REPORT NO. 1080

Tensile Testing of Metals

Proficiency Testing Program

Round 11

May 2018

ACKNOWLEDGMENTS

PTA wishes to gratefully acknowledge the technical assistance provided for this program by Mr S Sameem, ARL Laboratory Services Pty Ltd. Also our thanks go to ARL Laboratory Services Pty Ltd, for the supply and homogeneity testing of the samples.

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CONTENTS

1. FOREWORD

This report summarises the results of a proficiency testing program on the tensile properties of metals. It constitutes the eleventh round of an ongoing series of programs.

Proficiency Testing Australia (PTA) conducted the testing program in March / April 2018. The aim of the program was to assess laboratories' ability to competently perform the nominated tests.

The Program Coordinator was Dr M Bunt. The Technical Adviser was Mr S Sameem, ARL Laboratory Services Pty Ltd. This report was authorised by Mrs F Watton, PTA Quality Manager.

2. FEATURES OF THE PROGRAM

(a) A total of 25 laboratories participated in the program, two of which did not return results for inclusion in the final report. Laboratories from the following countries received samples:

13	AUSTRALIA
6	NEW ZEALAND
1	BOTSWANA
1	ETHIOPIA
1	ITALY
1	PHILIPPINES
1	QATAR
1	SAUDI ARABIA

To ensure confidential treatment of results, each laboratory was allocated a unique code number. All reference to participants in this report is by allocated code numbers. Please note that the code numbers of some laboratories (with appended letters) could appear several times in the same data set.

(b) The results reported by participants are presented in Appendix A.

(c) Laboratories were provided with two identical carbon steel round bar samples. Both samples were approximately 400 mm in length and 14 mm in diameter. One laboratory tested round bar samples that were approximately 600 mm in length and 14 mm in diameter. One of the samples was to be machined, while the other was to be tested as a parallel specimen. Laboratories were asked to perform tests for:

- 0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$);
- Lower and Upper Yield Strength (ReL and ReH) if applicable;
- Tensile Strength (Rm);
- Percentage Elongation after Fracture (A%); and
- Percentage Reduction in Area after Fracture (Z%).

(d) All testing, recording and reporting was to be performed in accordance with the laboratory's routine test methods, but testing in accordance with AS 1391 or ISO 6892-1 were the preferred test methods.

(e) Laboratories were requested to perform the tests according to the *Instructions to Participants* provided and to record the results, along with an estimate of their measurement uncertainty (MU) for each result, on the accompanying *Results Sheet*, which was distributed with the samples. Copies of these documents appear in Appendix C.

(f) Prior to distribution, the samples were tested for homogeneity by ARL Laboratory Services Pty Ltd. Based on the results of this testing, the homogeneity of the samples was established (see Appendix B).

3. FORMAT OF THE APPENDICES

(a) Appendix A is divided into seven sections (A1-A7).

Sections A1-A6 contain the analysis of results reported by laboratories for 0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$), Lower Yield (ReL), Upper Yield (ReH), Tensile Strength (Rm), Percentage Elongation after Fracture (A%) and Percentage Reduction in Area after Fracture (Z%). These sections contain, where appropriate:

i) a table of results reported by laboratories for each test, with estimates of their MUs and calculated z-scores;
ii) a listing of the summary statistics;
iii) ordered z-score charts; and
iv) a Youden diagram.

Section A7 contains information on the methods used by laboratories and the results reported by laboratories for Tensile Specimen Diameter, Tensile Specimen Gauge Length, Elastic Stress or Strain Rate and Plastic Strain Rate.

(b) Appendix B contains details of the homogeneity testing.

(c) Appendix C contains copies of the *Instructions to Participants* and *Results Sheet*.

4. DESIGN OF THE PROGRAM

The summary statistics calculated for each test / sample consists of:

- *No. of Results*: the total number of results for that test/sample;
- *Median*: the middle value of the results;
- *Normalised IQR*: the normalised interquartile range of the results;
- *Uncertainty of the Median*: a robust estimate of the standard deviation of the *Median*;
- *Robust CV*: the robust coefficient of variation expressed as a percentage, *i.e.* 100 x *Normalised IQR* / *Median*;
- *Minimum*: the lowest laboratory result;
- *Maximum*: the highest laboratory result; and
- *Range*: the difference between the *Maximum* and *Minimum*.

The median is a measure of the centre of the data.

The normalised IQR is a measure of the spread of the results. It is calculated by multiplying the interquartile range (IQR) by a correction factor, which converts the IQR to an estimate of the standard deviation. The IQR is the difference between the upper and lower quartiles (*i.e.* the values above and below which a quarter of the results lie, respectively).

For normally distributed data, the uncertainty of the median is approximated by:

$$\sqrt{\frac{\pi}{2}} \times \frac{normIQR}{\sqrt{n}}$$

where *normIQR* is the normalised IQR and *n* is the number of results.

In order to assess laboratories' testing performance, a robust statistical approach, using z-scores, was utilised. Z-scores give a measure of how far a result is from the consensus value (*i.e.* the median), and gives a "score" to each result relative to the other results in the group.

A z-score with an absolute value less than or equal to 2.0 is considered to be satisfactory, whereas, a z-score with an absolute value greater than or equal to 3.0 is considered to be an outlier and is marked by the symbol "§". Laboratories are also encouraged to review results which have an absolute z-score value between 2.0 and 3.0 (*i.e.* 2.0 < |z-score| < 3.0). These results are considered to be questionable results.

Ordered z-score charts indicate each laboratory's robust z-score, in order of magnitude, marked with its laboratory code number. From these charts, each laboratory can readily compare its performance relative to the other laboratories.

The ordered z-score charts in Appendix A are limited on the vertical axis to +3.0 and -3.0, so that outliers are clearly identifiable as those laboratories whose "bar" extends beyond the chart boundary.

Youden two-sample diagrams are presented to highlight laboratory systematic differences. They are based on a plot of each laboratory's pair of results (*i.e.* sample 2 versus sample 1) and represented by a black spot.

These diagrams also feature an approximate 95% confidence ellipse for the bivariate analysis of the results, and dashed lines which mark the median value for each of the samples.

All points which lie outside the ellipse are labelled with the laboratory's code number. Note, however, that these points may not correspond with those identified as outliers. This is because the outlier criteria ($|z\text{-score}| \geq 3.0$) has a confidence level of approximately 99%, whereas the ellipse is an approximate 95% confidence region.

The points outside the ellipse on the Youden diagram roughly correspond to those with z-scores greater than 2.0 or less than -2.0. Laboratories which are outside the ellipse but have not been identified as outliers (*i.e.* have $2.0 < |z\text{-score}| < 3.0$) are encouraged to review their results.

As a guide to the interpretation of these diagrams:

(i) Laboratories with significant systematic error components (*i.e.* between-laboratory variation) will usually have results outside the ellipse in either the upper right hand quadrant (as formed by the median lines) or the lower left hand quadrant (*i.e.* unusually high or low results for both samples); and

(ii) Laboratories with significant random error components (*i.e.* within-laboratory variation) will have returned results that are substantially more variable than other participants, and these results will usually lie outside the ellipse in either the upper left or lower right hand quadrants (*i.e.* an unusually high result for one sample and low for the other).

For further details on the calculation and interpretation of robust z-scores and ordered z-score charts and the construction and interpretation of Youden diagrams, please see the *Guide to Proficiency Testing Australia (2016)*.

5. OUTLIER RESULTS

The following table summarises the results submitted by participants for the program.

Table A: Summary Statistics for All Tests

Test	Summary Statistics	Sample 1	Sample 2
0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$) (MPa)	Number of Results	22	24
	Median	315.0	319.5
	Normalised IQR	8.0	8.2
	Uncertainty (Median)	2.1	2.1
Lower Yield (ReL) (MPa)	Number of Results	20	23
	Median	310.0	312.0
	Normalised IQR	9.3	9.6
	Uncertainty (Median)	2.6	2.5
Upper Yield (ReH) (MPa)	Number of Results	19	22
	Median	335.0	327.0
	Normalised IQR	25.2	13.7
	Uncertainty (Median)	7.2	3.7
Tensile Strength (Rm) (MPa)	Number of Results	25	28
	Median	449.0	444.5
	Normalised IQR	8.2	9.5
	Uncertainty (Median)	2.0	2.2
Percentage Elongation after Fracture (A%) 400 mm Length Samples	Number of Results	25	22
	Median	35.9	38.2
	Normalised IQR	2.2	3.1
	Uncertainty (Median)	0.6	0.8
Percentage Elongation after Fracture (A%) 600 mm Length Samples	Number of Results	0	6
	Median	n/a	29.5
	Normalised IQR	n/a	14.4
	Uncertainty (Median)	n/a	7.3
Percentage Reduction in Area after Fracture (Z%)	Number of Results	25	28
	Median	70.0	71.0
	Normalised IQR	3.0	2.2
	Uncertainty (Median)	0.7	0.5

Table B: Summary of Statistical Outliers
(by laboratory code number)

Test	Sample 1	Sample 2
0.2% Proof Stress	-	3B, 4, 23B
Lower Yield	19D, 21	4, 19D, 23B, 24A
Upper Yield	-	-
Tensile Strength	20, 21	4, 24A, 24B
Percentage Elongation after Fracture (400 mm)	3B, 8	-
Percentage Elongation after Fracture (600 mm)		23A, 23B
Percentage Reduction in Area after Fracture	11, 19D	11, 19D, 23A, 23B

Notes:

1. For each test, the results for all test methods were pooled for analysis.

2. Summary statistics and z-scores for Percentage Elongation after Fracture were calculated by converting the results to a proportional gauge length.

3. The summary statistics and z-scores for Percentage Elongation after Fracture were calculated separately for the samples that were 400 mm and 600 mm in length.

4. A target CV of 10.0% was used to calculate the robust z-scores for Percentage Elongation after Fracture for the samples that were 600 mm in length.

6. PTA AND TECHNICAL ADVISER'S COMMENTS

Consensus values (medians), derived from participants' results, are used as the assigned values in this program. These values are not metrologically traceable to an external reference. The summary statistics, uncertainties of the assigned values and outliers, for each of the tests, are reported in Tables A and B on the previous pages. Complete details of the statistical analyses appear in Appendix A.

6.1 Return rate

Twenty-three of the 25 laboratories (92%) that participated in the program returned results. Of the 23 laboratories that submitted results for the program, the return rate for all tests is as follows:

• 0.2% Proof Stress	20 out of 23	87%
• Lower Yield	20 out of 23	87%
• Upper Yield	19 out of 23	83%
• Tensile Strength	23 out of 23	100%
• Percentage Elongation after Fracture	23 out of 23	100%
• Percentage Reduction in Area after Fracture	23 out of 23	100%

6.2 Performance summary

One or more statistical outliers were reported by nine of the 23 laboratories (39%) that returned results for this round of the program. The last round of the Tensile Testing of Metals program where participants tested two steel round bar samples was Round 9. For comparison, 15% of the participants reported outlier results in Round 9 of the Tensile Testing of Metals program (see Report No. 967 for more details).

A total of 285 results were analysed in this round of the program. Of these results, twenty-four (8%) were outliers. For comparison, 7% of the results analysed in Round 9 of the Tensile Testing of Metals program were outliers (see Report No. 967 for more details).

6.3 0.2% Proof Stress

Of the 20 laboratories that tested the samples for 0.2% Proof Stress, 15 laboratories tested using AS 1391, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using ISO 6892-1. One laboratory used both AS 1391 and ISO 6892-1. One laboratory used the ASTM A370 method (see Appendix A7 for more details).

For the laboratories that used the AS 1391 method for sample 1, the median and standard error of the 0.2% Proof Stress results was 316.0 ± 1.7 MPa. For all methods pooled, the median and standard error of the 0.2% Proof Stress results for sample 1 was 315.0 ± 2.1 MPa.

For the laboratories that used the AS 1391 method for sample 2, the median and standard error of the 0.2% Proof Stress results was 319.5 ± 2.1 MPa. For all methods pooled, the median and standard error of the 0.2% Proof Stress results for sample 2 was 319.5 ± 2.1 MPa.

The methods were pooled when analysing the results for both samples.

There were no outliers reported for sample 1. Three laboratories (codes 3B, 4 and 23B) reported outlier results for sample 2. One laboratory (code 27) obtained an absolute z-score between 2.0 and 3.0 for sample 1. Three laboratories (codes 20, 23A and 25) obtained absolute z-scores between 2.0 and 3.0 for sample 2.

The outlier result for laboratory 3B for sample 2 may be due to not achieving the correct setting on the displacement / strain prior to testing. This is evident from the Tensile Strength reported by this laboratory being within the acceptable statistical limits. The load-displacement curve for this laboratory may have been shifted towards the positive displacement (+X axis).

The robust CVs for the 0.2% Proof Stress results were 2.5% and 2.6% for sample 1 and sample 2, respectively. The last round of this program where the 0.2% Proof Stress results for a round bar sample were analysed was Round 7. In Round 7 of this program, only one of the samples was a round bar. The robust CV obtained for this sample was 2.2%, which compares well with the robust CV values obtained in this round of the program (see Report No. 901 for more details).

Nineteen laboratories reported measurement uncertainties associated with their 0.2% Proof Stress test results in this round.

6.4 Lower Yield

Of the 20 laboratories that tested the samples for Lower Yield, 14 laboratories tested using AS 1391, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using ISO 6892-1. One laboratory used both AS 1391 and ISO 6892-1. One laboratory used the ASTM A370 method. One laboratory did not specify the method that they used for testing (see Appendix A7 for more details).

For the laboratories that used the AS 1391 method for sample 1, the median and standard error of the Lower Yield results was 310.0 ± 2.0 MPa. For all methods pooled, the median and standard error of the Lower Yield results for sample 1 was 310.0 ± 2.6 MPa.

For the laboratories that used the AS 1391 method for sample 2, the median and standard error of the Lower Yield results was 311.5 ± 1.9 MPa. For all methods pooled, the median and standard error of the Lower Yield results for sample 2 was 312.0 ± 2.5 MPa.

The methods were pooled when analysing the results for both samples.

Two laboratories (codes 19D and 21) reported outlier results for sample 1. Four laboratories (codes 4, 19D, 23B and 24A) reported outlier results for sample 2. Two laboratories (codes 23A and 24B) obtained absolute z-scores between 2.0 and 3.0 for sample 2.

The outlier results for laboratory 19D for both samples suggest a typographical error in reporting. This is evident from their other reported strength results all being within the statistically acceptable limits.

Both of the results reported by laboratory 23 for sample 2 are high, with the result for laboratory 23B being an outlier and the result of laboratory 23A obtaining an absolute z-score between 2.0 and 3.0. This is also the case for the 0.2% Proof Stress results reported by this laboratory. This suggests that the load-displacement curve for this laboratory may have been shifted towards the positive load (+Y Axis).

The robust CVs for the Lower Yield results were 3.0% and 3.1% for sample 1 and sample 2, respectively. This is the first round of the program where participants have been asked to report Lower Yield results for round bar samples, so these robust CV values cannot be compared to previous results.

Seventeen laboratories reported measurement uncertainties associated with their Lower Yield test results in this round.

6.5 Upper Yield

Of the 19 laboratories that tested the samples for Upper Yield, 13 laboratories tested using AS 1391, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using ISO 6892-1. One laboratory used both AS 1391 and ISO 6892-1. One laboratory used the ASTM A370 method. One laboratory did not specify the method that they used for testing (see Appendix A7 for more details).

For the laboratories that used the AS 1391 method for sample 1, the median and standard error of the Upper Yield results was 333.5 ± 6.6 MPa. For all methods pooled, the median and standard error of the Upper Yield results for sample 1 was 335.0 ± 7.2 MPa.

For the laboratories that used the AS 1391 method for sample 2, the median and standard error of the Upper Yield results was 325.0 ± 2.9 MPa. For all methods pooled, the median and standard error of the Upper Yield results for sample 2 was 327.0 ± 3.7 MPa.

The methods were pooled when analysing the results for both samples.

There were no outliers reported for either sample. Two laboratories (codes 13 and 24A) obtained absolute z-scores between 2.0 and 3.0 for sample 2.

The robust CVs for the Upper Yield results were 7.5% and 4.2% for sample 1 and sample 2, respectively. This is the first round of the program where participants have been asked to report Upper Yield results for round bar samples, so these robust CV values cannot be compared to previous results. However, the robust CVs for Upper Yield are higher than the robust CVs for Lower Yield, especially for the machined sample (sample 1). This wide range in the reported Upper Yield results was to be expected, since Upper Yield strength measurements are very sensitive to sample preparation, alignment of the specimen in the tensile machine, straining rate and machine stiffness.

Sixteen laboratories reported measurement uncertainties associated with their Upper Yield test results in this round.

6.6 Tensile Strength

A total of 23 laboratories tested the samples for Tensile Strength. Of these laboratories, 16 tested using the AS 1391 method, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using the ISO 6892-1 method. One laboratory used both AS 1391 and ISO 6892-1. Two laboratories used the ASTM A370 method. One laboratory did not specify the method that they used for testing (see Appendix A7 for more details).

For the laboratories that used the AS 1391 method for sample 1, the median and standard error of the Tensile Strength results was 449.0 ± 2.2 MPa. For all methods pooled, the median and standard error of the Tensile Strength results for sample 1 was 449.0 ± 2.0 MPa.

For the laboratories that used the AS 1391 method for sample 2, the median and standard error of the Tensile Strength results was 441.5 ± 2.3 MPa. For all methods pooled, the median and standard error of the Tensile Strength results for sample 2 was 444.5 ± 2.2 MPa.

The methods were pooled when analysing the results for both samples.

Two laboratories (codes 20 and 21) reported outlier results for sample 1. Three laboratories (codes 4, 24A and 24B) reported outlier results for sample 2. One laboratory (code 25) obtained an absolute z-score between 2.0 and 3.0 for sample 2.

The outlier result for laboratory 4 for sample 2 suggests that the load / force setting was not zeroed in prior to testing. This is also evident from the low results reported by laboratory 4 for sample 2 for 0.2% Proof Stress and Lower and Upper Yield (most of these results were also outliers). The load-displacement curve for this laboratory may have been shifted towards the negative load (-Y Axis). A similar trend can also observed for the results for laboratory 20 for sample 1. This suggests that the load-displacement curve may have also been shifted towards the negative load (-Y Axis) for this laboratory.

The outlier results for laboratory 21 for sample 1 and both of the results for laboratory 24 for sample 2 suggest a load / force setting that is the opposite of that for laboratory 4, as discussed above. The high results reported by these laboratories, which can also be observed in their other reported strength results, indicate that the load-displacement curve may have been shifted towards the positive load (+Y Axis) for these laboratories.

The robust CVs for the Tensile Strength results were 1.8% and 2.1% for sample 1 and sample 2, respectively. These values are lower than the values of 2.8% and 4.0%, obtained for the Tensile Strength results for Round 9 of this program (see Report No. 967 for more details).

Twenty-one laboratories reported measurement uncertainties associated with their Tensile Strength test results in this round.

6.7 Percentage Elongation after Fracture

A total of 23 laboratories tested the samples for Percentage Elongation after Fracture. Of these laboratories, 16 tested using the AS 1391 method, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using the ISO 6892-1 method. One laboratory used both AS 1391 and ISO 6892-1. Two laboratories used the ASTM A370 method. One laboratory did not specify the method that they used for testing (see Appendix A7 for more details).

Because the participants employed different gauge diameters and different gauge lengths for their tensile testing in this program, it was necessary to convert the Percentage Elongation after Fracture results submitted by the participants to a proportional gauge length of $5.65 \sqrt{S_0}$ (5.65 times the square root of the original cross-sectional area). The results were converted to a proportional gauge length using the formula of ISO 2566-1. These results are displayed in Appendix A5. The exact formula used to convert the results is given on page A5.3 of Appendix A5.

One of the participants in this round of the program (laboratory 23) tested samples that were approximately 600 mm in length. While the homogeneity testing, performed by ARL Laboratory Services Pty Ltd, did not indicate any significant differences between the 400 mm length samples and the 600 mm length samples for any of the other tests performed in this program, there was a significant difference found between the 400 mm length samples and the 600 mm length samples for Percentage Elongation after Fracture. Therefore, the Percentage Elongation after Fracture results were analysed separately for the different length samples. The results submitted by laboratory 23 for Percentage Elongation after Fracture were compared to the homogeneity testing results in order to calculate their z-scores for the 600 mm length samples (please see Appendix B for more details).

For the 400 mm length samples, for the laboratories that used the AS 1391 method for sample 1, the median and standard error of the Percentage Elongation after Fracture results (converted to a proportional gauge length) was 35.9 ± 0.4%. For all methods pooled, the median and standard error of the Percentage Elongation after Fracture results (converted to a proportional gauge length) for sample 1 was 35.9 ± 0.6%.

For the 400 mm length samples, for the laboratories that used the AS 1391 method for sample 2, the median and standard error of the Percentage Elongation after Fracture results (converted to a proportional gauge length) was 38.2 ± 1.2%. For all methods pooled, the median and standard error of the Percentage Elongation after Fracture results (converted to a proportional gauge length) for sample 2 was 38.2 ± 0.8%.

The methods were pooled when analysing the results for both samples.

For the 400 mm length samples, two laboratories (codes 3B and 8) reported outlier results for sample 1. There were no outliers reported for sample 2. One laboratory (code 19D) obtained an absolute z-score between 2.0 and 3.0 for sample 1.

The low result reported by laboratory 3B for sample 1 may be due to improper measuring techniques or using equipment that is not calibrated and verified appropriately.

The high result reported by laboratory 8 for sample 1 might have been within the acceptable limits if, perhaps, the correct techniques and equipment were used.

The robust CVs for the Percentage Elongation after Fracture results for the 400 mm length samples were 6.2% and 8.0% for sample 1 and sample 2, respectively. These values are lower than the values of 9.5% and 10.7%, obtained for the Percentage Elongation after Fracture results for Round 9 of this program (see Report No. 967 for more details).

For the 600 mm length samples, laboratory 23 did not machine their samples. This laboratory reported two Percentage Elongation after Fracture results, denoted by the laboratory codes 23A and 23B. Both of these results were outliers.

Although welding has had an effect on Percentage Elongation after Fracture, as observed from the homogeneity test results carried out by ARL Laboratory Services Pty Ltd (see Appendix B), the very low results reported by laboratory 23 suggest that incorrect techniques or equipment were used.

The robust CV for the Percentage Elongation after Fracture results for the 600 mm length samples was 48.6% for sample 2. This value was considered to be inappropriate to evaluate the performance of laboratory 23 in this round, so a target CV was used to calculate the z-scores for sample 2. The target CV chosen was 10.0%.

Twenty-two laboratories reported measurement uncertainties associated with their Percentage Elongation after Fracture test results in this round.

6.8 Percentage Reduction in Area after Fracture

A total of 23 laboratories tested the samples for Percentage Reduction in Area after Fracture. Of these laboratories, 16 tested using the AS 1391 method, including one laboratory that submitted four sets of results and one laboratory that submitted two sets of results. Three laboratories tested using the ISO 6892-1 method. One laboratory used both AS 1391 and ISO 6892-1. Two laboratories used the ASTM A370 method. One laboratory did not specify the method that they used for testing (see Appendix A7 for more details).

For the laboratories that used the AS 1391 method for sample 1, the median and standard error of the Percentage Reduction in Area after Fracture results was 70.0 ± 0.8%. For all methods pooled, the median and standard error of the Percentage Reduction in Area after Fracture results for sample 1 was 70.0 ± 0.7%.

For the laboratories that used the AS 1391 method for sample 2, the median and standard error of the Percentage Reduction in Area after Fracture results was 71.0 ± 0.5%. For all methods pooled, the median and standard error of the Percentage Reduction in Area after Fracture results for sample 2 was 71.0 ± 0.5%.

The methods were pooled when analysing the results for both samples.

Two laboratories (codes 11 and 19D) reported outlier results for sample 1. Four laboratories (codes 11, 19D, 23A and 23B) reported outlier results for sample 2.

The low results reported by laboratories 11, 19D, 23A and 23B indicate that the correct methodology for measuring this property was not applied by these participants. Although there are not many graphical illustrations of this property in online resources, materials published by ASM (American Society of Materials) are highly encouraged to be studied.

After issuing the summary sheets for this program, laboratory 11 contacted PTA to report that their outliers for Percentage Reduction in Area after Fracture for both samples were due to data entry and calculation errors.

The robust CVs for the Percentage Reduction in Area after Fracture results were 4.2% and 3.1% for sample 1 and sample 2, respectively. These values compare well with the values of 3.5% and 4.0%, obtained for the Percentage Elongation after Fracture results for Round 9 of this program (see Report No. 967 for more details).

Twenty-two laboratories reported measurement uncertainties associated with their Percentage Reduction in Area after Fracture test results in this round.

6.9 Measurement Uncertainty

The majority of participants in this round (84% – 96%) reported estimates of the measurement uncertainty associated with their results. The number and percentage of laboratories that reported estimates of their measurement uncertainty for each test is as follows:

• 0.2% Proof Stress	19 out of 20	95%
• Lower Yield	17 out of 20	85%
• Upper Yield	16 out of 19	84%
• Tensile Strength	21 out of 23	91%
• Percentage Elongation after Fracture	22 out of 23	96%
• Percentage Reduction in Area after Fracture	22 out of 23	96%

Any laboratories that reported a measurement uncertainty less than two times the uncertainty of the median may have underestimated their measurement uncertainty.

Any laboratories that reported a measurement uncertainty greater than three times the normalised IQR may have overestimated their measurement uncertainty.

All the participants are highly encouraged to report and use measurement uncertainty, so that the program analysis can provide a better outlook of the overall performance for this program. An approach, such as that described in AS 1391 Appendix H, “An Error Budget”, to the estimation of the measurement uncertainty in tensile testing is an example of an approach that could be followed.

6.10 Other Reported Results

In addition to reporting results for 0.2% Proof Stress, Lower Yield, Upper Yield, Tensile Strength, Percentage Elongation after Fracture and Percentage Reduction in Area after Fracture, participants were also asked to report the Tensile Specimen Diameter, Tensile Specimen Gauge Length, Elastic Stress or Strain Rate and Plastic Strain Rate. The details reported by each of the participants are displayed in Appendix A7.

It is highly recommended that all of the participants report all of this necessary information, in order to better analyse the test results. The Tensile Specimen Diameter and Tensile Specimen Gauge Length are required in order to convert the Percentage Elongation after Fracture results to a proportional gauge length, while the loading rates (both stress and strain rates) can be reviewed for any abnormal test results. The loading rates are particularly important when comparing test results for elongation and yield strength, as the loading rates can affect these properties.

6.11 General Comments

The aim of this round of the program was to determine the capabilities and proficiency of the participating laboratories in comparing and understanding the role of specimen geometry on the tensile properties of the materials.

The overall performance of the participating laboratories in this round was not as good as it has been in previous rounds. Compared to Round 9, there were more participants that reported outliers, although the total number of reported outlier results has only increased by 1%. Participating in proficiency testing programs is very important for laboratories, as it can assist them tremendously in identifying any weaknesses in their systems that may be present and it allows them to improve their overall technical competency and proficiency.

Following feedback from Round 10 of this program, all of the results reported by the participants in this round of the program were analysed exactly as they were reported, except when PTA received notification otherwise. Laboratories 23 and 24, for example, both informed PTA that they did not machine their samples, which is why both the results reported by these laboratories were analysed as sample 2 results. From examination of the Tensile Specimen Diameters and the Tensile Specimen Gauge Lengths reported, it is likely that laboratory 13 machined both of their samples, but PTA did not receive notification of this. Participants should be aware that there may be differences between the results for the machined and parallel samples. By not reporting if both samples were machined, or not machined, participants run the risk that results for machined samples will be analysed against the results for parallel samples and vice versa. This could lead to outliers being obtained that might not have occurred if PTA had been properly notified.

7. REFERENCES

1. *Guide to Proficiency Testing Australia (2016)*. (This document is located on the PTA website at www.pta.asn.au under Programs / Documents).

2. AS 1391 (2007) – *Metallic materials – Tensile testing at ambient temperature.*

3. ISO 6892-1 (2016) – *Metallic materials – Tensile testing – Part 1: Method of test at room temperature.*

4. *ISO 2566-1 (1984) – Steel – Conversion of elongation values – Part 1: Carbon and low alloy steels.*

5. ASTM A370 – *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*.

APPENDIX A

Summary of Results

Section A1

0.2% Proof Stress

A1.1

0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$) (MPa) – Results and Z-Scores

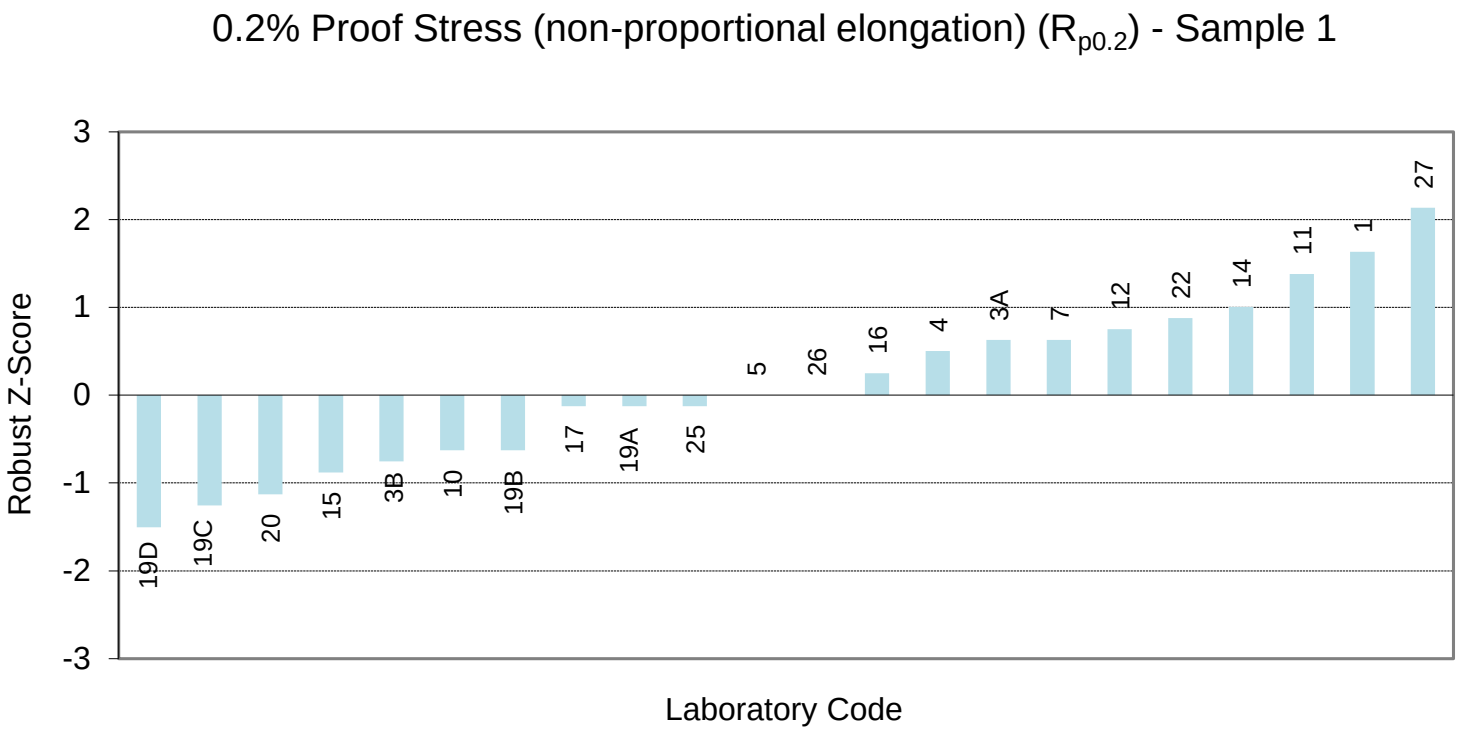
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	328	2%	1.63	319	2%	-0.06
3A	320	3%	0.63	316	3%	-0.43
3B	309	3%	-0.75	369	3%	6.07 **§**
4	319	0.13%	0.50	290	0.13%	-3.62 **§**
5	315	2.2	0.00	323	2.3	0.43
7	320	1	0.63	317	1	-0.31
10	310	17	-0.63	308	17	-1.41
11	326	-	1.38	320	-	0.06
12	321	3	0.75	320	3	0.06
14	323	8.3	1.00	-	-	-
15	308	6.4	-0.88	324	2.8	0.55
16	317	4.30	0.25	325	4.80	0.67
17	314	5	-0.13	319	4	-0.06
19A	314	-	-0.13	306	-	-1.66
19B	310	3.2	-0.63	312	3.2	-0.92
19C	305	3.2	-1.25	315	3.2	-0.55
19D	303	-	-1.51	311	-	-1.04
20	306.0	8.0	-1.13	300.0	8.0	-2.39
22	322	15	0.88	325	15	0.67
23A	-	-	-	341	3	2.64
23B	-	-	-	350	3	3.74 **§**
24A	-	-	-	330	-	1.29
24B	-	-	-	318	8	-0.18
25	314	0.09	-0.13	337	0.09	2.15
26	315	1%	0.00	-	-	-
27	332	2%	2.13	326	2%	0.80

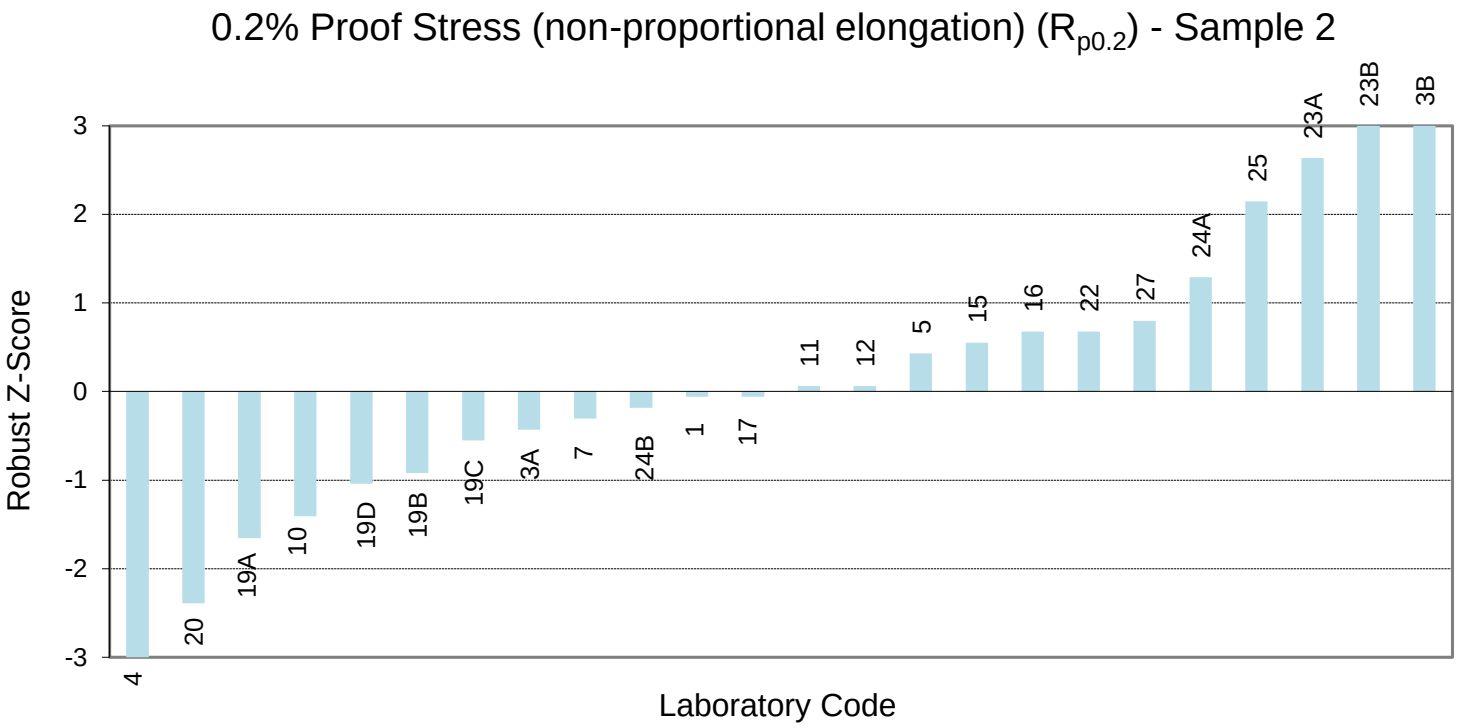
Summary Statistics

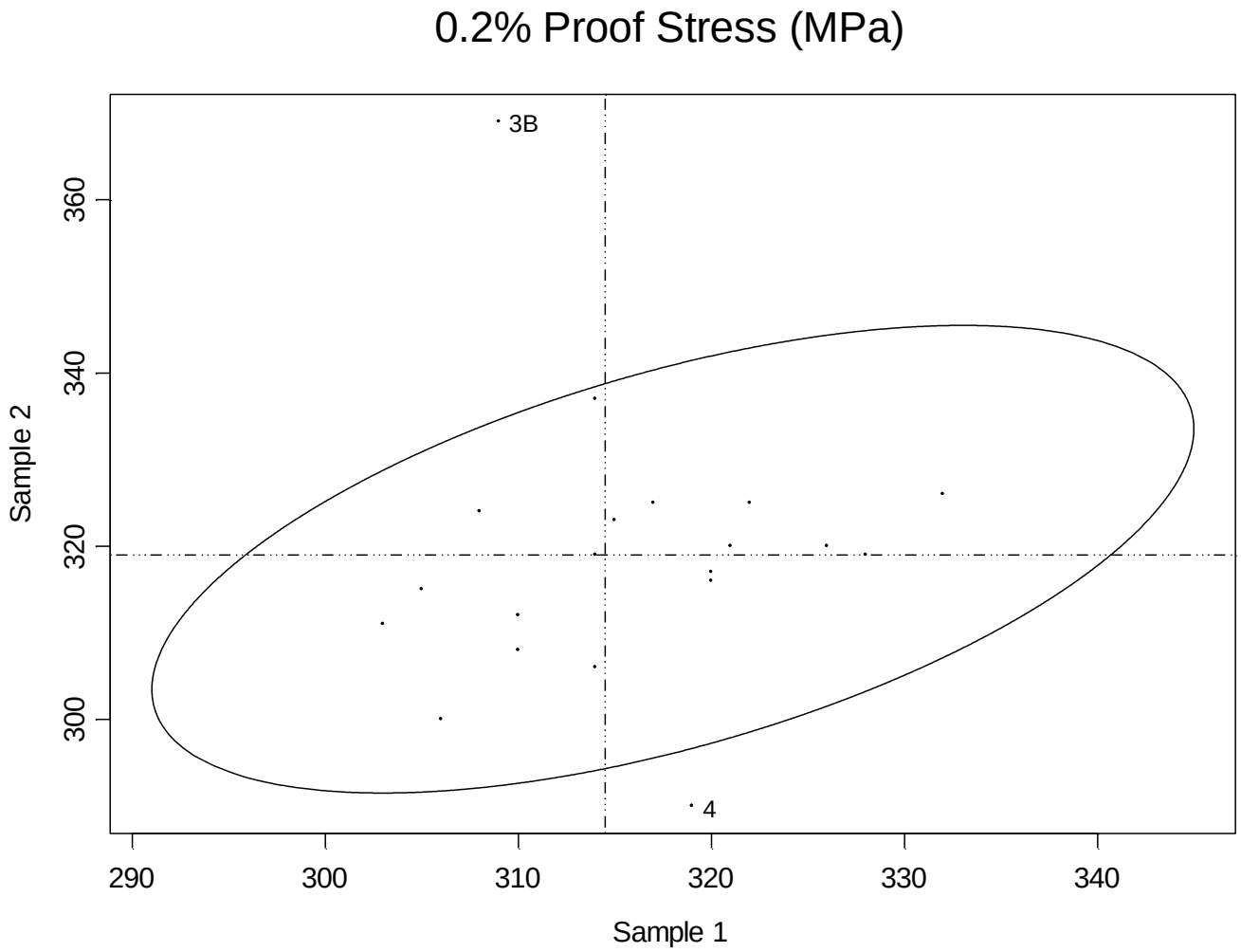
Statistic	Sample 1	Sample 2
Number of Results	22	24
Median	315.0	319.5
Normalised IQR	8.0	8.2
Uncertainty (Median)	2.1	2.1
Robust CV	2.5%	2.6%
Minimum	303	290
Maximum	332	369
Range	29	79

Notes:

1. **§** denotes an outlier (*i.e.* |z-score| ≥ 3.0).
2. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.
3. Laboratory 23 tested samples that were approximately 600 mm in length. These results have been pooled for analysis with the results reported by the other participants that tested the 400 mm length samples (see Appendix B for more details).
4. Laboratory 26 did not test sample 2, due to potential damage to their grips.
5. The Youden diagram on the following page is provided for information only.
6. Laboratories 14, 23, 24 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).




0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
4
20
19A
10
19D
19B
19C
3A
7
24B
1
17
11
12
5
15
16
22
27
24A
25
23A
23B
3B
Laboratory Code


0.2% Proof Stress (MPa)
Sample 2
360
340
320
300
3B
4
290
300
310
320
330
340
Sample 1

Section A2

Lower Yield

A2.1

Lower Yield (ReL) (MPa) – Results and Z-Scores

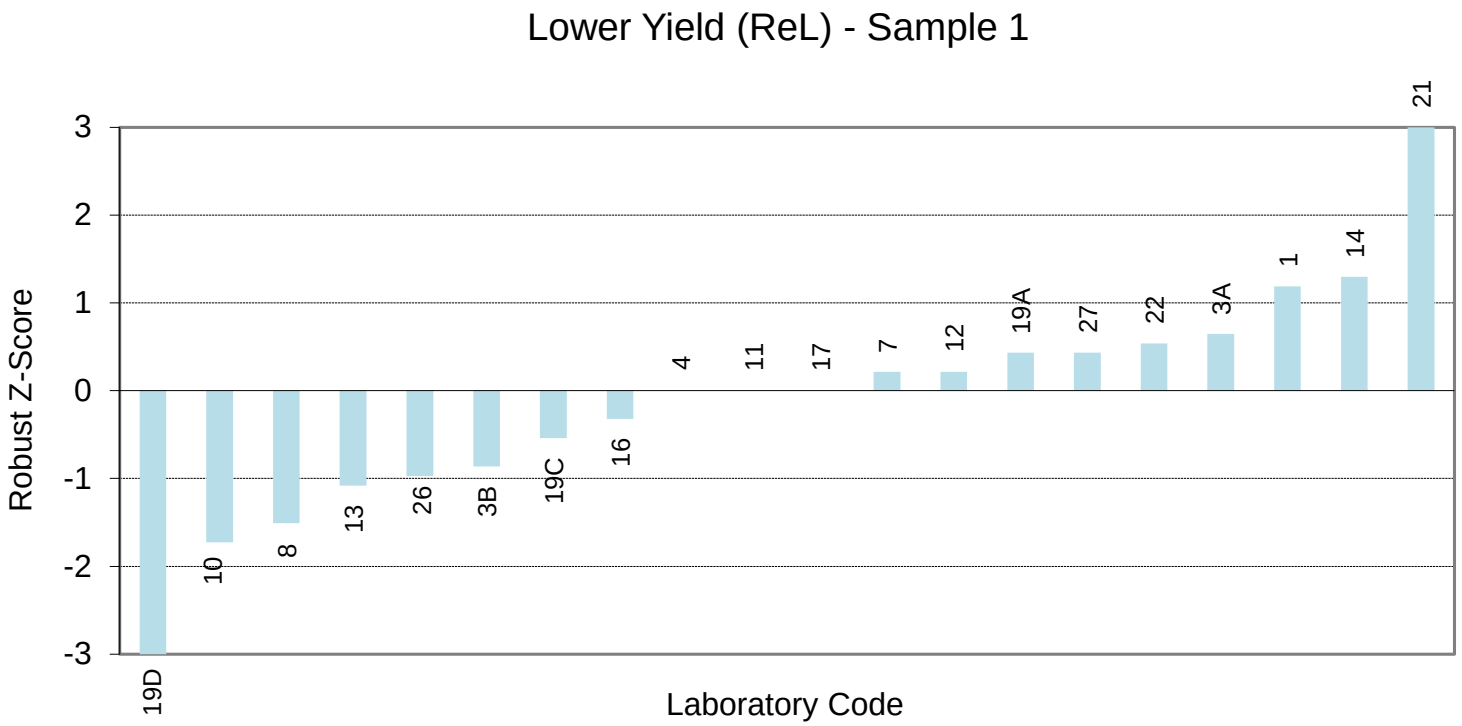
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	321	2%	1.19	311	2%	-0.10
3A	316	2.2%	0.65	-	2.2%	-
3B	302	2.2%	-0.86	-	2.2%	-
4	310	1.21%	0.00	281	1.21%	-3.22 **§**
7	312	1	0.22	315	1	0.31
8	296	8	-1.51	312	8	0.00
10	294	-	-1.73	306	-	-0.62
11	310	-	0.00	310	-	-0.21
12	312	3	0.22	316	3	0.42
13	300	-	-1.08	307	-	-0.52
14	322	8.3	1.30	323	8.3	1.14
15	-	-	-	324	2.8	1.25
16	307	3.40	-0.32	315	3.80	0.31
17	310	5	0.00	318	4	0.62
19A	314	-	0.43	300	-	-1.25
19B	-	-	-	308	3.1	-0.42
19C	305	3.2	-0.54	305	3.1	-0.73
19D	107	-	-21.91 **§**	53	-	-26.88 **§**
21	361	6	5.50 **§**	311	2	-0.10
22	315	15	0.54	312	15	0.00
23A	-	-	-	336	1.7	2.49
23B	-	-	-	342	1.7	3.11 **§**
24A	-	-	-	354	-	4.36 **§**
24B	-	-	-	340	8	2.91
26	301	1%	-0.97	-	-	-
27	314	2%	0.43	310	2%	-0.21

Summary Statistics

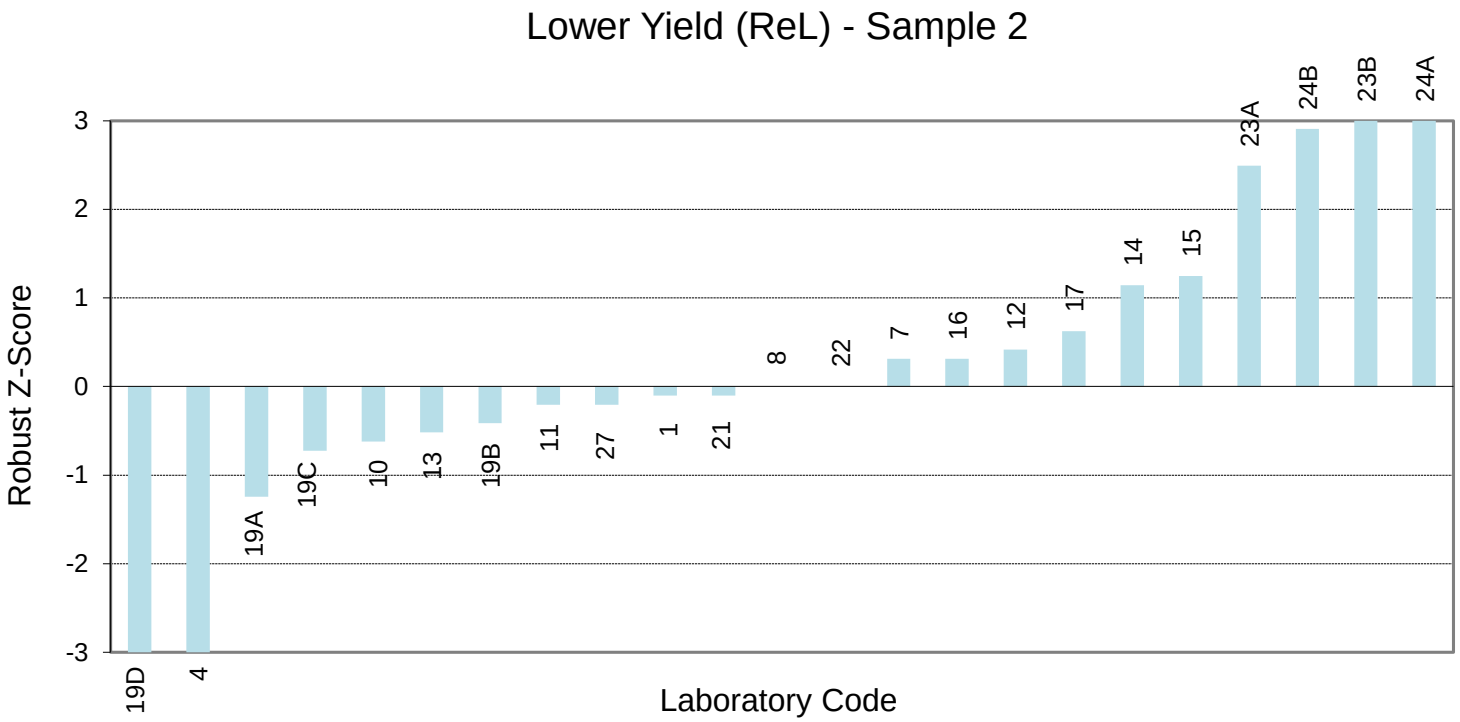
Statistic	Sample 1	Sample 2
Number of Results	20	23
Median	310.0	312.0
Normalised IQR	9.3	9.6
Uncertainty (Median)	2.6	2.5
Robust CV	3.0%	3.1%
Minimum	107	53
Maximum	361	354
Range	254	301

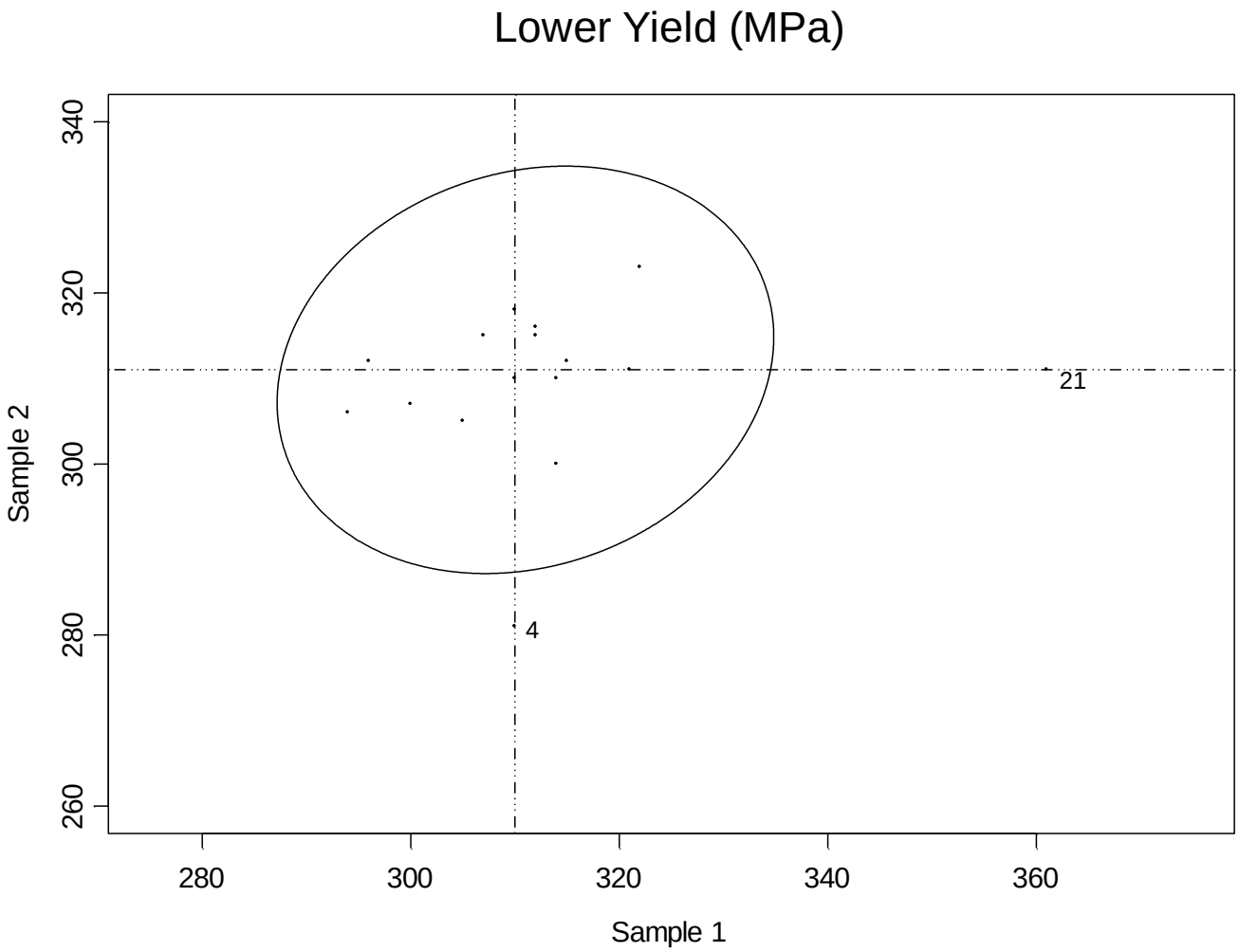
Notes:

1. **§** denotes an outlier (*i.e.* |z-score| ≥ 3.0).
2. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.
3. Laboratory 23 tested samples that were approximately 600 mm in length. These results have been pooled for analysis with the results reported by the other participants that tested the 400 mm length samples (see Appendix B for more details).
4. Laboratory 26 did not test sample 2, due to potential damage to their grips.
5. The Youden diagram on the following page is provided for information only.
6. Laboratories 3, 15, 19B, 23, 24 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).
7. Laboratory 19D is included in the Youden diagram, but their results are not displayed, as they lie outside the scale of the diagram.



A2.3


Lower Yield (ReL) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
19D
4
19A
19C
10
13
19B
11
27
1
21
8
22
7
16
12
17
14
15
23A
24B
23B
24A
Laboratory Code


Lower Yield (MPa)
Sample 2
340
320
300
280
260
21
4
280
300
320
340
360
Sample 1

Section A3

Upper Yield

A3.1

Upper Yield (ReH) (MPa) – Results and Z-Scores

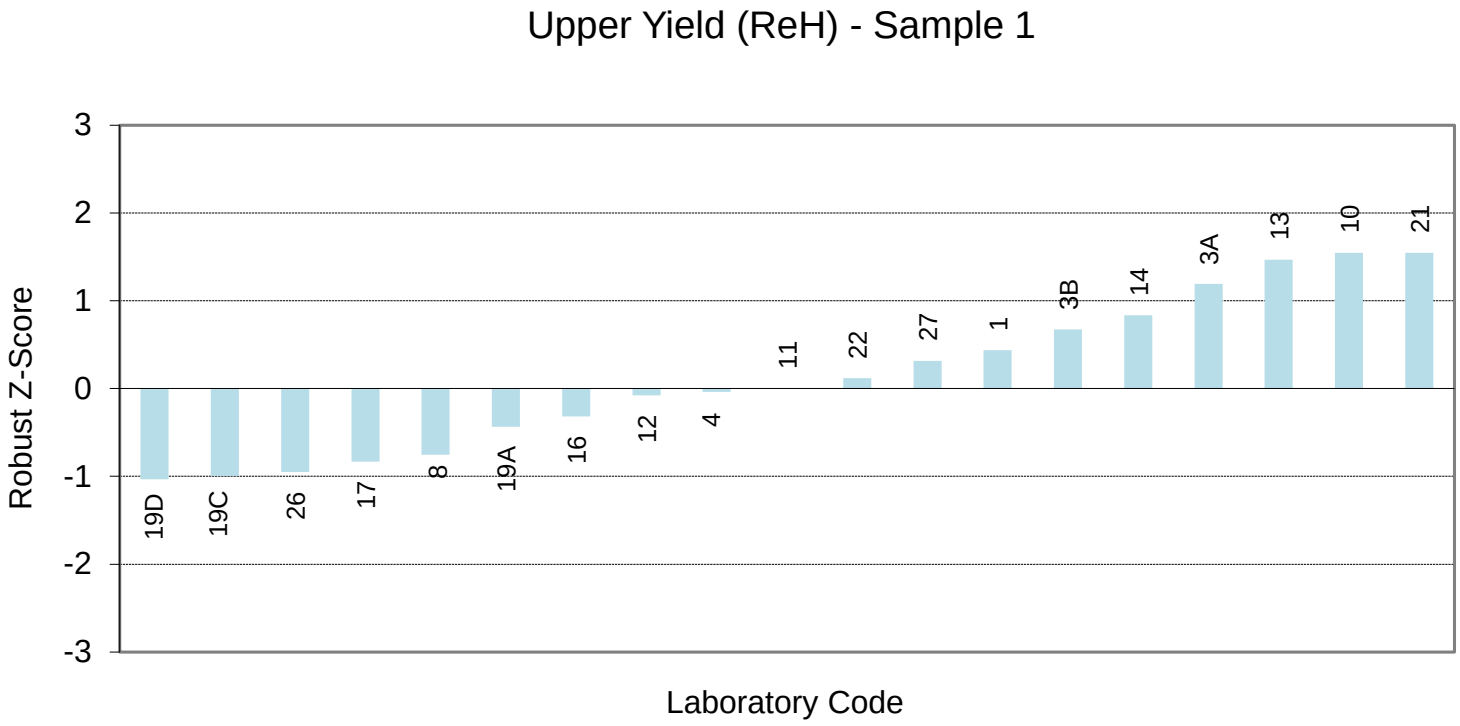
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	346	2%	0.44	321	2%	-0.44
3A	365	2.2%	1.19	-	2.2%	-
3B	352	2.2%	0.67	-	2.2%	-
4	334	1.21%	-0.04	305	1.21%	-1.60
8	316	8	-0.75	318	8	-0.66
10	374	-	1.55	315	-	-0.88
11	335	-	0.00	328	-	0.07
12	333	3	-0.08	330	3	0.22
13	372	-	1.47	362	-	2.55
14	356	8.3	0.83	336	8.3	0.66
15	-	-	-	334	2.8	0.51
16	327	5.30	-0.32	326	4.30	-0.07
17	314	5	-0.83	319	4	-0.58
19A	324	-	-0.44	308	-	-1.39
19B	-	-	-	325	3.3	-0.15
19C	310	3.2	-0.99	310	3.1	-1.24
19D	309	-	-1.03	322	-	-0.36
21	374	6	1.55	319	3	-0.58
22	338	15	0.12	331	15	0.29
23A	-	-	-	342	1.7	1.09
23B	-	-	-	350	1.7	1.68
24A	-	-	-	362	-	2.55
24B	-	-	-	348	8	1.53
26	311	1%	-0.95	-	-	-
27	343	2%	0.32	338	2%	0.80

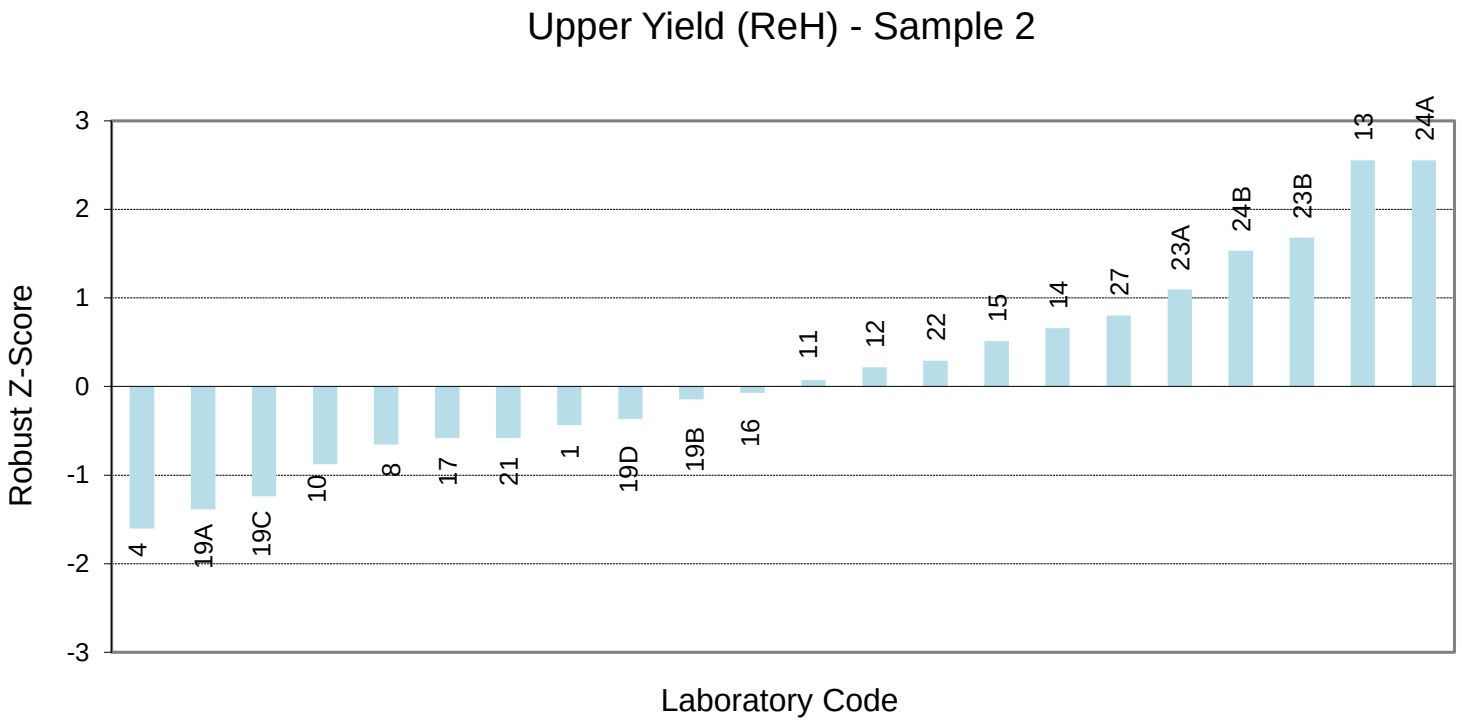
Summary Statistics

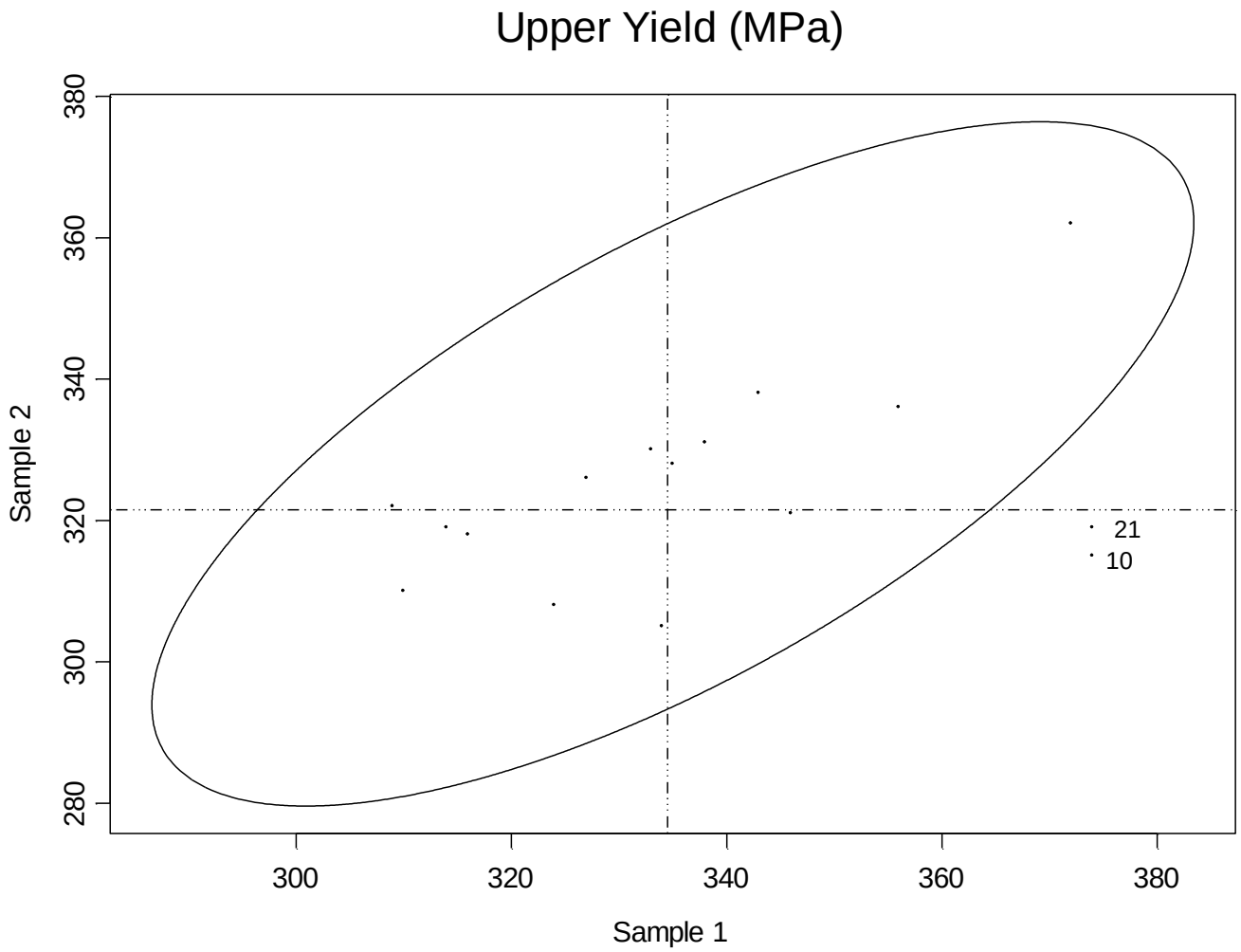
Statistic	Sample 1	Sample 2
Number of Results	19	22
Median	335.0	327.0
Normalised IQR	25.2	13.7
Uncertainty (Median)	7.2	3.7
Robust CV	7.5%	4.2%
Minimum	309	305
Maximum	374	362
Range	65	57

Notes:

1. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.
2. Laboratory 23 tested samples that were approximately 600 mm in length. These results have been pooled for analysis with the results reported by the other participants that tested the 400 mm length samples (see Appendix B for more details).
3. Laboratory 26 did not test sample 2, due to potential damage to their grips.
4. The Youden diagram on the following page is provided for information only.
5. Laboratories 3, 15, 19B, 23, 24 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).




Upper Yield (ReH) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
4
19A
19C
10
8
17
21
1
19D
19B
16
11
12
22
15
14
27
23A
24B
23B
13
24A
Laboratory Code


Upper Yield (MPa)
Sample 2
380
360
340
320
300
280
21
10
300
320
340
360
380
Sample 1

Section A4

Tensile Strength

Tensile Strength (Rm) (MPa) – Results and Z-Scores

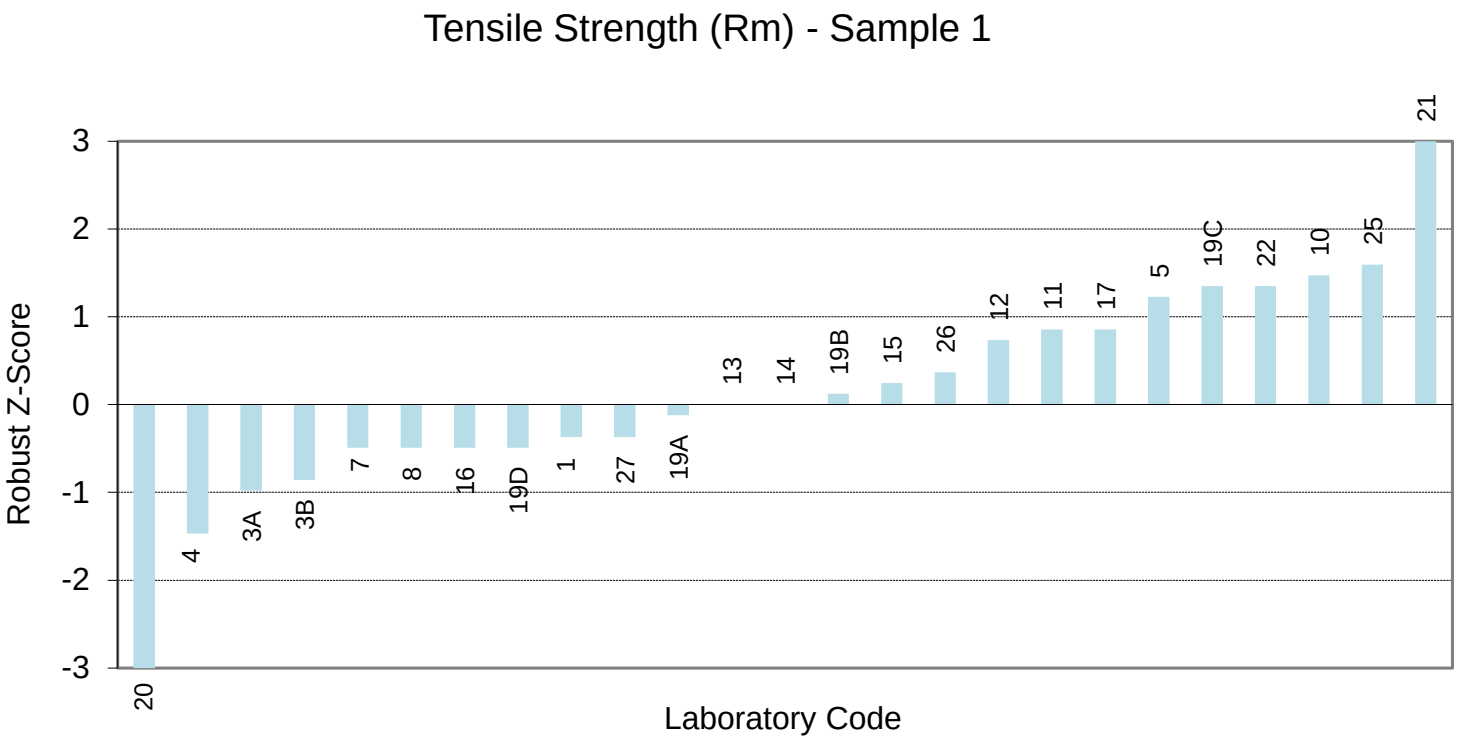
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	446	2%	-0.37	440	2%	-0.48
3A	441	1.7%	-0.98	439	1.7%	-0.58
3B	442	1.7%	-0.86	429	1.7%	-1.64
4	437	0.32%	-1.47	414	0.32%	-3.23 **§**
5	459	3.1	1.23	451	3.2	0.69
7	445	1	-0.49	443	1	-0.16
8	445	8	-0.49	442	8	-0.26
10	461	19	1.47	447	19	0.26
11	456	-	0.86	449	-	0.48
12	455	3	0.74	449	3	0.48
13	449	-	0.00	452	-	0.79
14	449	9.7	0.00	441	9.7	-0.37
15	451	5.9	0.25	452	2.8	0.79
16	445	4.70	-0.49	455	5.70	1.11
17	456	5	0.86	456	4	1.22
19A	448	-	-0.12	441	-	-0.37
19B	450	4.6	0.12	430	4.4	-1.53
19C	460	4.7	1.35	440	4.5	-0.48
19D	445	4.5	-0.49	437	4.4	-0.79
20	423.0	9.0	-3.19 **§**	432.0	3.0	-1.32
21	501	6	6.38 **§**	446	3	0.16
22	460	23	1.35	449	22	0.48
23A	-	-	-	428	3	-1.75
23B	-	-	-	450	3	0.58
24A	-	-	-	490	-	4.81 **§**
24B	-	-	-	473	0.14	3.02 **§**
25	462	0.14	1.59	464	0.15	2.06
26	452	1%	0.37	-	-	-
27	446	1%	-0.37	430	1%	-1.53

Summary Statistics

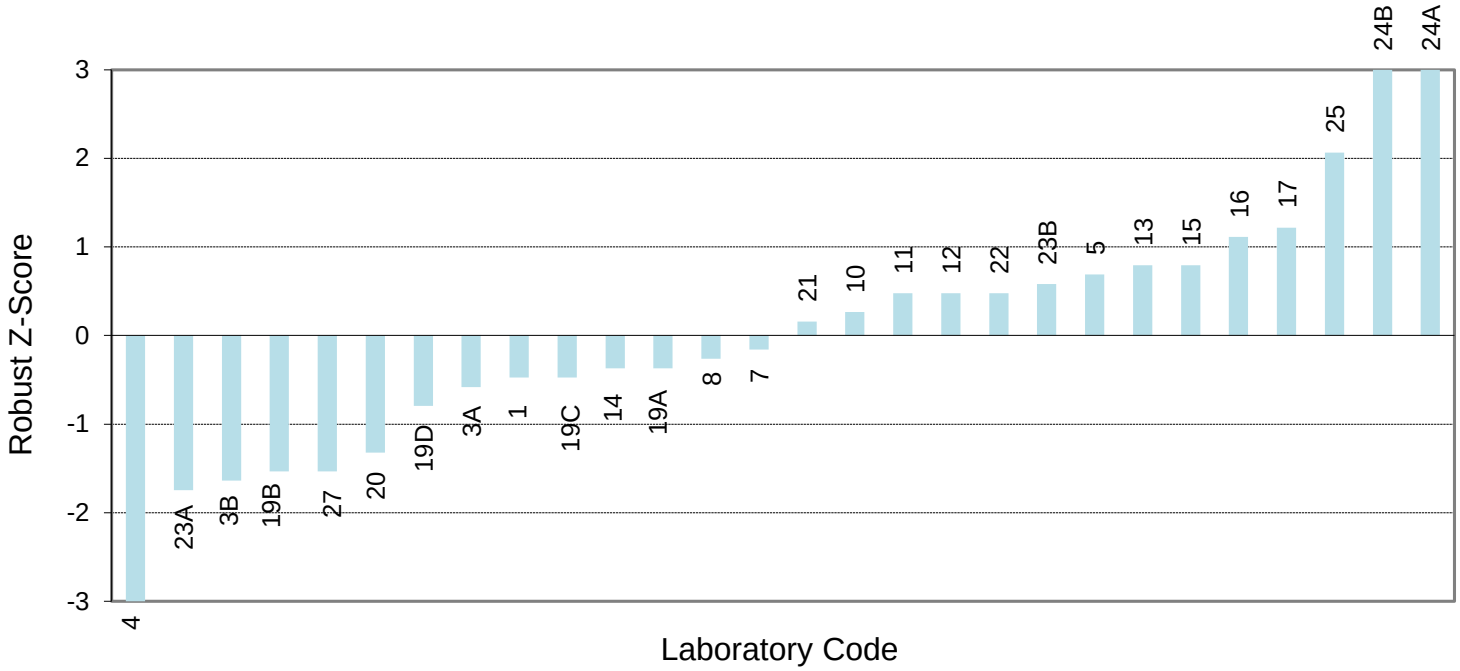
Statistic	Sample 1	Sample 2
Number of Results	25	28
Median	449.0	444.5
Normalised IQR	8.2	9.5
Uncertainty (Median)	2.0	2.2
Robust CV	1.8%	2.1%
Minimum	423	414
Maximum	501	490
Range	78	76

Notes:

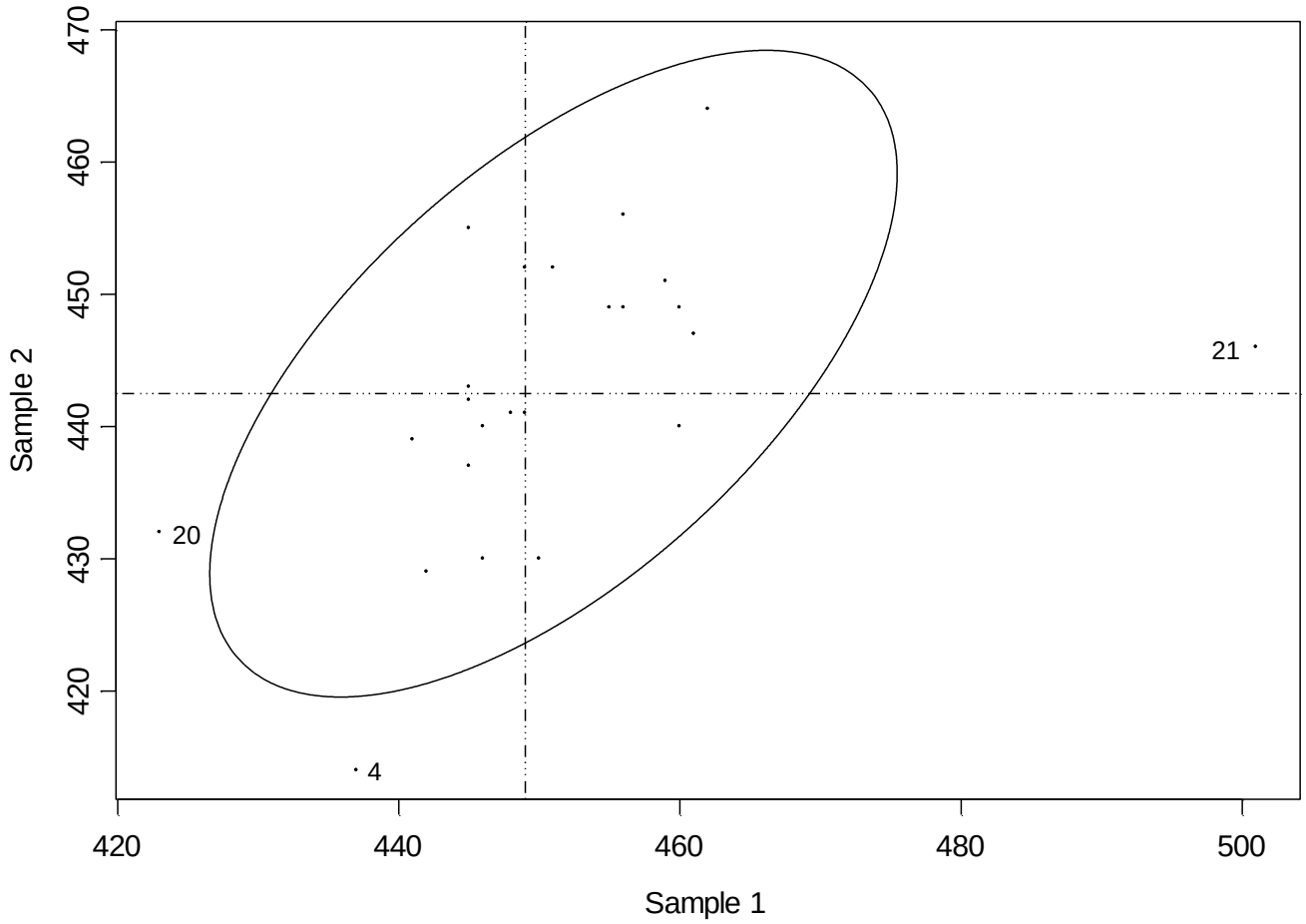
1. **§** denotes an outlier (*i.e.* |z-score| ≥ 3.0).
2. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.
3. Laboratory 23 tested samples that were approximately 600 mm in length. These results have been pooled for analysis with the results reported by the other participants that tested the 400 mm length samples (see Appendix B for more details).
4. Laboratory 26 did not test sample 2, due to potential damage to their grips.
5. The Youden diagram on the following page is provided for information only.
6. Laboratories 23, 24 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).



Tensile Strength (Rm) - Sample 2



Tensile Strength (MPa)



Section A5

Percentage Elongation after Fracture

Percentage Elongation after Fracture (A%) – Results and Proportional Gauge Length (PGL) Results

Lab Code	Sample 1			Sample 2		
	Result	MU (±)	PGL Result	Result	MU (±)	PGL Result
1	35.0	2%	35	~25.0	2%	-
3A	43	2%	39	33	2%	38
3B	31	2%	28	30	2%	34
4	36	0.16%	36	35	0.16%	36
5	35	2.3	35	43	2.5	38
7	39	1	39	42	1	42
8	40	0.8	46	38	0.8	38
10	33	3.4	33	37	3.4	37
11	37	0.019	33	-	0.019	-
12	38	1%	38	-	-	-
13	37	-	37	38	-	38
14	33	0.3	33	35	0.3	35
15	34	1.4	34	41	0.9	41
16	34	0.90	34	35	0.80	35
17	36	0.02%	36	36	0.01%	36
19A	34	-	34	41	-	41
19B	33	0.1	33	39	0.1	39
19C	36	0.1	36	41	0.1	41
19D	31	-	31	29	-	44
20	39.0	3.0	36	29.0	2.0	44
21	36.48	0.05	38	42.00	0.05	36
22	36	3	36	44	3	38
23A	-	-	-	10	0.05	10
23B	-	-	-	10	0.05	10
24A	-	-	-	40	-	40
24B	-	-	-	40	1	40
25	36	0.002	36	-	-	-
26	36	1%	36	-	-	-
27	37	6%	37	39	6%	39

Percentage Elongation after Fracture (A%) – 400 mm Length Samples
Proportional Gauge Length (PGL) Results and Z-Scores

Lab Code	Sample 1		Sample 2	
	PGL Result	Z-Score	PGL Result	Z-Score
1	35	-0.38	-	-
3A	39	1.57	38	-0.04
3B	28	-3.41 §	34	-1.24
4	36	0.00	36	-0.78
5	35	-0.41	38	-0.21
7	39	1.40	42	1.21
8	46	4.45 §	38	-0.08
10	33	-1.32	37	-0.39
11	33	-1.13	-	-
12	38	0.93	-	-
13	37	0.48	38	-0.06
14	33	-1.34	35	-1.09
15	34	-0.83	41	0.94
16	34	-0.77	35	-0.96
17	36	0.03	36	-0.73
19A	34	-0.87	41	0.88
19B	33	-1.30	39	0.25
19C	36	0.03	41	0.90
19D	31	-2.19	44	1.88
20	36	-0.10	44	1.88
21	38	0.83	36	-0.60
22	36	0.03	38	0.04
24A	-	-	40	0.56
24B	-	-	40	0.56
25	36	0.02	-	-
26	36	0.04	-	-
27	37	0.50	39	0.21

Summary Statistics

Statistic	Sample 1	Sample 2
Number of Results	25	22
Median	35.9	38.2
Normalised IQR	2.2	3.1
Uncertainty (Median)	0.6	0.8
Robust CV	6.2%	8.0%
Minimum	28	34
Maximum	46	44
Range	17	10

Percentage Elongation after Fracture (A%) – 600 mm Length Samples
Proportional Gauge Length (PGL) Results and Z-Scores

Lab Code	Sample 1		Sample 2	
	PGL Result	Z-Score	PGL Result	Z-Score
23A	-	-	10	-6.62 **§**
23B	-	-	10	-6.62 **§**

Summary Statistics

Statistic	Sample 1	Sample 2
Number of Results	0	6
Median	n/a	29.5
Normalised IQR	n/a	14.4
Uncertainty (Median)	n/a	7.3
Robust CV	n/a	48.6%
Target SD	n/a	3.0
Target CV	n/a	10.0%
Minimum	n/a	10
Maximum	n/a	31
Range	n/a	21

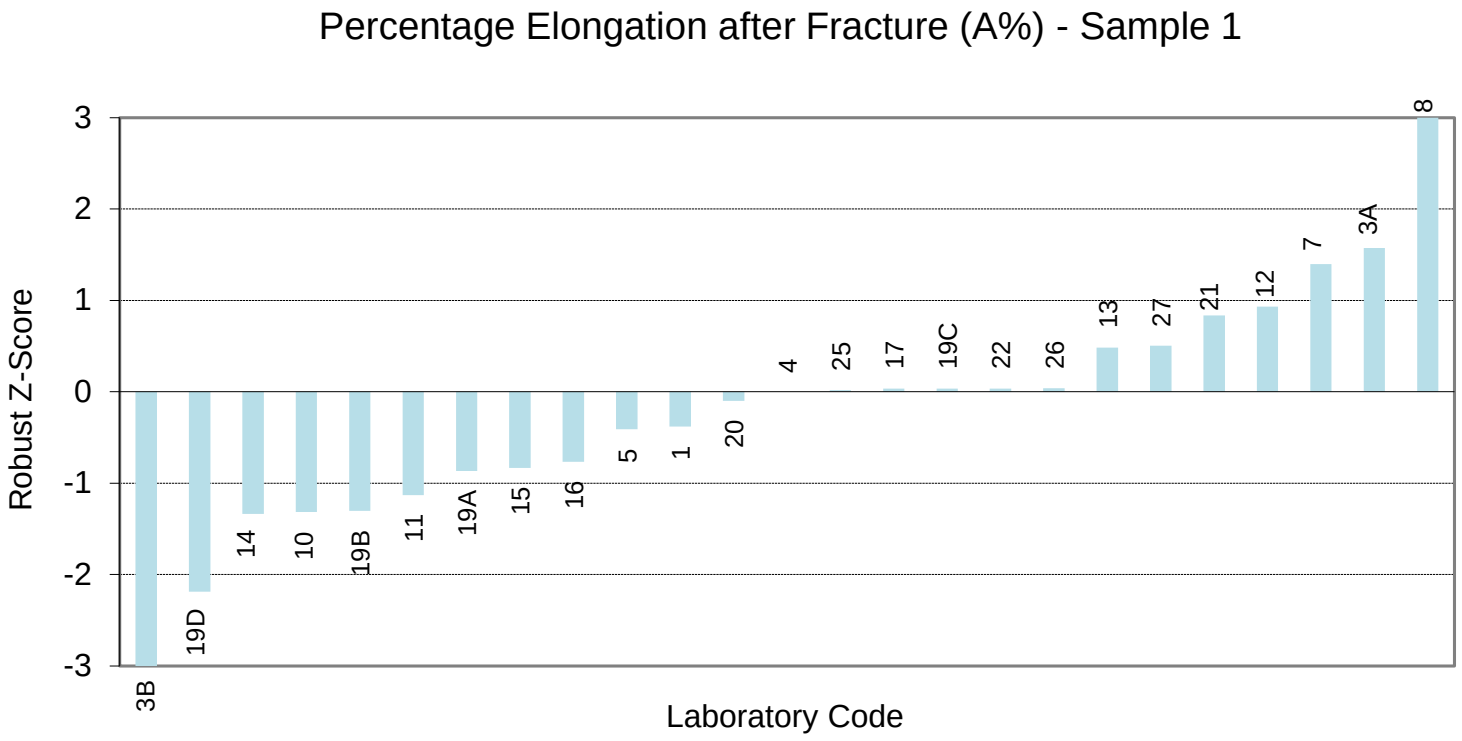
Notes:

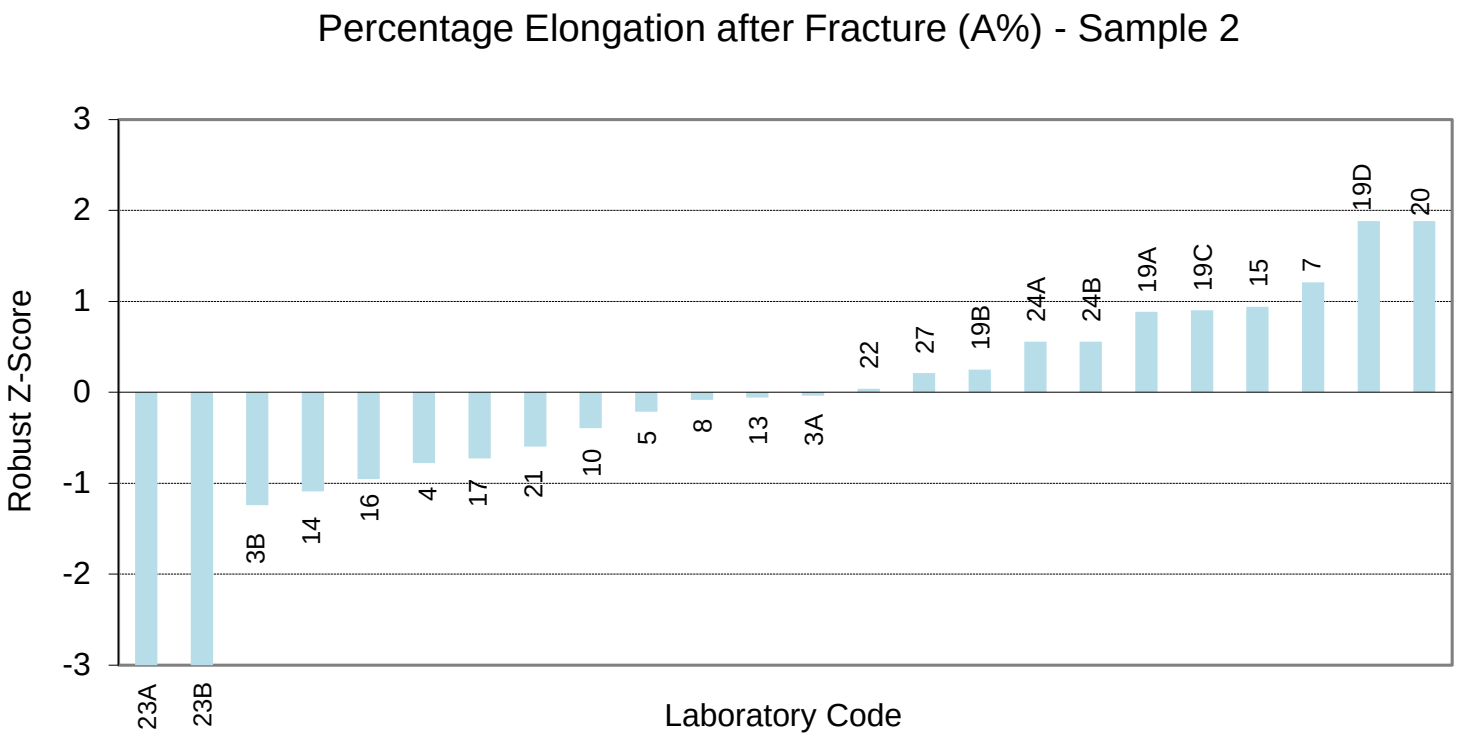
1. To analyse the Percentage Elongation after Fracture results, the results submitted by participants were converted to a proportional gauge length (PGL) using the following formula:

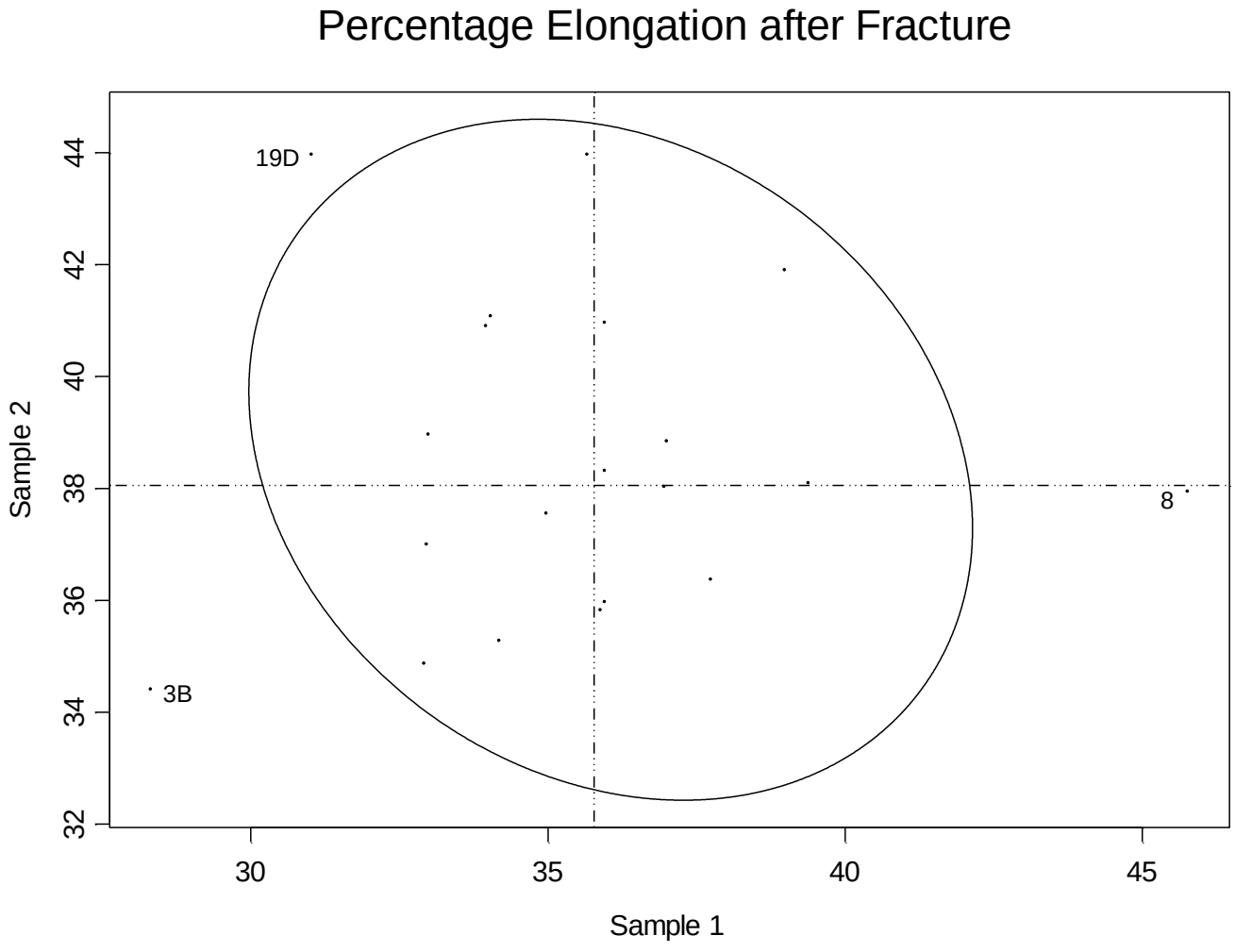
$$\text{PGL Result} = \frac{\text{Result}}{2} \times \left(\frac{\text{Tensile Specimen Gauge Length}}{\sqrt{\pi \times \left(\frac{\text{Tensile Specimen Diameter}}{2} \right)^2}} \right)^{0.4}.$$

2. **§** denotes an outlier (*i.e.* |z-score| ≥ 3.0).
3. Laboratory 1 reported their Percentage Elongation after Fracture result for sample 2 as an indication only. Their fracture surface for sample 2 was within one third of the original gauge length, to the nearest gauge mark. This result has not been analysed.
4. Laboratories 11 and 12 could not report a result for Percentage Elongation after Fracture for sample 2 because the sample fractured outside of the gauge.
5. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.

6. Laboratory 23 tested samples that were approximately 600 mm in length. The summary statistics and z-scores for their Percentage Elongation after Fracture results were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd for 600 mm long samples (see Appendix B for more details).
7. A target CV was used to calculate the robust z-scores for the Percentage Elongation after Fracture results for laboratory 23. The target CV chosen was 10.0%.
8. The target SD (standard deviation) for the 600 mm length samples was obtained by multiplying the target CV by the median. This target SD was used to calculate the z-scores for laboratory 23 for sample 2. For more information on the use of target CVs to calculate z-scores, please see the Guide to Proficiency Testing Australia (2016).
9. The Youden diagram on the following page is provided for information only.
10. Laboratories 1, 11, 12, 23, 24, 25 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).




Percentage Elongation after Fracture (A%) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
23A
23B
3B
14
16
4
17
21
10
5
8
13
3A
22
27
19B
24A
24B
19A
19C
15
7
19D
20
Laboratory Code


Percentage Elongation after Fracture
Sample 2
44
42
40
38
36
34
32
19D
3B
8
30
35
40
45
Sample 1

Section A6

Percentage Reduction in Area after Fracture

Percentage Reduction in Area after Fracture (Z%) – Results and Z-Scores

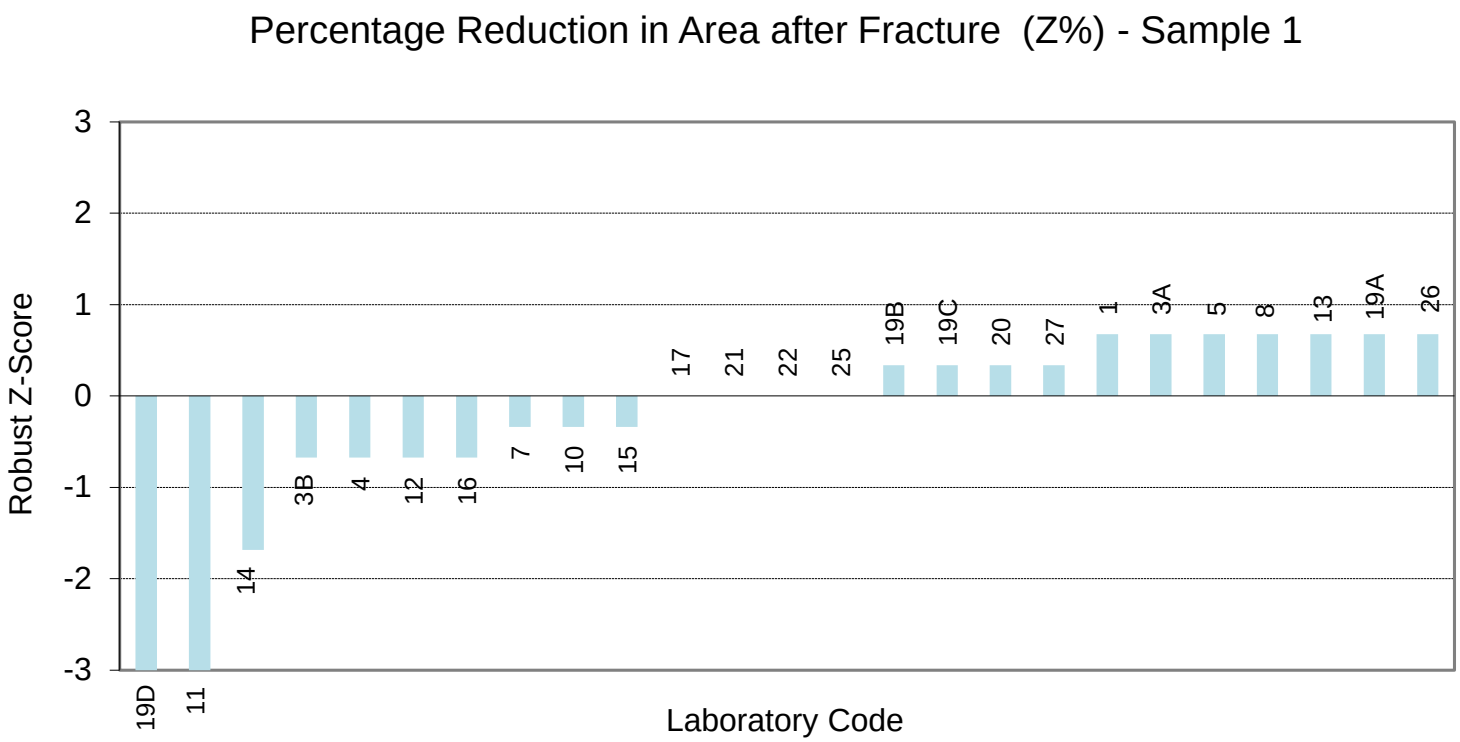
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	72	2%	0.67	71	2%	0.00
3A	72	2%	0.67	72	2%	0.45
3B	68	2%	-0.67	72	2%	0.45
4	68	0.16%	-0.67	72	0.16%	0.45
5	72	1.5	0.67	71	1.5	0.00
7	69	1	-0.34	67	1	-1.80
8	72	1.4	0.67	72	1.4	0.45
10	69	7.5	-0.34	69	7.5	-0.90
11	47	0.002	-7.76 **§**	48	0.002	-10.34 **§**
12	68	1%	-0.67	71	1%	0.00
13	72	-	0.67	72	-	0.45
14	65	0.3	-1.69	71	0.3	0.00
15	69	2.6	-0.34	69	1.6	-0.90
16	68	1.15	-0.67	69	1.00	-0.90
17	70	0.02%	0.00	71	0.01%	0.00
19A	72	-	0.67	72	-	0.45
19B	71	0.1	0.34	72	0.1	0.45
19C	71	0.1	0.34	72	0.1	0.45
19D	43	-	-9.11 **§**	44	-	-12.14 **§**
20	71.0	2.0	0.34	72.0	2.0	0.45
21	70.0	0.3	0.00	70.5	0.2	-0.22
22	70	5	0.00	71	5	0.00
23A	-	-	-	20	0.05	-22.93 **§**
23B	-	-	-	21	0.05	-22.48 **§**
24A	-	-	-	70	-	-0.45
24B	-	-	-	70	1	-0.45
25	70	0.002	0.00	70	0.002	-0.45
26	72	1%	0.67	-	-	-
27	71	1%	0.34	71	1%	0.00

Summary Statistics

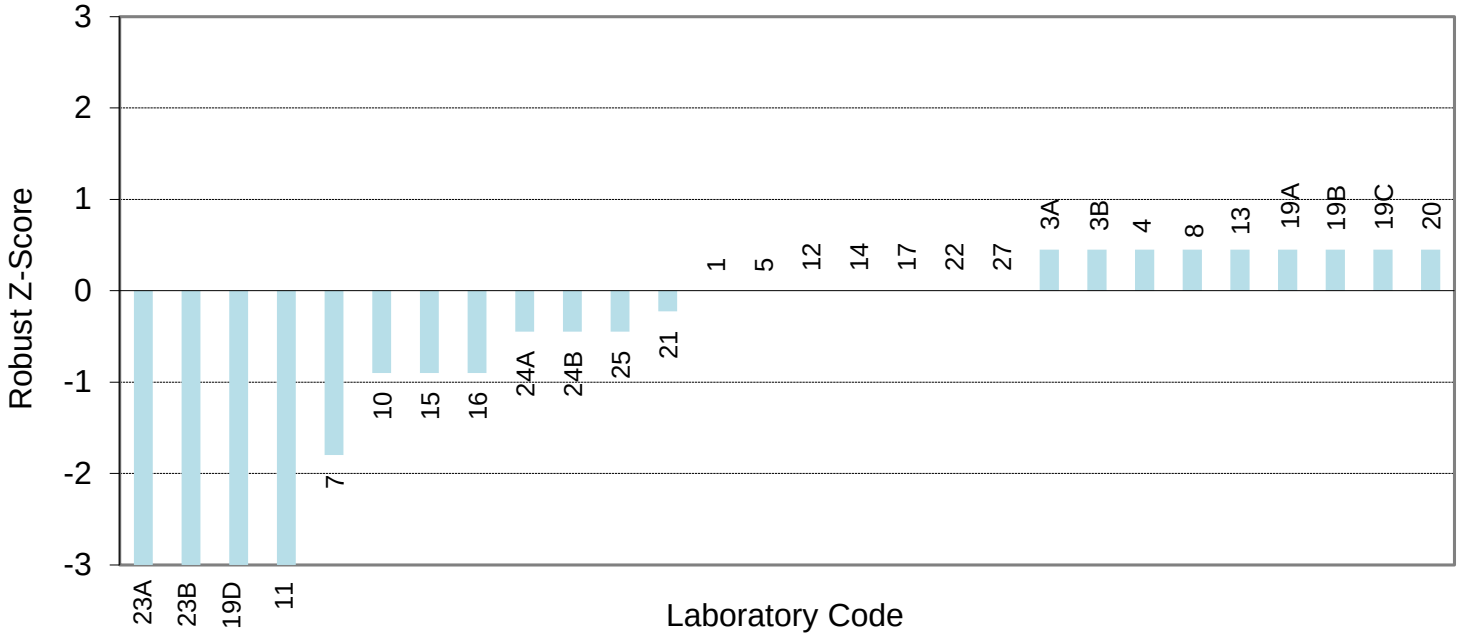
Statistic	Sample 1	Sample 2
Number of Results	25	28
Median	70.0	71.0
Normalised IQR	3.0	2.2
Uncertainty (Median)	0.7	0.5
Robust CV	4.2%	3.1%
Minimum	43	20
Maximum	72	72
Range	29	52

Notes:

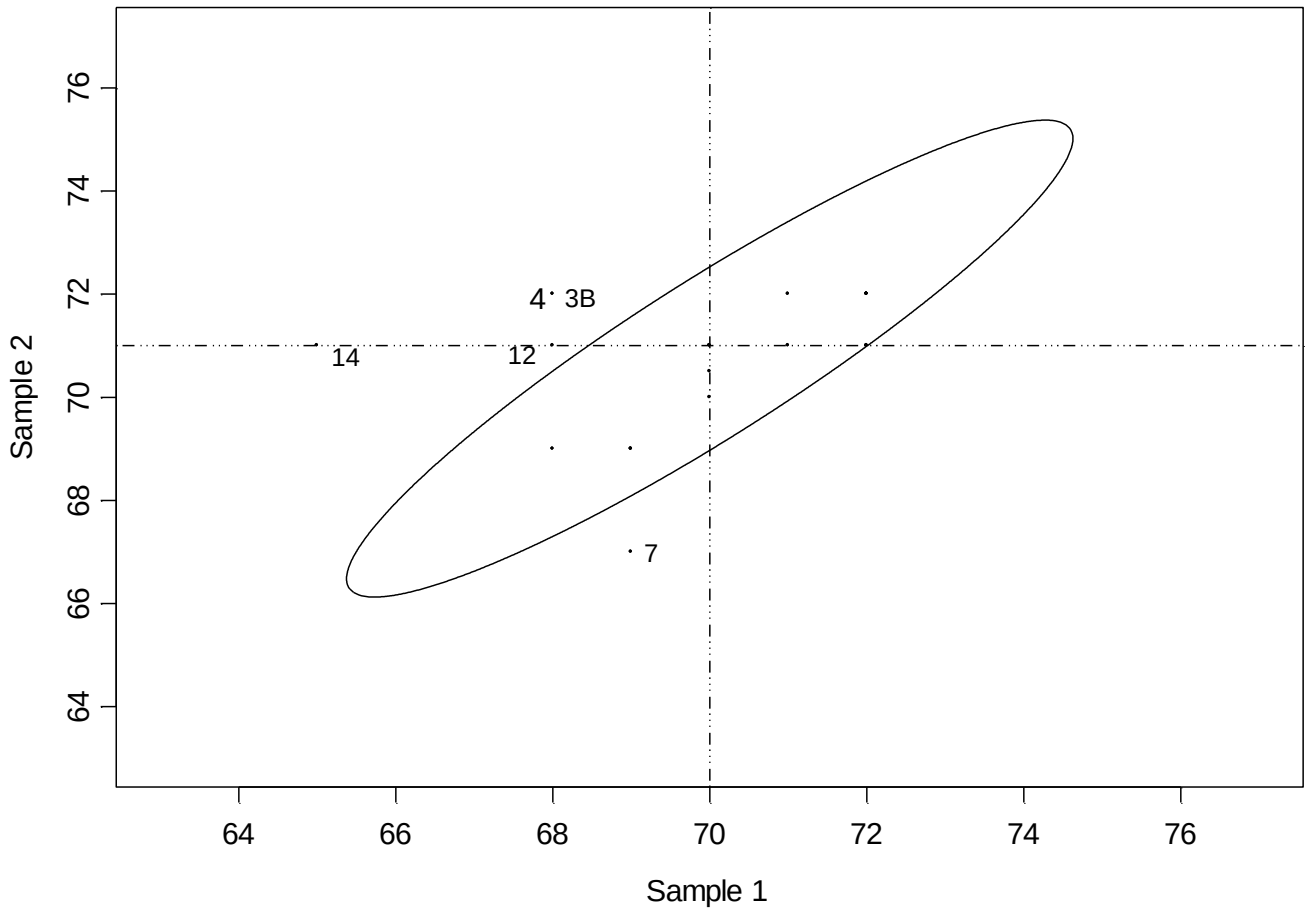
1. **§** denotes an outlier (*i.e.* |z-score| ≥ 3.0).
2. Laboratories 23 and 24 did not machine their samples. The results reported by these laboratories, for both samples, have been assessed against the parallel sample (sample 2) results. To distinguish between the two sets of sample 2 results for laboratories 23 and 24, the code letters A and B have been appended to these results.
3. Laboratory 23 tested samples that were approximately 600 mm in length. These results have been pooled for analysis with the results reported by the other participants that tested the 400 mm length samples (see Appendix B for more details).
4. Laboratory 26 did not test sample 2, due to potential damage to their grips.
5. The Youden diagram on the following page is provided for information only.
6. Laboratories 23, 24 and 26 are not included in the Youden diagram, as these laboratories did not report a pair of results (for sample 1 and sample 2).
7. Laboratories 11 and 19D are included in the Youden diagram, but their results are not displayed, as they lie outside the scale of the diagram.



Percentage Reduction in Area after Fracture (Z%) - Sample 2



Percentage Reduction in Area after Fracture



Section A7

Method Information and Other Reported Results

A7.1

Method Information

Lab Code	0.2% Proof Stress	Lower Yield	Upper Yield
1	AS 1391	AS 1391	AS 1391
3A	AS 1391	AS 1391	AS 1391
3B	AS 1391	AS 1391	AS 1391
4	AS 1391	AS 1391	AS 1391
5	AS 1391	-	-
7	AS 1391	AS 1391	-
8	-	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)
10	UNI EN ISO 6892-1 2016	UNI EN ISO 6892-1 2016	UNI EN ISO 6892-1 2016
11	AS 1391	AS 1391	AS 1391
12	AS 1391	AS 1391	AS 1391
13	-	-	-
14	AS 1391, ISO 6892-1	AS 1391, ISO 6892-1	AS 1391, ISO 6892-1
15	AS 1391	AS 1391	AS 1391
16	AS 1391: 2007	AS 1391: 2007	AS 1391: 2007
17	AS 1391: 2007	AS 1391: 2007	AS 1391: 2007
19A	AS 1391	AS 1391	AS 1391
19B	AS 1391	AS 1391	AS 1391
19C	AS 1391	AS 1391	AS 1391
19D	AS 1391	AS 1391	AS 1391
20	ASTM A370	-	-
21	-	ASTM A370	ASTM A370
22	AS 1391	AS 1391	AS 1391
23A	ISO 6892-1	ISO 6892-1	ISO 6892-1
23B	ISO 6892-1	ISO 6892-1	ISO 6892-1
24A	ISO 6892	ISO 6892	ISO 6892
24B	ISO 6892	ISO 6892	ISO 6892
25	AS 1391: 2007 (R 2017)	-	-
26	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)
27	AS 1391	AS 1391	AS 1391

Method Information

Lab Code	Tensile Strength	Percentage Elongation after Fracture	Percentage Reduction in Area after Fracture
1	AS 1391	AS 1391	AS 1391
3A	AS 1391	AS 1391	AS 1391
3B	AS 1391	AS 1391	AS 1391
4	AS 1391	AS 1391	AS 1391
5	AS 1391	AS 1391	AS 1391
7	AS 1391	AS 1391	AS 1391
8	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)
10	UNI EN ISO 6892-1 2016	UNI EN ISO 6892-1 2016	UNI EN ISO 6892-1 2016
11	AS 1391	AS 1391	AS 1391
12	AS 1391	AS 1391	AS 1391
13	-	-	-
14	AS 1391, ISO 6892-1	AS 1391, ISO 6892-1	AS 1391, ISO 6892-1
15	AS 1391	AS 1391	AS 1391
16	AS 1391: 2007	AS 1391: 2007	AS 1391: 2007
17	AS 1391: 2007	AS 1391: 2007	AS 1391: 2007
19A	AS 1391	AS 1391	AS 1391
19B	AS 1391	AS 1391	AS 1391
19C	AS 1391	AS 1391	AS 1391
19D	AS 1391	AS 1391	AS 1391
20	ASTM A370	ASTM A370	ASTM A370
21	ASTM A370	ASTM A370	ASTM A370
22	AS 1391	AS 1391	AS 1391
23A	ISO 6892-1	ISO 6892-1	ISO 6892-1
23B	ISO 6892-1	ISO 6892-1	ISO 6892-1
24A	ISO 6892	ISO 6892	ISO 6892
24B	ISO 6892	ISO 6892	ISO 6892
25	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)
26	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)	AS 1391: 2007 (R 2017)
27	AS 1391	AS 1391	AS 1391

Tensile Specimen Diameter (mm)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	11.93	1%	14.08	1%
3A	12.42	1%	13.94	1%
3B	12.50	1%	14.17	1%
4	10.05	0.0017	14.12	0.0017
5	9.99	0.02	14.00	0.02
7	9.98	0.03	14.05	0.03
8	9.97	0.07	14.02	0.10
10	9.00	0.02	13.97	0.02
11	12.90	0.002	14.23	0.002
12	10.00	0.01	13.83	0.01
13	10.00	-	9.96	-
14	12.44	0.014	13.90	0.014
15	8.75	0.02	13.90	0.02
16	9.84	0.013	13.70	0.013
17	10	0.01	14	0.01
19A	8.00	-	14.05	-
19B	9.98	0.01	14.00	0.01
19C	10.0	0.01	14.0	0.01
19D	9.95	-	14.1	-
20	8.73	0.03	14.10	0.05
21	9.16	0.02	14.30	0.02
22	10.00	0.05	14.10	0.05
23A	-	-	14.05	0.005
23B	-	-	14.10	0.005
24A	-	-	14.05	0.01
24B	-	-	14.05	0.01
25	10.02	0.002	13.89	0.002
26	9.99	1%	-	-
27	9.97	0.1%	14.11	0.3%

Tensile Specimen Gauge Length (mm)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	60	1%	70	1%
3A	50	1%	100	1%
3B	50	1%	100	1%
4	50	-	75	-
5	50.0	0.05	50.0	0.05
7	50	0.1	70	1
8	70	0.5	70	0.5
10	45	0.1	70	0.1
11	50	0.019	50	0.019
12	50	1	50	1
13	50	-	50	-
14	62	0.014	69.0	0.014
15	44	0.5	70	0.5
16	50	1.0	70	1.0
17	50	0.01	70	0.01
19A	40	-	70	-
19B	50	0.01	70	0.01
19C	50	0.5	70	0.5
19D	50	-	200	-
20	35.0	0.5	200.0	1.0
21	50.00	0.02	50	0.02
22	50.00	0.5	50	0.5
23A	-	-	70	0.002
23B	-	-	70	0.002
24A	-	-	70	0.6
24B	-	-	70	0.6
25	50	0.002	70	0.002
26	50	1%	-	-
27	50	0.2%	70	0.2%

Elastic Stress or Strain Rate (number / sec)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	1.83 kN/s	1%	2.69 kN/s	1%
3A	0.00962	-	0.0101	-
3B	0.0135	-	0.0204	-
4	0.0008	-	0.0008	-
5	0.002	0.0002	0.002	0.0002
7	0.0003	-	0.003	-
8	0.0008	0.000012	0.0008	0.000012
10	0.0002	-	0.0002	-
11	0.0008	-	0.0008	-
12	52 MPa/sec	3 MPa/sec	52 MPa/sec	3 MPa/sec
13	39 MPa/s	-	38 MPa/s	-
14	0.0001^{-1}	-	-	-
15	manual control	-	manual control	-
16	-	-	-	-
17	12 MPa/s	-	12 MPa/s	-
19A	0.0002	-	0.0002	-
19B	10 MPa/sec	-	10 MPa/sec	-
19C	10 MPa/sec	0.01	10 MPa/sec	0.01
19D	-	-	-	-
20	-	-	-	-
21	0.02 mm/sec	-	0.02 mm/sec	-
22	12 MPa/s	0.5	12 MPa/s	0.5
23A	-	-	10 MPa/s	-
23B	-	-	10 MPa/s	-
24A	-	-	-	-
24B	-	-	-	-
25	20 MPa s^{-1}	-	20 MPa s^{-1}	-
26	0.00025	-	-	-
27	0.000350	10%	0.000270	10%

Plastic Strain Rate (number / sec)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	1.63 kN/s	1%	2.14 kN/s	1%
3A	0.19087	-	0.05006	-
3B	0.1484	-	0.0605	-
4	0.0008	-	0.0008	-
5	0.002	0.0002	0.002	0.0002
7	0.0003	-	0.003	-
8	0.00024	0.000052	0.00024	0.000052
10	0.0067	-	0.0067	-
11	0.005	-	0.005	-
12	0.008	0.001	0.008	0.001
13	0.00024	-	0.00025	-
14	0.001^{-1}	-	-	-
15	manual control	-	manual control	-
16	-	-	-	-
17	12 MPa/s	-	12 MPa/s	-
19A	0.001	-	0.001	-
19B	0.0005	-	0.0005	-
19C	10 MPa/sec	0.01	10 MPa/sec	0.01
19D	-	-	-	-
20	-	-	-	-
21	0.17 mm/sec	-	0.17 mm/sec	-
22	-	-	-	-
23A	-	-	30 MPa/s	-
23B	-	-	30 MPa/s	-
24A	-	-	-	-
24B	-	-	-	-
25	0.008	-	0.008	-
26	0.008	-	-	-
27	0.003200	10%	0.001700	10%

APPENDIX B

Homogeneity Testing

HOMOGENEITY TESTING

Before the test pieces were distributed to participants, eight specimens from each 400 mm length sample were selected at random and tested by ARL Laboratory Services Pty Ltd. This was done to assess the variability of the samples to be used in the program. The results of this testing appear in the following tables.

Homogeneity Testing Results (400 mm Length Samples)

Sample 1 – Machined Sample

Sample Number	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Original Gauge Length (mm)	% Elongation on $5.65\sqrt{S_0}$
1-1	76.2	450	310	50	32
1-7	77.0	450	320	50	33
1-14	77.8	460	325	50	33
1-18	77.8	460	310	50	35
1-21	78.5	450	325	50	33
1-24	78.5	460	310	50	35
1-34	77.8	450	320	50	34
1-39	70.1	440	300	50	34

Homogeneity Testing Results (400 mm Length Samples)

Sample 2 – Parallel Sample

Sample Number	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Original Gauge Length (mm)	% Elongation on $5.65\sqrt{S_0}$
2-2	147.4	455	325	70	34
2-5	145.3	440	310	70	35
2-12	149.6	440	310	70	34
2-14	149.6	445	315	70	34
2-24	149.6	445	320	70	36
2-25	149.6	460	320	70	36
2-30	148.5	440	310	70	36
2-38	149.6	435	305	70	35

Analysis of this testing data indicated that the 400 mm length samples were sufficiently homogeneous for the program and, therefore, any participant results identified as outliers cannot be attributed to sample variability.

Since one of the participants in this round of the program requested samples that were approximately 600 mm in length to test, ARL Laboratory Services Pty Ltd welded some samples for this participant to test. Four of these samples were also tested for homogeneity by ARL Laboratory Services Pty Ltd. The participant indicated that they would not be machining their samples, so the samples were tested for homogeneity as parallel samples. The results of this testing appear in the following table.

Homogeneity Testing Results (600 mm Length Samples)

Sample 2 – Parallel Sample

Sample Number	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Original Gauge Length (mm)	% Elongation on $5.65\sqrt{S_0}$	% Reduction in Area
1	147.4	455	320	70	29	70
2	149.6	450	320	70	30	70
3	151.7	445	325	70	31	71
4	149.6	450	315	70	30	70

Analysis of this testing data indicated that the 600 mm length samples were sufficiently homogeneous for the program and, therefore, any participant results identified as outliers cannot be attributed to sample variability.

Comparing the homogeneity results, and the results by the participants, for the 400 mm length samples to the homogeneity results for the 600 mm length samples showed that their were no significant differences between the results for the 400 mm length samples and the 600 mm length samples, except for Percentage Elongation after Fracture. This was to be expected, due to the heat input of welding introduced into the material to make the 600 mm length samples, and that Percentage Elongation after Fracture is the most sensitive of all the tensile properties tested for in this program. As a consequence of this analysis, the results submitted by the participant that tested the 600 mm length samples were pooled for analysis with the other participants' results for all tests except Percentage Elongation after Fracture. For Percentage Elongation after Fracture, the results submitted by the participant that tested the 600 mm length samples were compared to the homogeneity testing results obtained by ARL Laboratory Services Pty Ltd (shown in the table above).

APPENDIX C

Instructions to Participants

and

Results Sheet

PROFICIENCY TESTING AUSTRALIA

Tensile Testing Of Metals Proficiency Testing Program Round 11, March 2018

Instructions To Participants

To ensure that the results of this program can be analysed correctly, participants are asked to note carefully:

1) The samples for this tensile testing program comprise of two identical carbon steel round bar samples. The samples are labelled 1-x for Sample 1 and 2-x for Sample 2.

2) Only one of the samples is to be machined, the other should be tested as a parallel specimen. The results for the machined sample should be reported as the Sample 1 results, while the results of the parallel specimen should be reported as the Sample 2 results.

3) The tests to be performed in this program are:

- 0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$);
- Lower and Upper Yield Strength (ReL and ReH) if applicable;
- Tensile Strength (Rm);
- Percentage Elongation after Fracture (A%); and
- Percentage Reduction in Area after Fracture (Z%).

4) **Caution must be exercised while testing the parallel specimen. If the specimen breaks at the grip section it may cause significant damage to the grips or the machine. Please check the relevant codes and specifications for guidance on testing parallel specimens safely.**

5) All testing, recording and reporting is to be performed in accordance with your routine test methods, but testing in accordance with AS 1391 – *Metallic materials – Tensile testing at ambient temperature* (2007) or ISO 6892-1 – *Metallic materials – Tensile testing – Part 1: Method of test at room temperature* (2016) are the preferred test methods.

6) Report only one result per sample, based on the determination for each property. For each determination, results are to be reported to the accuracy and in the units indicated on the Results Sheet.

7) The method of testing used should also be reported on the Results Sheet (*e.g.* AS 1391, ISO 6892-1, etc.)

8) The Percentage Elongation after Fracture (A%) results will be converted to a proportional gauge length before analysis. Participants should therefore report the Tensile Specimen Diameter and Tensile Specimen Gauge Length.

9) Participants are also requested to calculate and report an estimate of uncertainty of measurement for each reported measurement result. All estimates of uncertainty of measurement must be given as a 95% confidence interval (coverage factor $k \approx 2$).

10) For this program, your laboratory has been allocated the code number on the attached Results Sheet. All reference to your laboratory in reports associated with this program will be via this code number, ensuring the confidentiality of your results.

11) Return the Results Sheet, either by mail, email or facsimile, to:

Mark Bunt
Proficiency Testing Australia
PO Box 7507
Silverwater NSW 2128
AUSTRALIA

Telephone: + 61 2 9736 8397 (1300 782 867)
Fax: +61 2 9743 6664
Email: mbunt@pta.asn.au

All results should arrive at the above address by no later than **Friday 23 March 2018**. Results reported later than this date may not be analysed in the final report.

PROFICIENCY TESTING AUSTRALIA

Tensile Testing Of Metals Proficiency Testing Program Round 11, March 2018

RESULTS SHEET

Laboratory Code: ____

Test	Report results to nearest	Sample 1		Sample 2		Method
		Result	MU (±)	Result	MU (±)	
0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$)	1 MPa					
Lower Yield Strength (ReL)	1 MPa					
Upper Yield Strength (ReH)	1 MPa					
Tensile Strength (Rm)	1 MPa					
Percentage Elongation after Fracture (A%)	1%					
Percentage Reduction in Area after Fracture (Z%)	1%					

Where possible, please also report the values for the following:

Test	Report results to nearest	Sample 1		Sample 2	
		Result	MU (±)	Result	MU (±)
Tensile Specimen Diameter	0.01 mm				
Tensile Specimen Gauge Length	1 mm				
Elastic Stress or Strain Rate	number / sec				
Plastic Strain Rate	number / sec				

All estimates of measurement uncertainty (MU) must be given as a 95% confidence interval (coverage factor $k \approx 2$).

Print Name: _____ Signature & Date: _____

-----End of Report-----