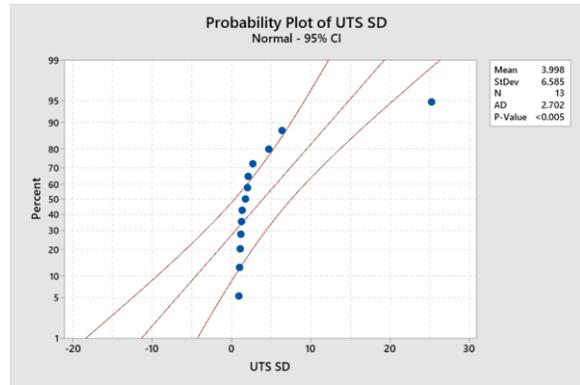
A: UTS Confidence intervals. Note some intervals going below the minimum limit.



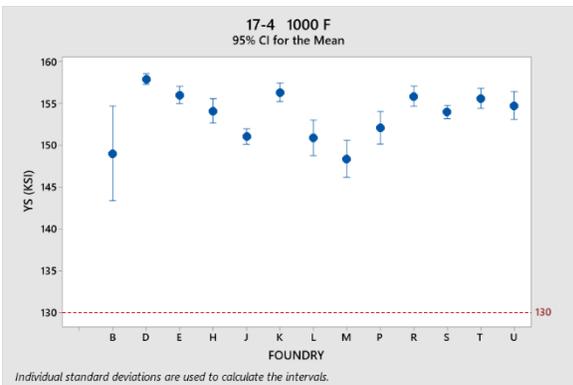
B: UTS Individual data plot. Note that generally the values below the specification appear to be outliers.



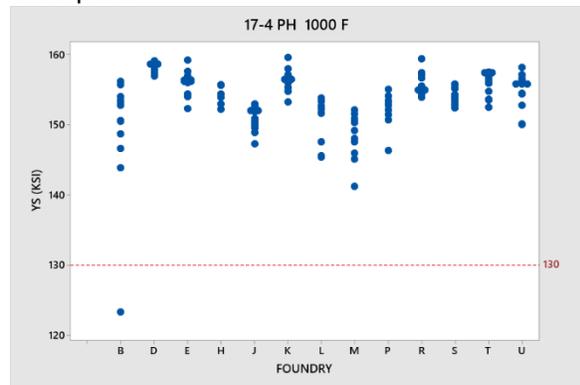
C: Probability plot of UTS averages for each foundry. One significant outliers beyond normal variation, however, below desired value.



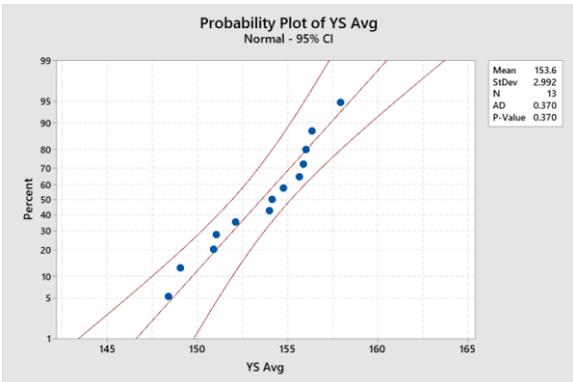
D: Probability plot of UTS standard deviations by foundry. One significant outliers beyond normal variation indicating more variation than anticipated.



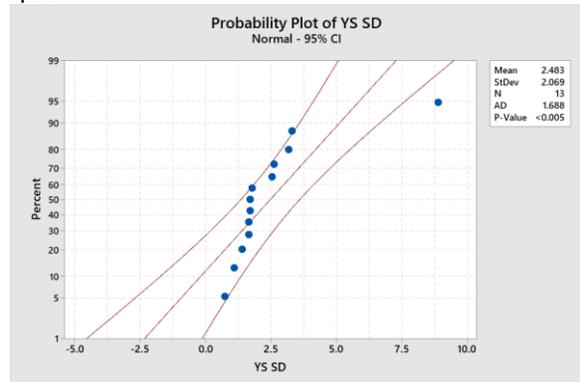
E: Yield strength confidence intervals.



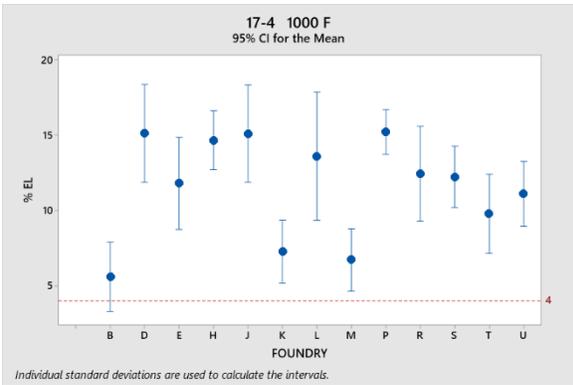
F: Yield strength individual plot. Note variation is quite uniform.



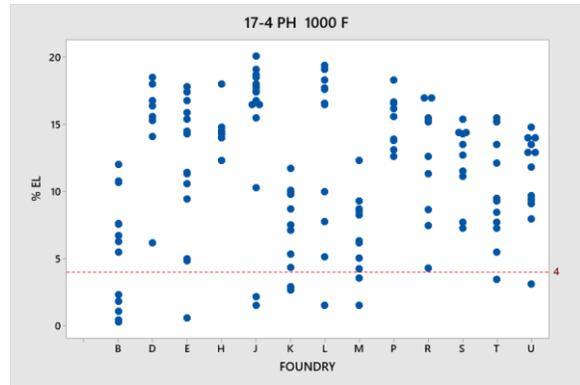
G: Probability plot of yield strength averages for each foundry. No significant outliers beyond normal variation.



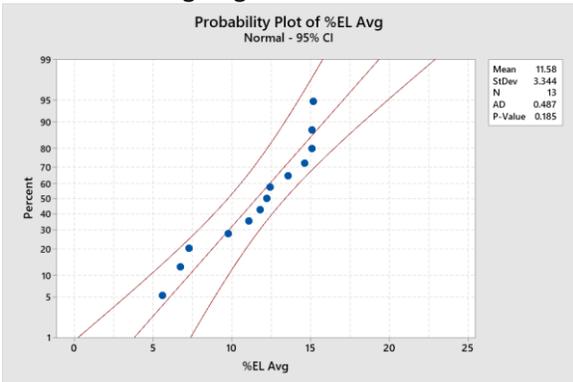
H: Probability plot of yield strength standard deviations by foundry. One significant outliers beyond normal variation indicating more variation than anticipated.



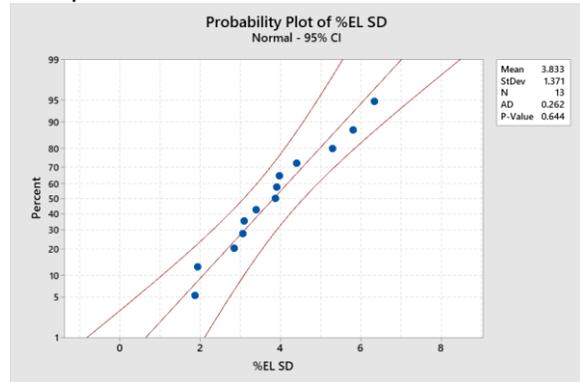
I: Percent elongation confidence intervals. Note some intervals going below the minimum limit.



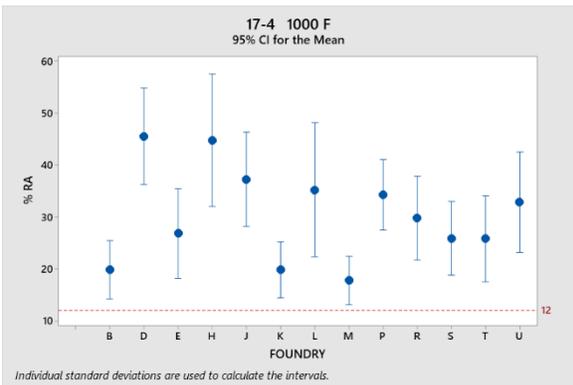
J: Percent elongation individual plot. Note many data points below standard.



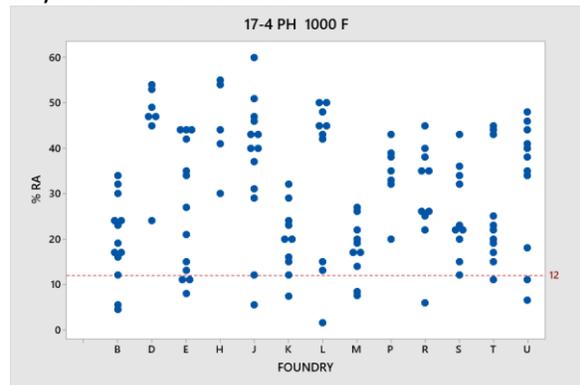
K: Probability plot of percent elongation averages for each foundry. No significant outliers beyond normal variation.



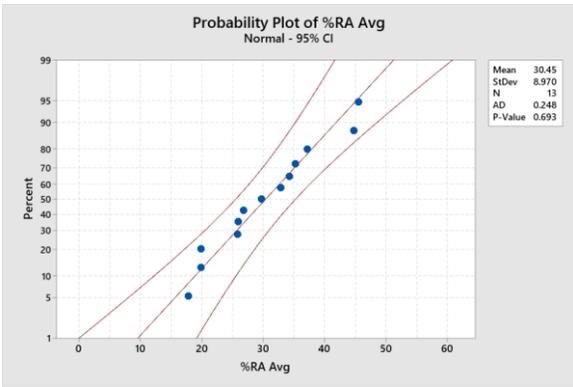
L: Probability plot of percent elongation standard deviations by foundry. No significant outliers beyond normal variation.



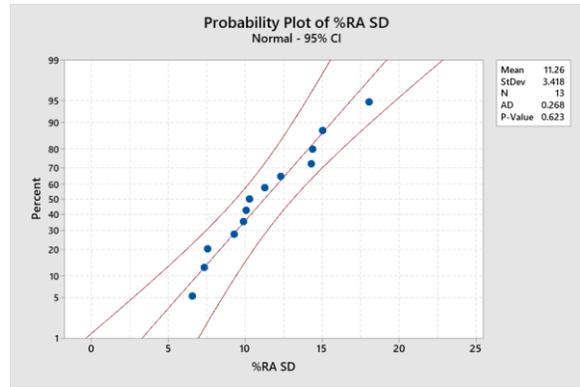
I: Percent reduction in area confidence intervals. Note no intervals going below the minimum limit but many values in the next graph.



J: Percent reduction in area individual plot. Note many data points below standard.

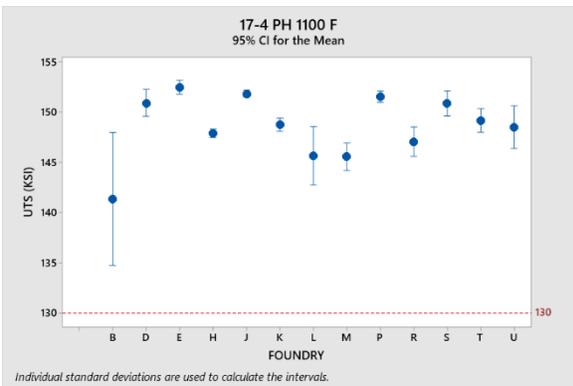


K: Probability plot of percent reduction in area averages for each foundry. No significant outliers beyond normal variation.

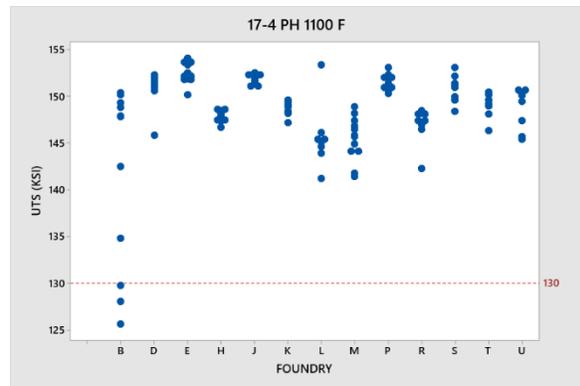


L: Probability plot of percent reduction in area standard deviations by foundry. No significant outliers beyond normal variation.

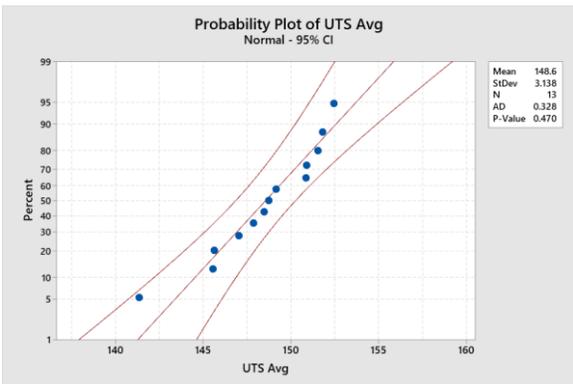
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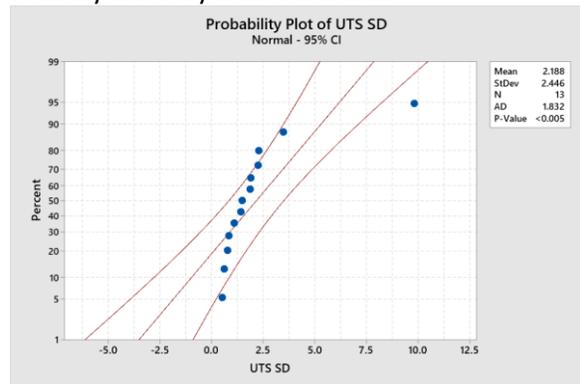
A: UTS Confidence intervals.



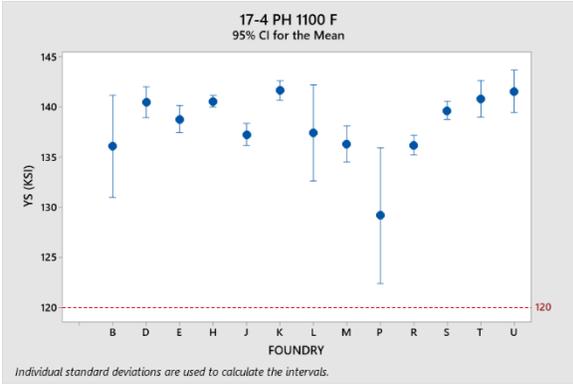
B: UTS Individual data plot. Note that one foundry has very wide variation.



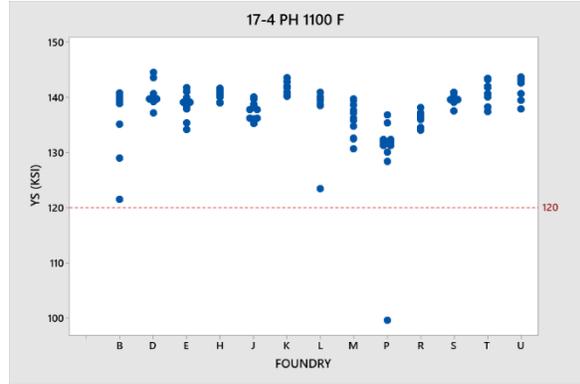
C: Probability plot of UTS averages for each foundry. No significant outliers beyond normal variation.



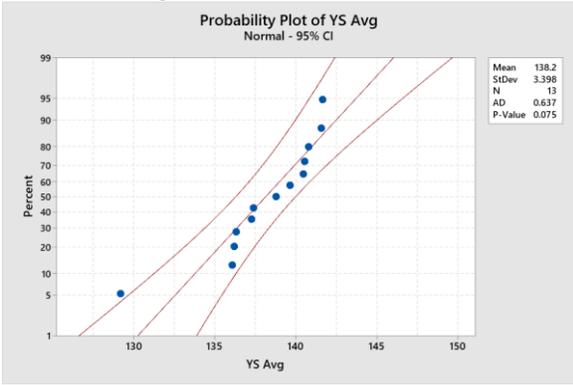
D: Probability plot of UTS standard deviations by foundry. One significant outliers beyond normal variation indicating more variation than anticipated compared to other foundries.



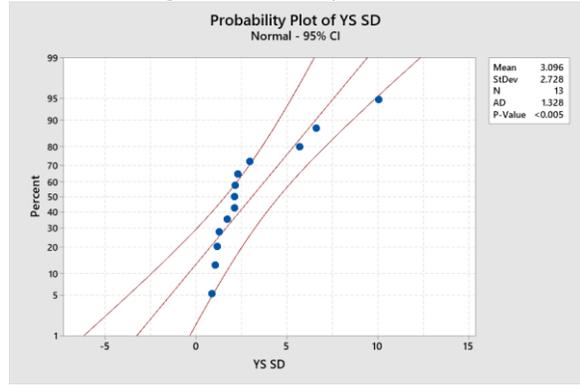
E: Yield strength confidence intervals.



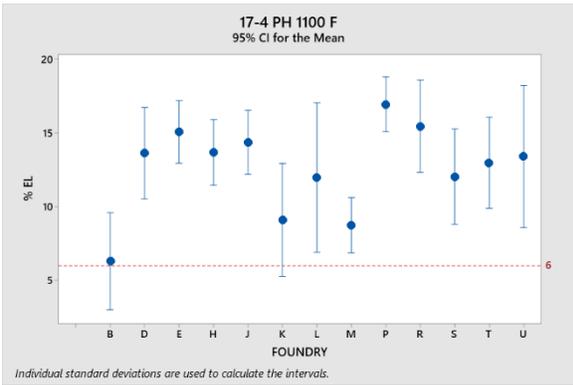
F: Yield strength individual plot.



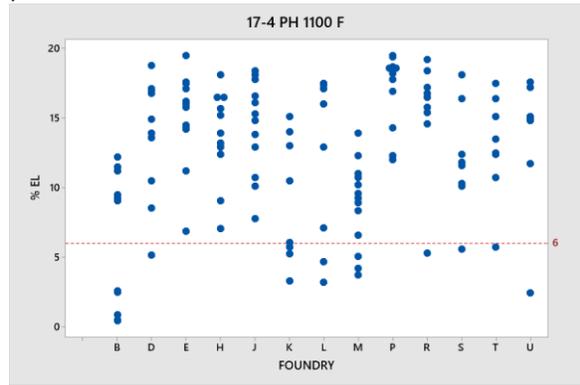
G: Probability plot of yield strength averages for each foundry. One significant outlier beyond normal variation on the low end.



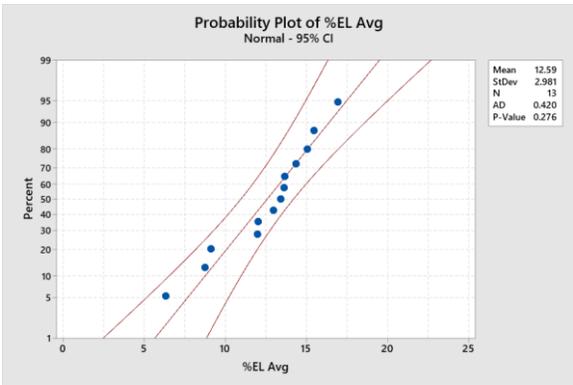
H: Probability plot of yield strength standard deviations by foundry. One significant outlier with higher normal variation than expected from peer foundries.



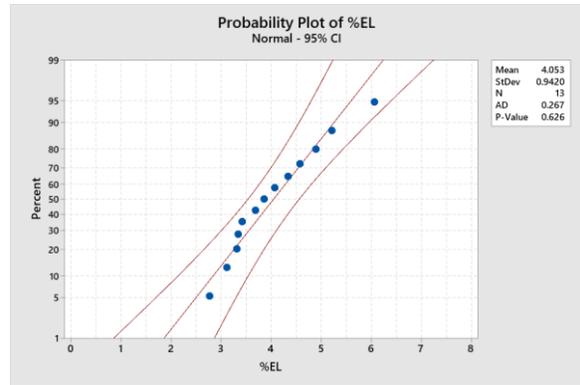
I: Percent elongation confidence intervals. Note some intervals going below the minimum limit.



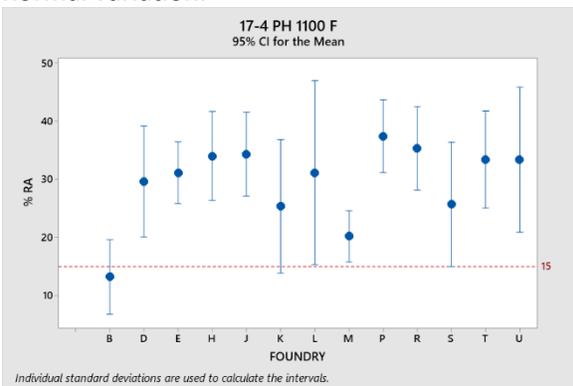
J: Percent elongation individual plot. Note many data points below standard.



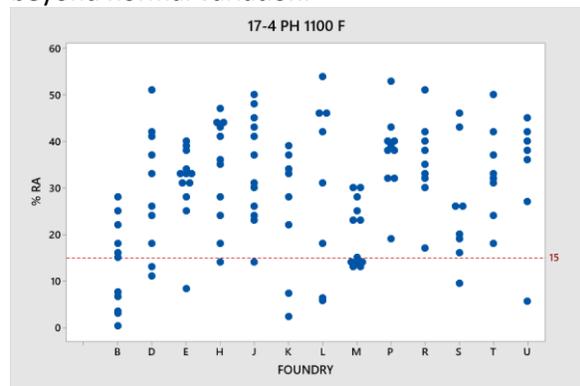
K: Probability plot of percent elongation averages for each foundry. No significant outliers beyond normal variation.



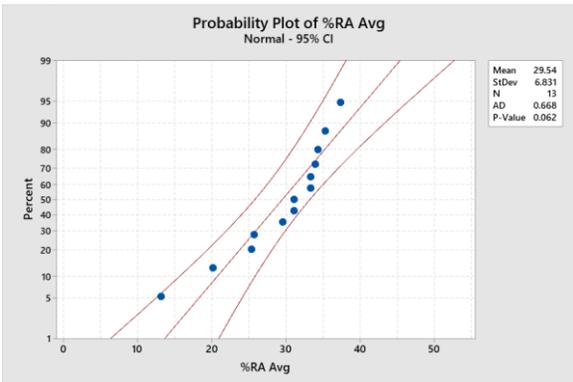
L: Probability plot of percent elongation standard deviations by foundry. No significant outliers beyond normal variation.



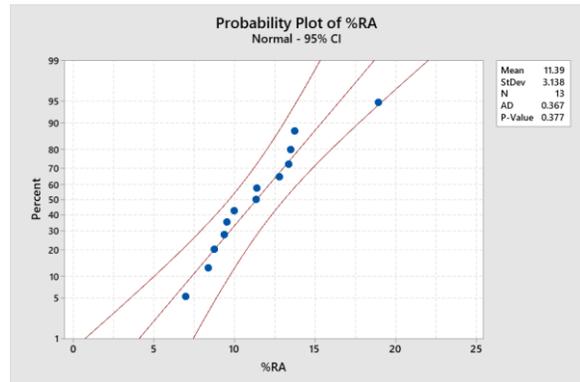
I: Percent reduction in area confidence intervals. Note some intervals going below the minimum limit.



J: Percent reduction in area individual plot. Note many data points below standard.



K: Probability plot of percent reduction in area averages for each foundry. No significant outliers beyond normal variation.



L: Probability plot of percent reduction in area standard deviations by foundry. No significant outliers beyond normal variation.