REPORT NO. 1028

Tensile Testing of Metals

Proficiency Testing Program

Round 10

June 2017

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 tenth round of an ongoing series of programs.

Proficiency Testing Australia (PTA) conducted the testing program in April 2017. 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 K Cividin, PTA Quality Coordinator / Senior Scientific Officer.

2. FEATURES OF THE PROGRAM

(a) A total of 19 laboratories participated in the program, one of which did not return results for inclusion in the final report. Laboratories from the following countries received samples:

13	AUSTRALIA
3	NEW ZEALAND
2	SAUDI ARABIA
1	HONG KONG

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 some laboratories' code numbers (with letter) 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 flat bar samples. Both samples were approximately 300 mm in length, 40 mm in width and 5 mm in thickness. 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) ($R_{p0.2}$);
- Tensile Strength (Rm); and
- Percentage Elongation after Fracture (A%).

(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 four sections (A1-A4).

Sections A1-A3 contain the analysis of results reported by laboratories for 0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$), Tensile Strength (Rm) and Percentage Elongation after Fracture (A%). 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 A4 contains information on the methods used by laboratories and the results reported by laboratories for Tensile Specimen Thickness, Tensile Specimen Gauge Width, 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-score| ≥ 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-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	18	11
	Median	462.0	464.0
	Normalised IQR	19.1	19.3
	Uncertainty (Median)	5.6	7.3
Tensile Strength (Rm) (MPa)	Number of Results	20	13
	Median	532.5	534.0
	Normalised IQR	11.1	8.2
	Uncertainty (Median)	3.1	2.8
Percentage Elongation after Fracture (A%)	Number of Results	20	13
	Median	23.6	24.5
	Normalised IQR	2.6	3.6
	Uncertainty (Median)	0.7	1.3

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

Test	Sample 1	Sample 2
0.2% Proof Stress	9	-
Tensile Strength	7A, 7B, 11, 16	1, 11
Percentage Elongation after Fracture	-	18A, 18B

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.

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 above. Complete details of the statistical analyses appear in Appendix A.

6.1 Return rate

Eighteen of the 19 laboratories (95%) that participated in the program returned results. Of the 18 laboratories that submitted results for the program, the return rate for all tests is as follows:

- 0.2% Proof Stress 16 out of 18 89%
- Tensile Strength 18 out of 18 100%
- Percentage Elongation after Fracture 18 out of 18 100%

6.2 Performance summary

One or more statistical outliers were reported by six of the 18 laboratories (33%) that returned results for this round of the program. The last round of the Tensile Testing of Metals program where participants tested two steel flat bar samples was Round 8. For comparison, 40% of the participants reported outlier results in Round 8 of the Tensile Testing of Metals program (see Report No. 926 for more details)

A total of 95 results were analysed in this round of the program. Of these results, nine (9%) were outliers. For comparison, 8% of the results analysed in Round 8 of the Tensile Testing of Metals program were outliers (see Report No. 926 for more details).

6.3 0.2% Proof Stress

Of the 16 laboratories that tested the samples for 0.2% Proof Stress, ten laboratories tested using AS 1391, one laboratory tested using ISO 6892-1 and one laboratory used both AS 1391 and ISO 6892-1. Two laboratories used the ASTM A370 method. Two laboratories did not specify the method that they used for testing (see Appendix A4 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 461.0 ± 6.5 MPa. For all methods pooled, the median and standard error of the 0.2% Proof Stress results for sample 1 was 462.0 ± 5.6 MPa.

There were not enough results submitted for any specific method for sample 2 to draw reliable conclusions from analysing grouped methods on this occasion.

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

One laboratory (code 9) reported an outlier result for sample 1. One other laboratory (code 11) obtained an absolute z-score between 2.0 and 3.0 for sample 1. Laboratory 12 reported Lower Yield Strength results instead of 0.2% Proof Stress results.

The low 0.2% Proof Stress result for sample 1 for laboratory 9 (397 MPa compared to the median of 462 MPa) may suggest the presence and effects of machine slack on the test results. This may be evident on the tensile curve of this test, where the displacement or the strain of the curve did not start at zero. As the 0.2% Proof Stress of the material is sensitive to the strain of the material, it is very important to ensure that, before the test is initiated, all the slack in the system is removed and the system is reset. To remove slack, it may be useful to preload the test specimen with small loads only and then reset the system.

The robust CVs for the 0.2% Proof Stress results were 4.1% and 4.2% for sample 1 and sample 2, respectively. The last round of this program where participants tested two steel flat bar samples was Round 8. In Round 8 of this program, only one of the samples was tested for 0.2% Proof Stress. The robust CV obtained for this sample was 11.1%, which is much higher than the robust CV values obtained in this round of the program (see Report No. 926 for more details).

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

6.4 Tensile Strength

A total of 18 laboratories tested the samples for Tensile Strength. Of these laboratories, eleven tested using the AS 1391 method. Two 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. Two laboratories did not specify the method that they used for testing (see Appendix A4 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 531.5 ± 3.9 MPa. For all methods pooled, the median and standard error of the Tensile Strength results was 532.5 ± 3.1 MPa.

There were not enough results submitted for any specific method for sample 2 to draw reliable conclusions from analysing grouped methods on this occasion.

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

Laboratory 11 reported outliers for both samples. Laboratory 16 reported an outlier for sample 1. Laboratory 7 machined both samples. Both of these results were assessed as sample 1 results and both were outliers. Laboratory 1 reported an outlier for sample 2. Laboratory 1 also obtained an absolute z-score between 2.0 and 3.0 for sample 1.

Although the 0.2% Proof Stress and Percentage Elongation after Fracture results for laboratories 7 and 11 are within the acceptable limits, it may be possible that the calibration of their machines is due soon. Some servo-hydraulic universal testing machines may exhibit slightly higher than normal results as they age, especially where high loads are applied extensively. Preparation of the test specimen also plays an important part, especially for the ultimate tensile strength. Cold work machining and preparation, such as the use of angle grinders, cold saws, table grinders etc. may introduce enough heat input that it may work harden the specimen, therefore hardening the material. This may also be true for the other two laboatories (codes 1 and 16) with outlier results.

In order to avoid the effects of unintentional heat input on the microstructure of the test samples, laboratories should ensure that the guidelines provided by codes and standards are followed.

The robust CVs for the Tensile Strength results were 2.1% and 1.5% for sample 1 and sample 2, respectively. These values are lower than the values of 3.0% and 4.7%, obtained for the Tensile Strength results for Round 8 of this program (see Report No. 926 for more details).

Twelve laboratories reported measurement uncertainties associated with their Tensile Strength test results in this round.

6.5 Percentage Elongation after Fracture

A total of 18 laboratories tested the samples for Percentage Elongation after Fracture. Of these laboratories, eleven tested using the AS 1391 method. Two 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. Two laboratories did not specify the method that they used for testing (see Appendix A4 for more details).

Because the participants employed different gauge widths 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 A3. The exact formula used to convert the results is given on page A3.1 of Appendix A3.

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 23.6 ± 0.9%. For all methods pooled, the median and standard error of the Percentage Elongation after Fracture results (converted to a proportional gauge length) was 23.6 ± 0.7%.

There were not enough results submitted for any specific method for sample 2 to draw reliable conclusions from analysing grouped methods on this occasion.

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

On the recommendation of the Technical Adviser for this program, the two Percentage Elongation after Fracture results submitted by laboratory 18 were both assessed against the sample 2 results and both results were outliers. One other laboratory (code 6) obtained an absolute z-score between 2.0 and 3.0 for sample 1.

The proof strengths and ultimate tensile strengths reported by laboratory 18 are within the acceptable limits, meaning that the methodology the laboratory followed is appropriate. However, the reason the elongation results are abnormally high could be due to incorrect measurement of the elongation after fracture. Following the guidelines by AS, ASTM and ISO standards on determining elongation after fracture results will greatly help to produce acceptable results in the future.

The robust CVs for the Percentage Elongation after Fracture results were 11.0% and 14.8% for sample 1 and sample 2, respectively. These values are higher than the values of 4.6% and 6.1%, obtained for the Percentage Elongation after Fracture results for Round 8 of this program (see Report No. 926 for more details).

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

6.6 Measurement Uncertainty

The majority of participants in this round (63% – 67%) 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	10 out of 16	63%
• Tensile Strength	12 out of 18	67%
• Percentage Elongation after Fracture	12 out of 18	67%

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.

6.7 Other Reported Results

In addition to reporting results for 0.2% Proof Stress, Tensile Strength and Percentage Elongation after Fracture, participants were also asked to report the Tensile Specimen Thickness, Tensile Specimen Gauge Width, 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 A4.

The information reported is limited, but it was requested in the hope that it would assist in the analysis of the results, especially in converting the Percentage Elongation after Fracture results to a proportional gauge length.

There was a large range in the stress and strain rates reported by the participants in this round of the program and many of these results were reported in unusual units. The range of test conditions and test pieces (allowed by the standards), along with test setups, will always allow for variation in the test results obtained.

6.8 General Comments

Overall the performance of the participants in this round of the program is commendable. Comparing the tensile properties for a machined and parallel specimen, a high level of uncertainty in the yield strength and percentage elongation results would be expected, as these tests are geometry-sensitive. However, only three results were outliers for these properties. This shows the effectiveness of the methodologies and proficiency of the participant laboratories. This program is carefully designed and developed to test the knowns and the unknowns of the tensile testing of materials and it provides a great opportunity for any laboratory to check their proficiency.

The aim of this round 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. For the next round of the program, it is suggested that round bars be used, where only one sample is machined and the other is tested as a parallel specimen.

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

0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$) (MPa)

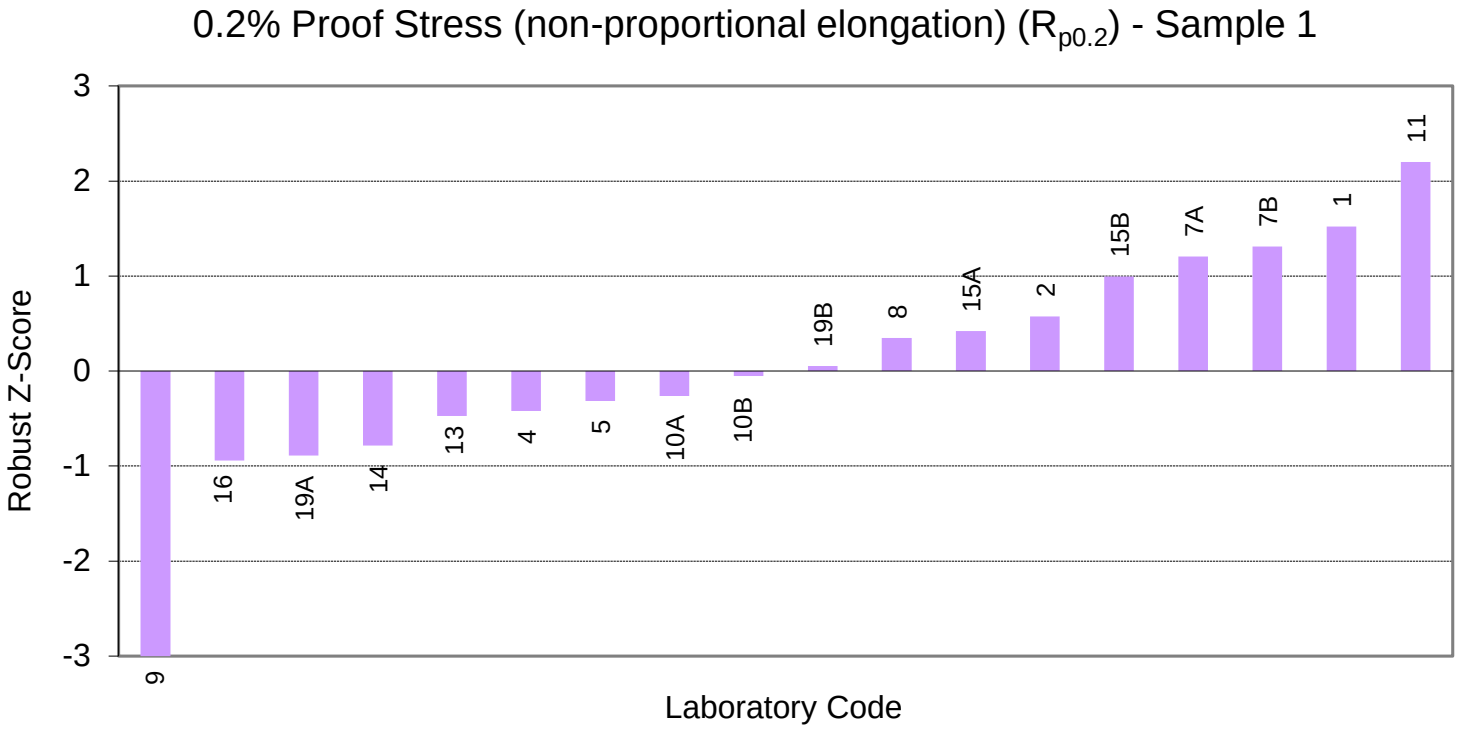
Lab Code	Sample 1			Sample 2		
	Result	MU (±)	Z-Score	Result	MU (±)	Z-Score
1	491.0	6.0	1.52	492.0	6.0	1.45
2	473	-	0.58	-	-	-
3A	-	-	-	483	6	0.99
3B	-	-	-	482	6	0.93
4	454	5	-0.42	-	-	-
5	456	13	-0.31	458	13	-0.31
7A	485	-	1.20	-	-	-
7B	487	-	1.31	-	-	-
8	468.67	-	0.35	467.80	-	0.20
9	397	36	-3.41 **§**	-	-	-
10A	457	8.3	-0.26	-	-	-
10B	461	8.3	-0.05	-	-	-
11	504	-	2.20	499	-	1.82
12	No Proof LYS 449	6.35	-	No Proof LYS 453	6.35	-
13	453	2	-0.47	457	2	-0.36
14	447	2.5	-0.79	464	2.3	0.00
15A	470	0.40%	0.42	-	-	-
15B	481	0.40%	1.00	-	-	-
16	444	-	-0.94	456	-	-0.42
18A	-	-	-	447	-	-0.88
18B	-	-	-	449	-	-0.78
19A	445	3.6%	-0.89	-	-	-
19B	463	3.6%	0.05	-	-	-

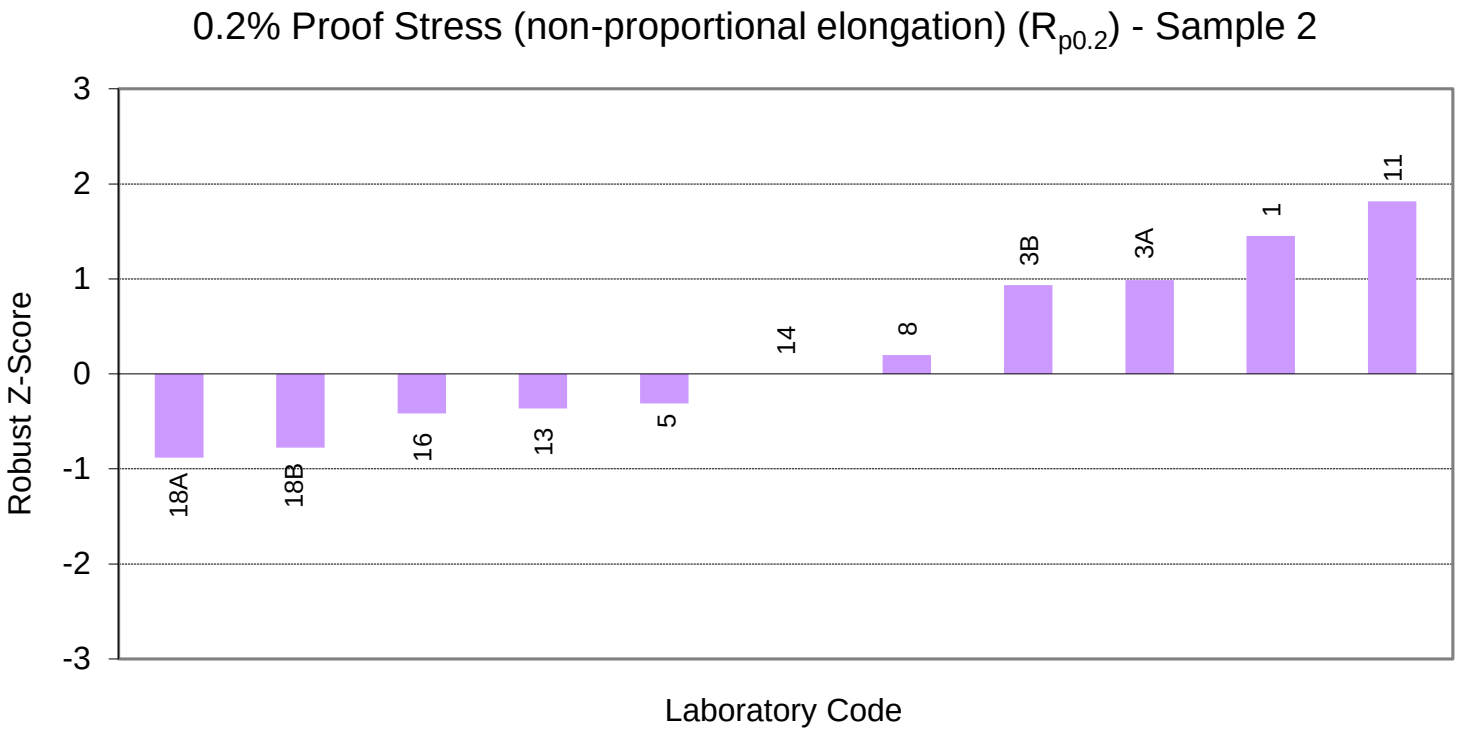
Summary Statistics

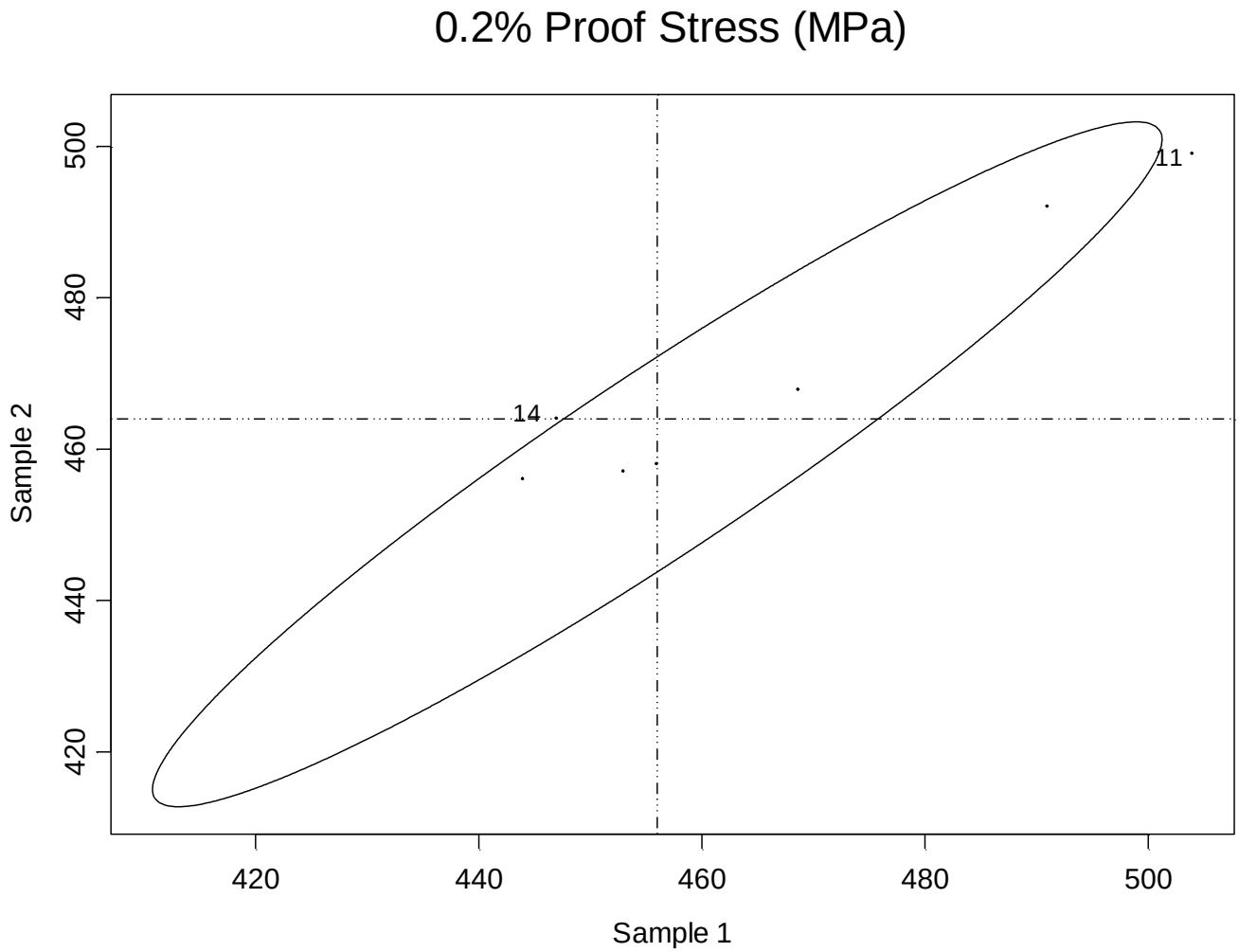
Statistic	Sample 1	Sample 2
Number of Results	18	11
Median	462.0	464.0
Normalised IQR	19.1	19.3
Uncertainty (Median)	5.6	7.3
Robust CV	4.1%	4.2%
Minimum	397	447
Maximum	504	499
Range	107	52

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. Laboratory 2 did not report results for sample 2 because they machined the first sample incorrectly.
3. Laboratory 9 was unable to grip the parallel sample (sample 2) on the jaws of their machine. A longer sample will be provided at a later date for this laboratory to test.
4. Laboratory 14 had to machine 5 mm from the width of sample 2 to reduce the cross-sectional area for their machine capacity.
5. Laboratory 7 reported that they accidentally machined both of the samples. Their sample 1 results were denoted by the code 7A, while their sample 2 results were denoted by the code 7B and were assessed against the other machined sample (sample 1) results.
6. The Technical Adviser for this program also recommended that the sample 2 results reported by laboratories 10, 15 and 19 should be assessed as sample 1 results, while the sample 1 results reported by laboratories 3 and 18 should be assessed as sample 2 results.
7. To distinguish between the two sets of sample 1 results for laboratories 10, 15 and 19 and the two sets of sample 2 results for laboratories 3 and 18, code letters A and B have been appended to these results.
8. The Youden diagram on the following page is provided for information only.
9. The Youden diagram only includes laboratories 1, 5, 8, 11, 13, 14 and 16.




0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
18A
18B
16
13
5
14
8
3B
3A
1
11
Laboratory Code


0.2% Proof Stress (MPa)
Sample 2
500
480
460
440
420
11
14
420
440
460
480
500
Sample 1

Section A2

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	564.0	6.0	2.83	567.0	6.0	4.05 **§**
2	526	-	-0.58	-	-	-
3A	-	-	-	540	6	0.74
3B	-	-	-	539	6	0.61
4	534	6	0.13	-	-	-
5	531	11	-0.13	532	11	-0.25
6	526	1.66	-0.58	529	2.84	-0.61
7A	566	-	3.01 **§**	-	-	-
7B	568	-	3.19 **§**	-	-	-
8	535.20	-	0.24	535.20	-	0.15
9	522	62	-0.94	-	-	-
10A	533	9.7	0.04	-	-	-
10B	526	9.7	-0.58	-	-	-
11	591	-	5.26 **§**	565	-	3.80 **§**
12	529	5.09	-0.31	534	5.09	0.00
13	531	2	-0.13	527	2	-0.86
14	529	2.8	-0.31	521	2.6	-1.59
15A	528	0.40%	-0.40	-	-	-
15B	532	0.40%	-0.04	-	-	-
16	592	-	5.35 **§**	536	-	0.25
18A	-	-	-	528	-	-0.74
18B	-	-	-	525	-	-1.10
19A	537	0.6%	0.40	-	-	-
19B	535	0.6%	0.22	-	-	-

Summary Statistics

Statistic	Sample 1	Sample 2
Number of Results	20	13
Median	532.5	534.0
Normalised IQR	11.1	8.2
Uncertainty (Median)	3.1	2.8
Robust CV	2.1%	1.5%
Minimum	522	521
Maximum	592	567
Range	70	46

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. Laboratory 2 did not report results for sample 2 because they machined the first sample incorrectly.
3. Laboratory 9 was unable to grip the parallel sample (sample 2) on the jaws of their machine. A longer sample will be provided at a later date for this laboratory to test.
4. Laboratory 14 had to machine 5 mm from the width of sample 2 to reduce the cross-sectional area for their machine capacity.
5. Laboratory 7 reported that they accidentally machined both of the samples. Their sample 1 results were denoted by the code 7A, while their sample 2 results were denoted by the code 7B and were assessed against the other machined sample (sample 1) results.
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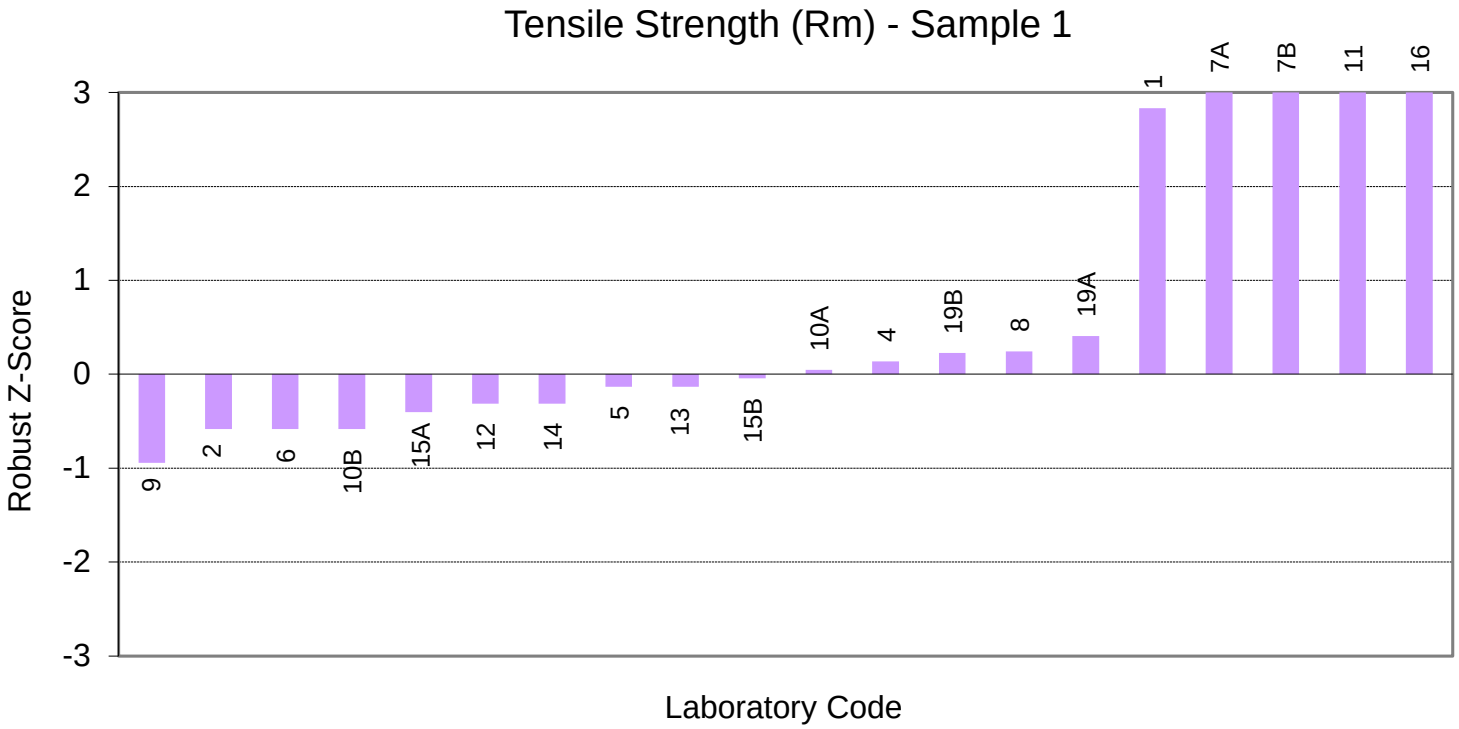
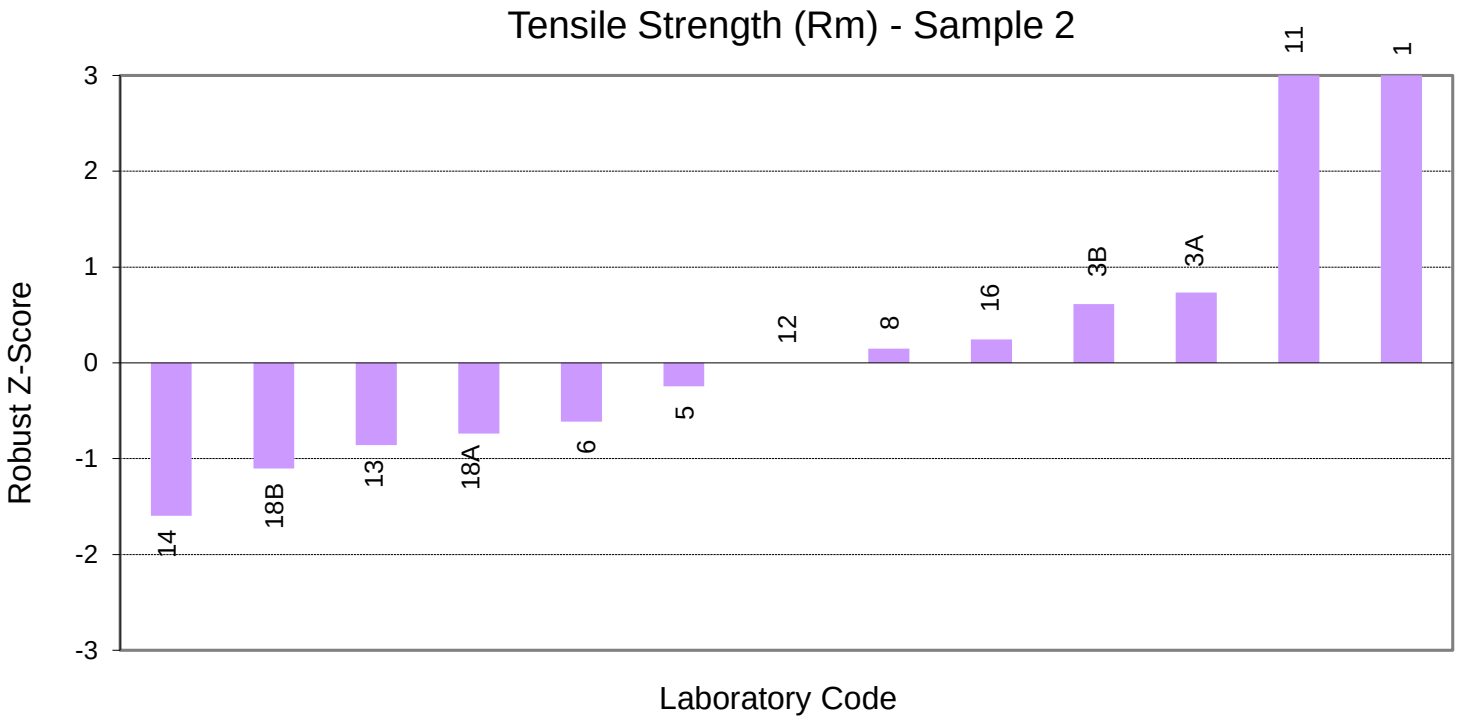
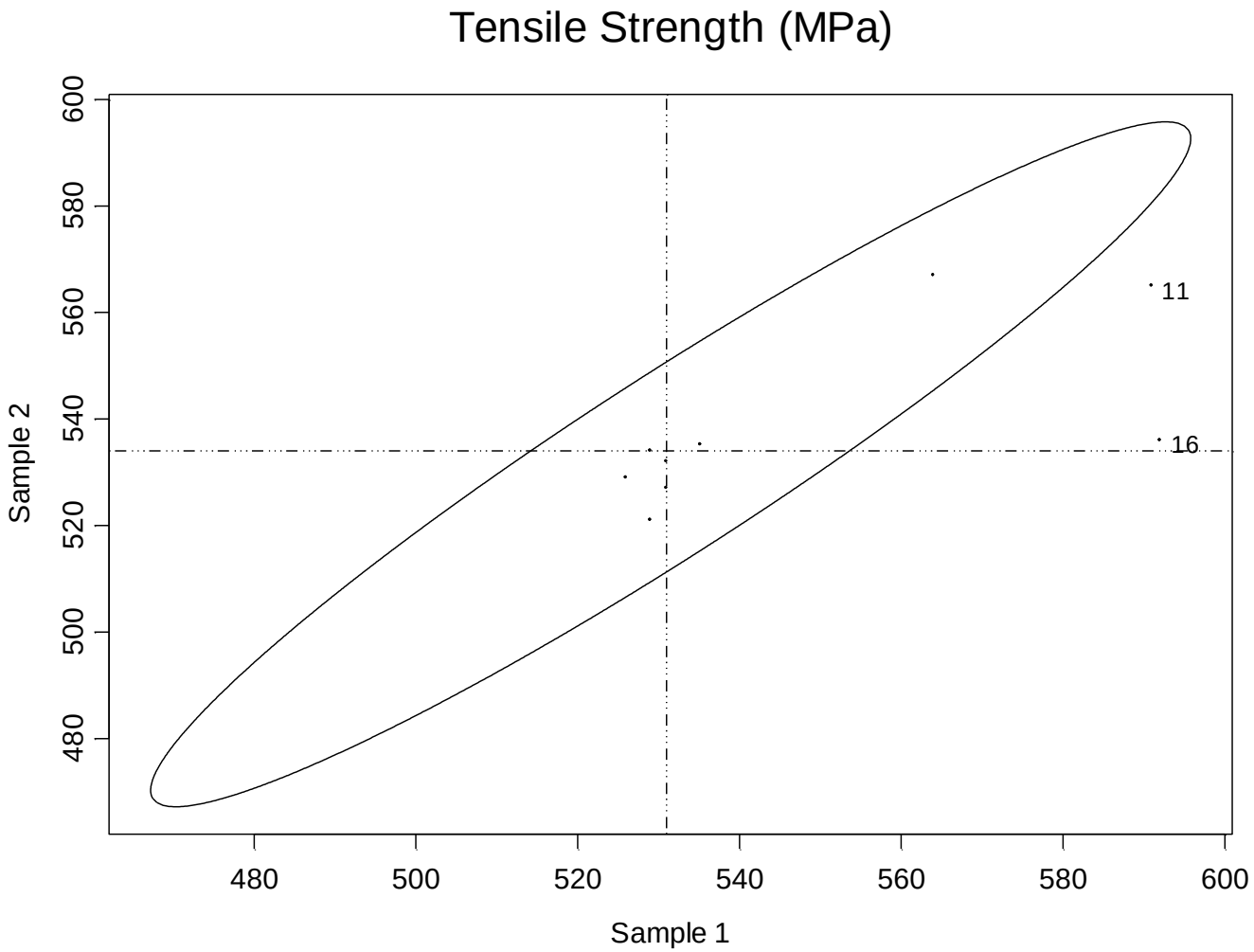


A2.3


Tensile Strength (Rm) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
14
18B
13
18A
6
5
12
8
16
3B
3A
11
1
Laboratory Code


Tensile Strength (MPa)
Sample 2
600
580
560
540
520
500
480
11
16
480
500
520
540
560
580
600
Sample 1

Section A3

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	21.0	1.0	22	30.0	1.0	25
2	20	-	23	-	-	-
3A	-	-	-	21	0.1	21
3B	-	-	-	21	0.1	21
4	22	1%	22	-	-	-
5	24	1	25	25	1	21
6	18	0.29	30	18	0.29	26
7A	22	-	23	-	-	-
7B	20	-	21	-	-	-
8	27.51	-	25	29.24	-	25
9	25	2	26	-	-	-
10A	17	0.3	20	-	-	-
10B	21	0.3	24	-	-	-
11	22	-	22	22	-	22
12	22.5	1.70	26	28.8	1.70	29
13	21	< 0.5	21	21	< 0.5	21
14	24	0.32%	24	26	0.21%	26
15A	19	0.40%	20	-	-	-
15B	16	0.40%	18	-	-	-
16	24	-	25	20	-	24
18A	-	-	-	26	-	38
18B	-	-	-	24	-	35
19A	23	1%	24	-	-	-
19B	25	1%	25	-	-	-

Note:

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

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

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

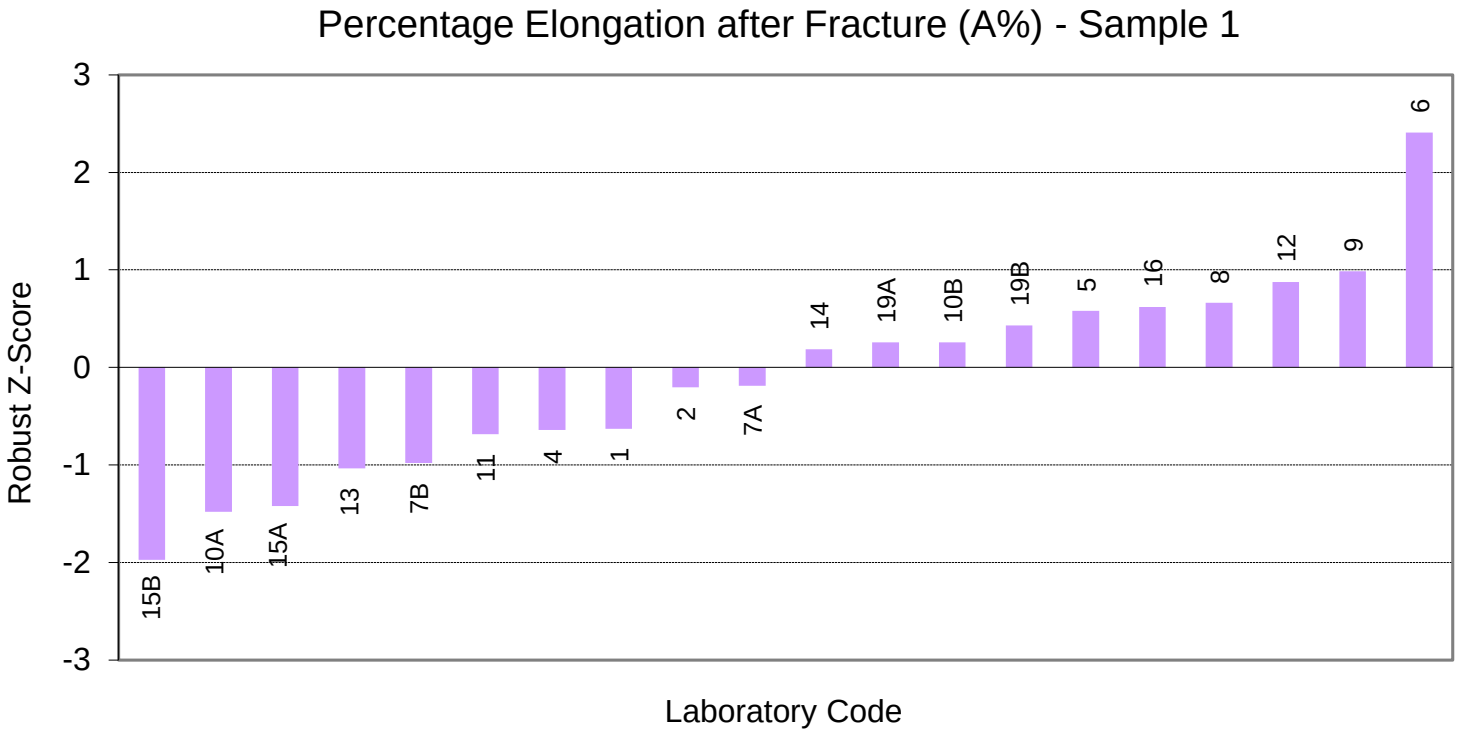
Lab Code	Sample 1		Sample 2	
	PGL Result	Z-Score	PGL Result	Z-Score
1	22	-0.63	25	0.12
2	23	-0.20	-	-
3A	-	-	21	-0.96
3B	-	-	21	-0.99
4	22	-0.64	-	-
5	25	0.58	21	-1.02
6	30	2.41	26	0.41
7A	23	-0.19	-	-
7B	21	-0.98	-	-
8	25	0.66	25	0.00
9	26	0.99	-	-
10A	20	-1.48	-	-
10B	24	0.26	-	-
11	22	-0.69	22	-0.72
12	26	0.88	29	1.18
13	21	-1.03	21	-0.94
14	24	0.19	26	0.39
15A	20	-1.42	-	-
15B	18	-1.97	-	-
16	25	0.62	24	-0.13
18A	-	-	38	3.61 **§**
18B	-	-	35	3.01 **§**
19A	24	0.26	-	-
19B	25	0.43	-	-

Summary Statistics

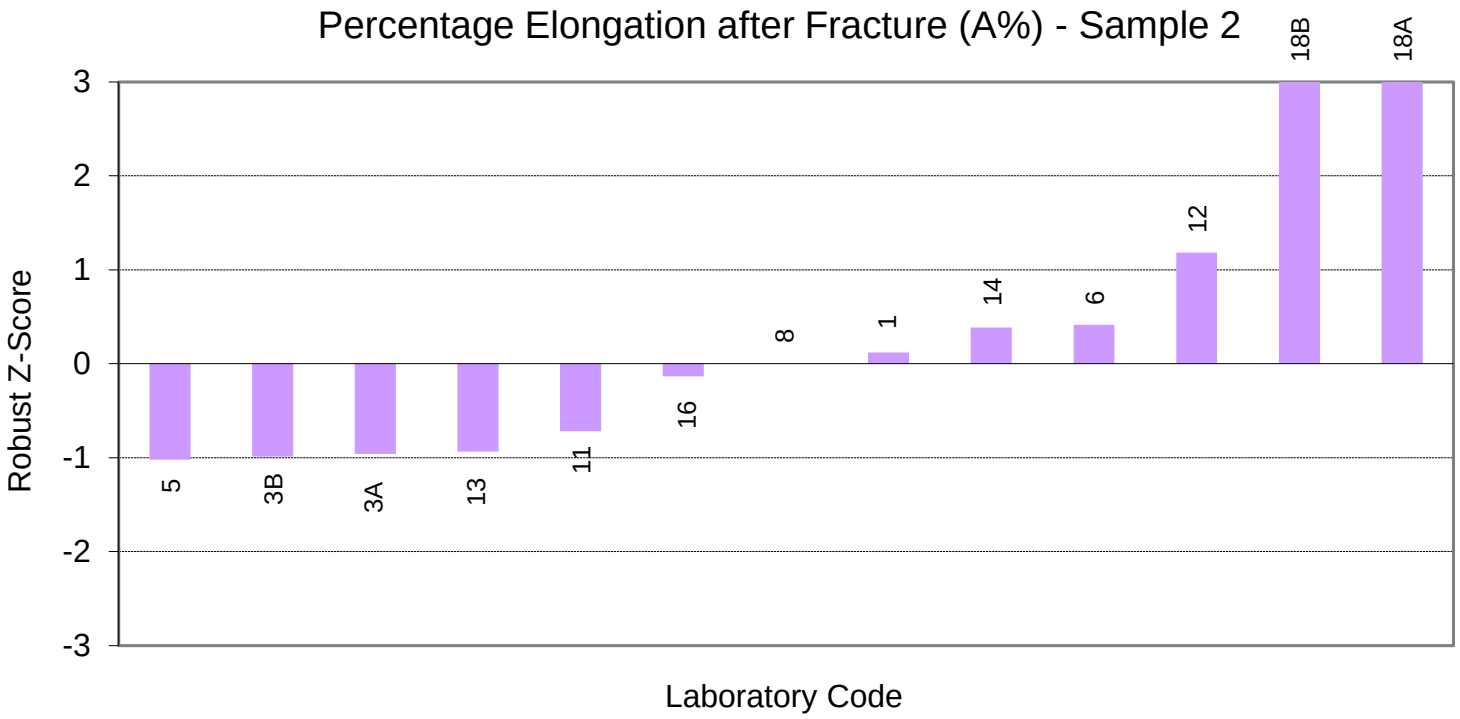
Statistic	Sample 1	Sample 2
Number of Results	20	13
Median	23.6	24.5
Normalised IQR	2.6	3.6
Uncertainty (Median)	0.7	1.3
Robust CV	11.0%	14.8%
Minimum	18	21
Maximum	30	38
Range	11	17

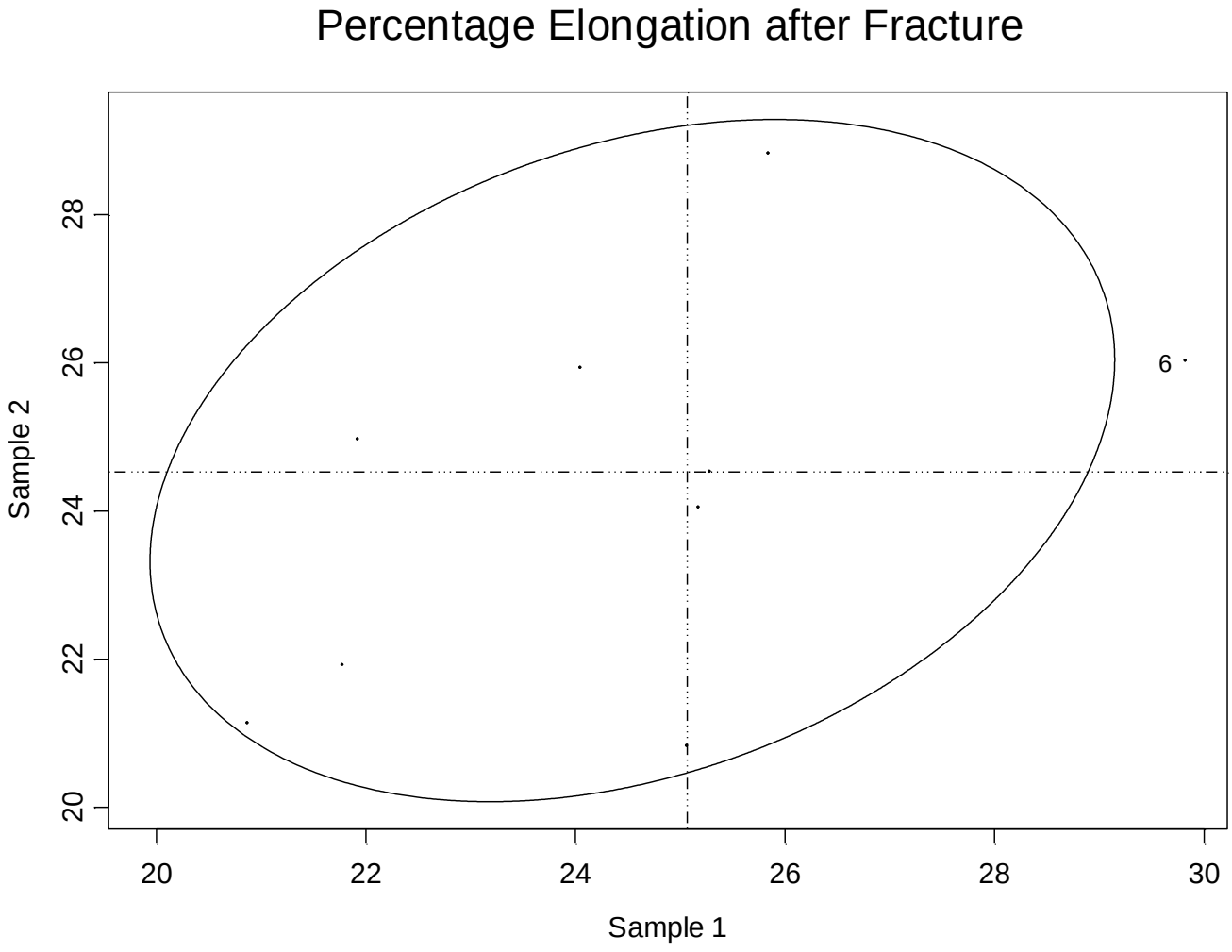
Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. Laboratory 2 did not report results for sample 2 because they machined the first sample incorrectly.
3. Laboratory 9 was unable to grip the parallel sample (sample 2) on the jaws of their machine. A longer sample will be provided at a later date for this laboratory to test.
4. Laboratory 14 had to machine 5 mm from the width of sample 2 to reduce the cross-sectional area for their machine capacity.
5. Laboratory 7 reported that they accidentally machined both of the samples. Their sample 1 results were denoted by the code 7A, while their sample 2 results were denoted by the code 7B and were assessed against the other machined sample (sample 1) results.
6. The Technical Adviser for this program also recommended that the sample 2 results reported by laboratories 10, 15 and 19 should be assessed as sample 1 results, while the sample 1 results reported by laboratories 3 and 18 should be assessed as sample 2 results.
7. To distinguish between the two sets of sample 1 results for laboratories 10, 15 and 19 and the two sets of sample 2 results for laboratories 3 and 18, code letters A and B have been appended to these results.
8. The Youden diagram on the following page is provided for information only.
9. The Youden diagram only includes laboratories 1, 5, 6, 8, 11, 12, 13, 14 and 16.



A3.4


Percentage Elongation after Fracture (A%) - Sample 2
Robust Z-Score
3
2
1
0
-1
-2
-3
5
3B
3A
13
11
16
8
1
14
6
12
18B
18A
Laboratory Code


Percentage Elongation after Fracture
Sample 2
20
22
24
26
28
6
20
22
24
26
28
30
Sample 1

Section A4

Method Information and Other Reported Results

Method Information

Lab Code	0.2% Proof Stress	Tensile Strength	Percentage Elongation after Fracture
1	ASTM A370	ASTM A370	ASTM A370
2	AS 1391	AS 1391	AS 1391
3A	ISO 6892-1	ISO 6892-1	ISO 6892-1
3B	ISO 6892-1	ISO 6892-1	ISO 6892-1
4	-	-	-
5	AS 1391	AS 1391	AS 1391
6	-	AS 1391	AS 1391
7A	AS 1391	AS 1391	AS 1391
7B	AS 1391	AS 1391	AS 1391
8	ASTM A370	ASTM A370	ASTM A370
9	AS 1391	AS 1391	AS 1391
10A	AS 1391 / ISO 6892-1	AS 1391 / ISO 6892-1	AS 1391 / ISO 6892-1
10B	AS 1391 / ISO 6892-1	AS 1391 / ISO 6892-1	AS 1391 / ISO 6892-1
11	AS 1391	AS 1391	AS 1391
12	ISO 6892-1*****	ISO 6892-1	ISO 6892-1
13	AS 1391	AS 1391	AS 1391
14	AS 1391	AS 1391	AS 1391
15A	AS 1391	AS 1391	AS 1391
15B	AS 1391	AS 1391	AS 1391
16	AS 1391 - 2007	AS 1391 - 2007	AS 1391 - 2007
18A	-	-	-
18B	-	-	-
19A	AS 1391 - 2007	AS 1391 - 2007	AS 1391 - 2007
19B	AS 1391 - 2007	AS 1391 - 2007	AS 1391 - 2007

Note:

***** Laboratory 12 reported Lower Yield Strength results instead of 0.2% Proof Stress results.

Tensile Specimen Thickness and Tensile Specimen Gauge Width

Lab Code	Tensile Specimen Thickness (mm)				Tensile Specimen Gauge Width (mm)			
	Sample 1		Sample 2		Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)	Result	MU (±)	Result	MU (±)
1	4.96	0.01	4.94	0.01	12.70	0.01	39.65	0.01
2	4.94	-	-	-	19.98	-	-	-
3A	-	-	4.88	0.01	-	-	39.53	0.03
3B	-	-	4.85	0.01	-	-	39.75	0.03
4	4.01	0.014	-	-	19.95	0.014	-	-
5	4.96	0.002	4.93	0.002	12.67	0.019	39.50	0.019
6	4.97	0.0013	4.97	0.0013	20.13	0.053	39.80	0.053
7A	4.95	-	-	-	12.43	-	-	-
7B	4.94	-	-	-	12.36	-	-	-
8	4.84	-	4.94	-	25.40	-	39.30	-
9	5.01	-	-	-	12.50	-	-	-
10A	4.78	0.014	-	-	19.95	0.014	-	-
10B	4.89	0.014	-	-	20.01	0.014	-	-
11	4.85	-	4.85	-	20.50	-	39.95	-
12	4.98	0.001	4.91	0.001	20.08	0.01	39.56	0.01
13	4.92	0.01	4.92	0.01	19.81	0.01	39.40	0.03
14	4.95	0.002	4.97	0.002	12.65	0.014	34.91	0.014
15A	4.92	0.40%	-	-	12.70	0.40%	-	-
15B	4.90	0.40%	-	-	20.14	0.40%	-	-
16	4.91	-	4.90	-	12.52	-	39.67	-
18A	-	-	4.98	-	-	-	39.62	-
18B	-	-	4.98	-	-	-	35.74	-
19A	4.80	0.2%	-	-	12.55	0.2%	-	-
19B	4.70	0.2%	-	-	17.70	0.2%	-	-

Tensile Specimen Gauge Length (mm)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	50	1.0	50	1.0
2	80	-	-	-
3A	-	-	79	0.05
3B	-	-	78	0.05
4	50	0.014	-	-
5	50	0.019	50	0.019
6	200	0.58	200	0.58
7A	50.0	-	-	-
7B	50.0	-	-	-
8	50.80	-	50.80	-
9	50	-	-	-
10A	80.00	-	-	-
10B	80.00	-	-	-
11	55	-	78	-
12	80	0.01	79	0.01
13	55	0.01	80	0.01
14	45	0.29	74	0.29
15A	50	0.40%	-	-
15B	80	0.40%	-	-
16	50	-	125	-
18A	-	-	200	-
18B	-	-	200	-
19A	50	0.2%	-	-
19B	50	0.2%	-	-

Elastic Stress or Strain Rate (number / sec)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	-	-	-	-
2	1.2 mm/min	-	-	-
3A	-	-	0.00025	-
3B	-	-	0.00025	-
4	6 MPa/s	1%	-	-
5	0.0001	-	0.0001	-
6	-	-	-	-
7A	0.0020	-	-	-
7B	0.0020	-	-	-
8	-	-	-	-
9	0.002	-	-	-
10A	0.00022	-	-	-
10B	0.00012	-	-	-
11	10 MPa/s	-	10 MPa/s	-
12	0.0008	-	0.0008	-
13	15 MPa/s	-	15 MPa/s	-
14	0.02% /s	0.25%	0.02% /s	0.25%
15A	-	-	-	-
15B	-	-	-	-
16	0.0025	-	0.0025	-
18A	-	-	-	-
18B	-	-	-	-
19A	0.001	-	-	-
19B	0.001	-	-	-

Plastic Strain Rate (number / sec)

Lab Code	Sample 1		Sample 2	
	Result	MU (±)	Result	MU (±)
1	-	-	-	-
2	10 mm/min	-	-	-
3A	-	-	0.0067	-
3B	-	-	0.0067	-
4	0.00025	1%	-	-
5	0.002	-	0.001	-
6	-	-	-	-
7A	-	-	-	-
7B	-	-	-	-
8	-	-	-	-
9	0.008	-	-	-
10A	0.00031	-	-	-
10B	0.00018	-	-	-
11	10 MPa/s	-	10 MPa/s	-
12	0.0075	-	0.0075	-
13	0.006	-	0.006	-
14	0.25 mm/s	0.25%	0.25 mm/s	0.25%
15A	-	-	-	-
15B	-	-	-	-
16	0.008	-	0.008	-
18A	-	-	-	-
18B	-	-	-	-
19A	0.003	-	-	-
19B	0.003	-	-	-

APPENDIX B

Homogeneity Testing

HOMOGENEITY TESTING

Before the test pieces were distributed to participants, ten specimens from each 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

Sample 1 – Machined Sample

Sample Number	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Original Gauge Length (mm)	% Elongation
1-1	93.59	545	470	80	17
1-2	91.63	550	480	80	15
1-3	94.08	540	475	80	16
1-4	93.59	540	470	80	17
1-5	89.18	540	470	80	15
1-6	93.59	540	475	80	16
1-7	94.08	550	485	80	16
1-8	88.69	550	485	80	15
1-9	89.18	545	480	80	15
1-10	90.16	540	470	80	16

Homogeneity Testing Results

Sample 2 – Parallel Sample

Sample Number	Cross-sectional Area (mm^2)	Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Original Gauge Length (mm)	% Elongation
2-1	196.00	525	460	200	16
2-2	198.00	525	445	200	16
2-3	197.50	525	455	200	17
2-4	198.00	520	415	200	16
2-5	196.50	535	470	200	18
2-6	198.50	525	465	200	16
2-7	197.00	535	470	200	16
2-8	198.00	535	470	200	18
2-9	198.50	525	460	200	16
2-10	198.00	520	455	200	16

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

APPENDIX C

Instructions to Participants

and

Results Sheet

PROFICIENCY TESTING AUSTRALIA

Tensile Testing Of Metals Proficiency Testing Program
Round 10, April 2017

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 flat bar samples. Only one of the samples is to be machined, the other should be tested as a parallel specimen.

2) The samples are not numbered. The results for the machined sample should be reported as the Sample 1 results, while the results of the parallel specimen should be regarded as the Sample 2 results.

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

- 0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$);
- Tensile Strength (Rm); and
- Percentage Elongation after Fracture (A%).

3) Proof Stress and Percentage Elongation after Fracture for the parallel specimen is mandatory.

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 specimen safely.**

5) Tests may commence as soon as samples are received. The samples are to be treated in the same manner as routinely tested samples.

6) 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.

7) 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.

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

9) The Percentage Elongation after Fracture (A%) results will be converted by Proficiency Testing Australia to a proportional gauge length before analysis. Participants should therefore report the Tensile Specimen Gauge Width, Tensile Specimen Gauge Length and Tensile Specimen Thickness.

10) 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 $k \approx 2$).

11) 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.

12) 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 **Wednesday 19 April 2017**. 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 10, April 2017

RESULTS SHEET

Laboratory Code: _____

Test	Report results to nearest	Sample 1 Machined		Sample 2 Parallel		Method
		Result	MU (±)	Result	MU (±)	
0.2% Proof Stress (non-proportional elongation) ($R_{p0.2}$)	1 MPa					
Tensile Strength (Rm)	1 MPa					
Percentage Elongation after Fracture (A%)	1%					

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

Test	Report results to nearest	Sample 1 Machined		Sample 2 Parallel	
		Result	MU (±)	Result	MU (±)
Tensile Specimen Thickness	0.01 mm				
Tensile Specimen Gauge Width	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 ≈ 2).

Print Name: _____ Signature & Date: _____

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