REPORT NO. 1213

Hardness Testing of Metals

Proficiency Testing Program

Round 18

September 2020

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.

PO Box 7507 Silverwater NSW 2128 AUSTRALIA

CONTENTS

1. FOREWORD

This report summarises the results of a proficiency testing program on the hardness properties of metals. It constitutes the eighteenth round of an ongoing series of programs. This program is accredited to ISO/IEC 17043: 2010 "*Conformity assessment – General requirements for proficiency testing"* by International Accreditation New Zealand (IANZ).

Proficiency Testing Australia (PTA) conducted the testing program in June / July 2020. 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 Manager.

2. FEATURES OF THE PROGRAM

(a) A total of 23 laboratories received samples, all of which returned results for inclusion in the final report. Laboratories from the following countries received samples:

14	AUSTRALIA
3	NEW ZEALAND
1	BRAZIL
1	SAUDI ARABIA
1	TAIWAN
1	TANZANIA
1	THAILAND
1	UNITED KINGDOM

To ensure confidential treatment of results, each laboratory was allocated a unique random code number. Reference to each laboratory in this report is by its code number.

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

(c) Each laboratory was provided with one of two different steel samples, each approximately 60 mm in diameter and approximately 30 mm thick. Seventeen laboratories tested a lower hardness sample, while six laboratories tested a higher hardness sample. The samples were to be tested for Brinell, Vickers and Rockwell hardness.

(d) 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.

(e) 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 five sections (A1-A5).

Sections A1-A4 contain the analysis of results reported by laboratories for Brinell, Vickers, Rockwell B and Rockwell C hardness. 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; and
iii) ordered z-score charts.

Section A5 contains information on the methods used by the participants and the surface preparations they performed.

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

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

4. STATISTICAL 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.

For further details on the calculation and interpretation of robust z-scores and ordered z-score charts, please see the *Guide to Proficiency Testing Australia (2019)*.

5. OUTLIER RESULTS

The tables on the following pages summarise the results submitted by the participants in the program for both the lower and higher hardness samples.

Table A: Summary Statistics for the Lower Hardness Sample

Test	Summary Statistics	Average Result
Brinell Hardness (HBW)	Number of Results	13
	Median	198.0
	Normalised IQR	2.2
	Uncertainty (Median)	0.8
Vickers Hardness (HV)	Number of Results	16
	Median	209.0
	Normalised IQR	7.7
	Uncertainty (Median)	2.4
Rockwell B Hardness (HRB)	Number of Results	15
	Median	92.60
	Normalised IQR	0.70
	Uncertainty (Median)	0.23

Table B: Summary Statistics for the Higher Hardness Sample

Test	Summary Statistics	Average Result
Brinell Hardness (HBW)	Number of Results	9
	Median	277.3
	Normalised IQR	5.8
	Uncertainty (Median)	2.4
Vickers Hardness (HV)	Number of Results	12
	Median	283.3
	Normalised IQR	8.4
	Uncertainty (Median)	3.0
Rockwell B Hardness (HRB)	Number of Results	7
	Median	102.70
	Normalised IQR	0.77
	Uncertainty (Median)	0.36
Rockwell C Hardness (HRC)	Number of Results	7
	Median	29.60
	Normalised IQR	0.17
	Uncertainty (Median)	0.08

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

Test	Outliers (Laboratory Code No.)
Brinell Hardness	8
Vickers Hardness	8, 12
Rockwell B Hardness	17
Rockwell C Hardness	-

Notes:

1. For each test, the results for all test methods were pooled for analysis.
2. Summary statistics and z-scores were calculated for the average hardness value reported for each test.
3. The summary statistics and z-scores for the higher hardness sample were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd (see Appendix B).

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

All of the 23 laboratories that received samples submitted results for inclusion in the final report.

The return rate for all tests is as follows:

- Brinell Hardness 16 out of 23 70%
- Vickers Hardness 22 out of 23 96%
- Rockwell B Hardness 16 out of 23 70%
- Rockwell C Hardness 1 out of 23 4%

6.2 Performance summary

Statistical outliers were reported by three of the 23 laboratories (13%) that returned results in this round of the program. For comparison, 8% of the participants reported outlier results in Round 17 of this program (see Report No. 1183 for more details).

A total of 55 results were analysed in this program. Of these results, four (7%) were outlier results. For comparison, 3% of the results analysed in Round 17 of this program were outlier results (see Report No. 1183 for more details).

6.3 Brinell Hardness

A total of 13 laboratories tested the lower hardness sample for Brinell hardness. Of these laboratories, nine tested using the AS 1816 method. Two laboratories tested using the ISO 6506 method. One laboratory tested using the ASTM A370 method. One laboratory tested using the AS 1816 method, the ISO 6506 method and the ASTM E10 method (see Appendix A5 for more details).

There were not enough results submitted for any specific method to draw reliable conclusions from analysing grouped methods on this occasion for the lower hardness sample. The methods were pooled when analysing the results.

For all methods pooled, the median and its standard uncertainty for the Brinell hardness results for the lower hardness sample used this round was 198.0 ± 0.8 HB.

The CV for the Brinell hardness results for the lower hardness sample used this round was 1.1%. This is lower than the CV of 3.1%, obtained for the Brinell hardness results in Round 17 of this program (see Report No. 1183).

One laboratory (code 8) reported an outlier for Brinell hardness for the lower hardness sample, while one laboratory (code 20) obtained an absolute z-score between 2.0 and 3.0.

A total of three laboratories tested the higher hardness sample for Brinell hardness. Of these laboratories, one tested using the AS 1816 method, one tested using the ISO 6506 method and one tested using the ASTM E10 method (see Appendix A5 for more details). ARL Laboratory Services Pty Ltd also tested six of the higher hardness samples using the AS 1816 method. These results (see Appendix B) were included with the participants' results to calculate summary statistics and z-scores.

There were not enough results submitted for any specific method to draw reliable conclusions from analysing grouped methods on this occasion for the higher hardness sample. The methods were pooled when analysing the results.

For all methods pooled, the median and its standard uncertainty for the Brinell hardness results for the higher hardness sample used this round was 277.3 ± 2.4 HB.

The CV for the Brinell hardness results for the higher hardness sample used this round was 2.1%. This is lower than the CV of 3.1%, obtained for the Brinell hardness results in Round 17 of this program (see Report No. 1183).

There were no outliers reported for Brinell hardness for the higher hardness sample.

Ten laboratories reported measurement uncertainties associated with their Brinell hardness test results in this round.

6.4 Vickers Hardness

A total of 16 laboratories tested the lower hardness sample for Vickers hardness. Of these laboratories, twelve tested using the AS 1817 method. Three laboratories tested using the ISO 6507 method. One laboratory tested using both the AS 1817 method and the ASTM E92 method (see Appendix A5 for more details).

For the laboratories that used an Australian Standard method for the lower hardness sample, the median and its standard uncertainty for the Vickers hardness results was 209.0 ± 2.7 HV. For all methods pooled, the median and its standard uncertainty for the Vickers hardness results was 209.0 ± 2.4 HV. The methods were pooled when analysing the results.

The CV for the Vickers hardness results for the lower hardness sample used this round was 3.7%. This is higher than the CV of 2.5%, obtained for the Vickers hardness results in Round 17 of this program (see Report No. 1183).

One laboratory (code 8) reported an outlier for Vickers hardness for the lower hardness sample, while one laboratory (code 18) obtained an absolute z-score between 2.0 and 3.0.

Laboratory code 8 has reported a very high Vickers hardness result of 301.5 HV against the median of 209 HV. This laboratory also reported a very high Brinell hardness result of 428 HBW against the median of 198 HBW. Such high results suggest deficiencies in this laboratory's testing procedures including, but not limited to, testing machines being out of calibration or due for maintenance, test methodology not being aligned with the standardised testing methods or, perhaps, testing personnel requiring further training and evaluation on the Brinell and Vickers hardness testing procedures. This laboratory is strongly advised to review their testing processes and take advantage of these proficiency testing programs to evaluate their techniques and methodologies.

A total of six laboratories tested the higher hardness sample for Vickers hardness. Of these laboratories, two tested using the AS 1817 method, two tested using the ISO 6507 method and two tested using the ASTM E92 method (see Appendix A5 for more details). ARL Laboratory Services Pty Ltd also tested six of the higher hardness samples using the AS 1817 method. These results (see Appendix B) were included with the participants' results to calculate summary statistics and z-scores.

There were not enough results submitted for any specific method to draw reliable conclusions from analysing grouped methods on this occasion for the higher hardness sample. The methods were pooled when analysing the results.

For all methods pooled, the median and its standard uncertainty for the Vickers hardness results for the higher hardness sample used this round was 283.3 ± 3.0 HV.

The CV for the Vickers hardness results for the higher hardness sample used this round was 3.0%. This is higher than the CV of 2.5%, obtained for the Vickers hardness results in Round 17 of this program (see Report No. 1183).

One laboratory (code 12) reported an outlier for Vickers hardness for the higher hardness sample.

Laboratory code 12 has reported a Vickers hardness result of 309 HV against the median of 283 HV. This may be due to incorrect sequencing of testing or, perhaps, testing closer to other hardness indentations carried out. This laboratory is highly encouraged to evaluate their testing procedures and ensure correct equipment management is in place. This will greatly assist the laboratory in improving their overall results. Participating in these proficiency testing programs will be very beneficial for this laboratory to ensure that they improve their technical competency.

Sixteen laboratories reported measurement uncertainties associated with their Vickers hardness test results in this round.

6.5 Rockwell B Hardness

A total of 15 laboratories tested the lower hardness sample for Rockwell B hardness. Of these laboratories, ten tested using the AS 1815 method. Three laboratories tested using the ISO 6508 method. One laboratory tested using the JIS Z 2245 method. One laboratory tested using both the AS 1815 method and the ASTM E18 method (see Appendix A5 for more details).

For the laboratories that used an Australian Standard method for the lower hardness sample, the median and its standard uncertainty for the Rockwell B hardness results was 92.70 ± 0.38 HRB. For all methods pooled, the median and its standard uncertainty for the Rockwell B hardness results was 92.60 ± 0.23 HRB. The methods were pooled when analysing the results.

The CV for the Rockwell B hardness results for the lower hardness sample used this round was 0.8%. This is lower than the CV of 1.2%, obtained for the Rockwell B hardness results in Round 17 of this program (see Report No. 1183).

One laboratory (code 17) reported an outlier for Rockwell B hardness for the lower hardness sample, while four laboratories (codes 1, 9, 10 and 22) obtained absolute z-scores between 2.0 and 3.0.

Laboratory code 17 has reported a low Rockwell B hardness result of 90.3 HRB against the median of 92.6 HRB. This low result may be due to an inappropriate load applied or correct testing procedures not followed. It may also be that this laboratory's machine was out of calibration or was due for a maintenance check. It is recommended that this laboratory evaluates their Rockwell hardness readings against their Brinell or Vickers results using standardised hardness conversion charts to ensure they report correct test results. Another possible reason that the Rockwell B hardness result reported by laboratory code 17 is lower than the results reported by the other participants could be that their Rockwell results are not representative of the whole test surface area. All the participants are highly encouraged to report the hardness of the samples that may represent the whole surface, as there may exist some variation of the material across the surface, e.g. Rockwell readings close to the grooves and in the centre. This may mean that participants carry out more than three tests and report results that include a wider range.

Only one laboratory tested the higher hardness sample for Rockwell B hardness. This laboratory tested using the ISO 6508 method (see Appendix A5 for more details). ARL Laboratory Services Pty Ltd also tested six of the higher hardness samples using the AS 1815 method. These results (see Appendix B) were included with the participant's result to calculate summary statistics and z-scores.

There were not enough results submitted for any specific method to draw reliable conclusions from analysing grouped methods on this occasion for the higher hardness sample. The methods were pooled when analysing the results.

For all methods pooled, the median and its standard uncertainty for the Rockwell B hardness results for the higher hardness sample used this round was 102.70 ± 0.36 HRB.

The CV for the Rockwell B hardness results for the higher hardness sample used this round was 0.7%. This value was considered to be inappropriate to evaluate the performance of the laboratory that submitted Rockwell B hardness results for the higher hardness sample, so a target CV was used. The target CV chosen was 1.2%, which was the same CV value as that obtained for the Rockwell B hardness results in Round 17 of this program (see Report No. 1183).

There were no outliers reported for Rockwell B hardness for the higher hardness sample.

Twelve laboratories reported measurement uncertainties associated with their Rockwell B hardness test results in this round.

6.6 Rockwell C Hardness

One laboratory reported that the sample they received was too hard to report Rockwell B hardness results. This laboratory reported Rockwell C hardness results instead. The laboratory tested using the AS 1815 method (see Appendix A5 for more details). ARL Laboratory Services Pty Ltd also tested six of the higher hardness samples using the AS 1815 method. These results (see Appendix B) were included with the participant's result to calculate summary statistics and z-scores.

For the AS 1815 method (the only method used for Rockwell C testing), the median and its standard uncertainty for the Rockwell C hardness results for the higher hardness sample used this round was 29.60 ± 0.08 HRC.

The CV for the Rockwell C hardness results for the higher hardness sample used this round was 0.6%. This is lower than the CV of 6.5%, obtained for the Rockwell C hardness results in Round 17 of this program (see Report No. 1183).

There were no outliers reported for Rockwell C hardness for the higher hardness sample.

The laboratory that reported Rockwell C hardness results also reported a measurement uncertainty associated with their test results.

6.7 Measurement Uncertainty

The number and percentage of laboratories that reported estimates of their measurement uncertainty for each test is as follows:

• Brinell Hardness	10 out of 16	63%
• Vickers Hardness	16 out of 22	73%
• Rockwell B Hardness	12 out of 16	75%
• Rockwell C Hardness	1 out of 1	100%

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

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

All 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.

6.8 General Comments

The overall performance of the participating laboratories in this round was very good, considering that two different material types were sent out.

Participating in proficiency testing programs is very important for testing laboratories, as it can assist in identifying any weaknesses in a laboratory's system that may be present and allow laboratories to address such weaknesses and help to improve their overall technical competency and proficiency.

All the participants are encouraged to report on all the necessary information, in order to better analyse the test results.

7. REFERENCES

1. *Guide to Proficiency Testing Australia (2019)*. (This document is located on the PTA website at www.pta.asn.au under Programs / Documents).
2. *ISO/IEC 17043: 2010 Conformity assessment – General requirements for proficiency testing*.
3. *AS 1815.1: 2007 Metallic materials – Rockwell hardness test – Test method (scales A, B, C, D, E, F, G, H, K, N, T)*.
4. *AS 1816.1: 2007 Metallic materials – Brinell hardness test – Test method (ISO 6506-1: 2005, MOD).*
5. *AS 1817.1: 2003 Metallic materials – Vickers hardness test – Test method (ISO 6507-1: 1997, MOD)*.
6. *ISO 6506-1: 2014 Metallic materials – Brinell hardness test – Part 1: Test method.*
7. *ISO 6507-1: 2018 Metallic materials – Vickers hardness test – Part 1: Test method*.
8. *ISO 6508-1: 2016 Metallic materials – Rockwell hardness test – Part 1*: *Test method*.
9. *ASTM A370-17 – Standard Test Methods and Definitions for Mechanical Testing of Steel Products.*
10. *ASTM E10-18 Standard Test Method for Brinell Hardness of Metallic Materials*.
11. *ASTM E18-20 Standard Test Methods for Rockwell Hardness of Metallic Materials.*
12. *ASTM E92-17 Standard Test Method for Vickers Hardness and Knoop Hardness of Metallic Materials.*
13. *JIS Z 2245: 2016 – Rockwell hardness test – Test method*.

APPENDIX A

Summary of Results

Section A1

Brinell Hardness

A1.1

Brinell Hardness (HBW) – Lower Hardness Sample – Results and Z-Scores

Lab Code	Scale	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
1	10/3000/15	18	202	200	201	201	-	1.35
2	10/3000/12	20	199	198	198	198	1.6%	0.00
3	10/3000/15	15	202	201	203	202	10.4	1.80
6	10/3000	23.5	193.7	195.6	196.5	195.3	-	-1.21
8	10/3000/25	24	430	425	430	428.33	5	103.57 **§**
9	10/3000/10	22	198	198	197	197.7	-	-0.13
10	10/3000/10	23	198	200	201	200	1.09%	0.90
13	10/3000/12	21	200	197	198	198	6	0.00
15	10/3000/15	19	197	197	197	197	3	-0.45
19	5/750	19.2	191	195	203	196.33	5	-0.75
20	10/3000/12	23	192	193	191	192	2%	-2.70
22	10/3000/4	22	197	199	200	199	-	0.45
23	10/3000	22	197	197	197	197	-	-0.45

Summary Statistics

Statistic	Average Result
Number of Results	13
Median	198.0
Normalised IQR	2.2
Uncertainty (Median)	0.8
Robust CV	1.1%
Minimum	192
Maximum	428
Range	236

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. The results for all test methods were pooled for analysis.
3. Summary statistics and z-scores have been calculated for the average results reported.

A1.2

Brinell Hardness (HBW) – Higher Hardness Sample – Results and Z-Scores

Lab Code	Scale	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
12	10/3000/15	20.0	285	285	277	282	9	0.80
16	10/3000/12	25	272.9	270.7	271.8	271.8	-	-0.95
21	10/3000/12	22.9	290	280	280	283	7.30	0.97

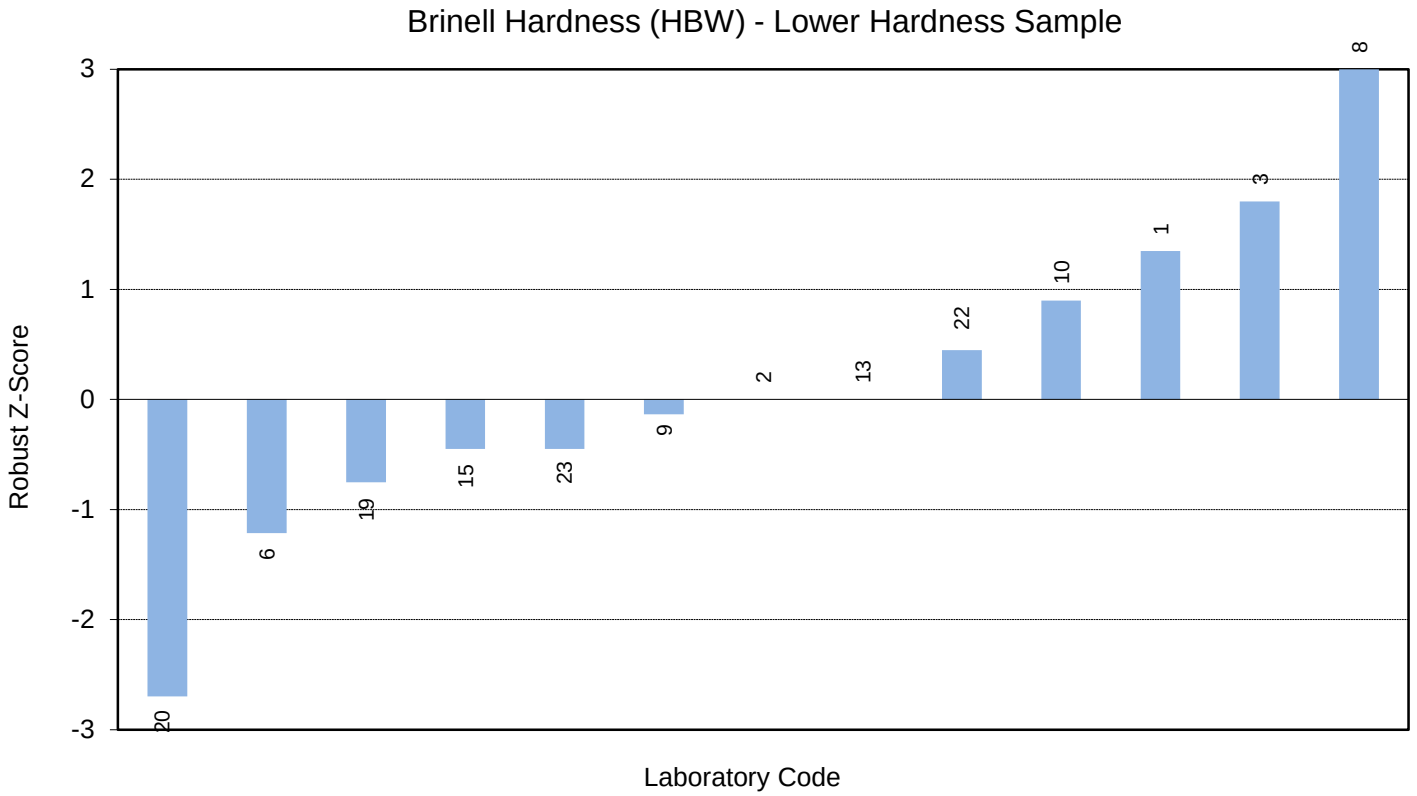
Summary Statistics

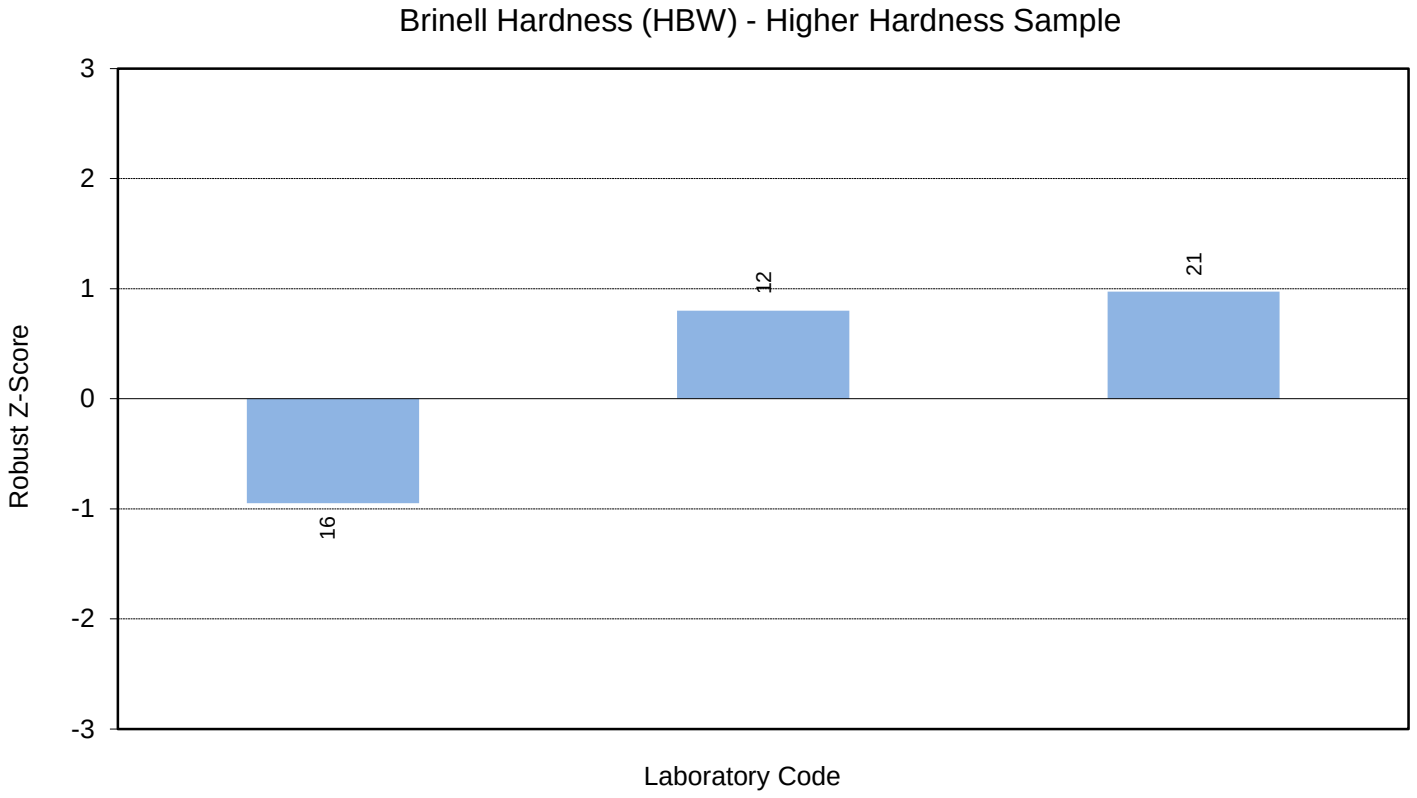
Statistic	Average Result
Number of Results	9
Median	277.3
Normalised IQR	5.8
Uncertainty (Median)	2.4
Robust CV	2.1%
Minimum	272
Maximum	283
Range	11

Notes:

1. The results for all test methods were pooled for analysis.
2. Summary statistics and z-scores have been calculated for the average results reported.
3. The summary statistics and z-scores were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd (see Appendix B).

A1.3


Brinell Hardness (HBW) - Lower Hardness Sample
Robust Z-Score
3
2
1
0
-1
-2
-3
20
6
19
15
23
9
2
13
22
10
1
3
8
Laboratory Code


Brinell Hardness (HBW) - Higher Hardness Sample
Robust Z-Score
3
2
1
0
-1
-2
-3
16
12
21
Laboratory Code

Section A2

Vickers Hardness

Vickers Hardness (HV) – Lower Hardness Sample – Results and Z-Scores

Lab Code	Load	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
1	10	18	196	201	203	200	-	-1.16
2	10	20	213	209	209	210	1.6%	0.13
3	20	15	210	212	206	209	18.9	0.00
6	10	23.5	206	205.7	204.1	205.3	-	-0.48
8	10	24	304	298.5	302	301.5	6	11.94 **§**
9	10	22	205	209	208	207.3	-	-0.22
10	30	23	197.3	198.7	199.6	199	0.58%	-1.29
13	20	21	204	207	216	209	4	0.00
14	10	22	221	222	219	221	1.55	1.55
15	20	21	205	215	214	211	8	0.26
17	10	21	218	216	217	217	4.6	1.03
18	30	22.4	194	197	181	191	95%	-2.32
19	30	19.3	208	214	201	207.67	5	-0.17
20	20	23	211	204	212	209	2%	0.00
22	1	22	224	219	219	221	-	1.55
23	10	22	215	219	220	218	5	1.16

Summary Statistics

Statistic	Average Result
Number of Results	16
Median	209.0
Normalised IQR	7.7
Uncertainty (Median)	2.4
Robust CV	3.7%
Minimum	191
Maximum	302
Range	111

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. The results for all test methods were pooled for analysis.
3. Summary statistics and z-scores have been calculated for the average results reported.

A2.2

Vickers Hardness (HV) – Higher Hardness Sample – Results and Z-Scores

Lab Code	Load	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
5	10	20	283	283	283	283	3.619	-0.04
7	10	25	290	293	295	293	-	1.15
11	30	19	296	293	295	295	3.3	1.39
12	30	22.0	304	315	308	309	11	3.06 **§**
16	10	25	287.9	286.0	287.0	286.96	-	0.43
21	10	23.3	292	285	297	291	10.77	0.91

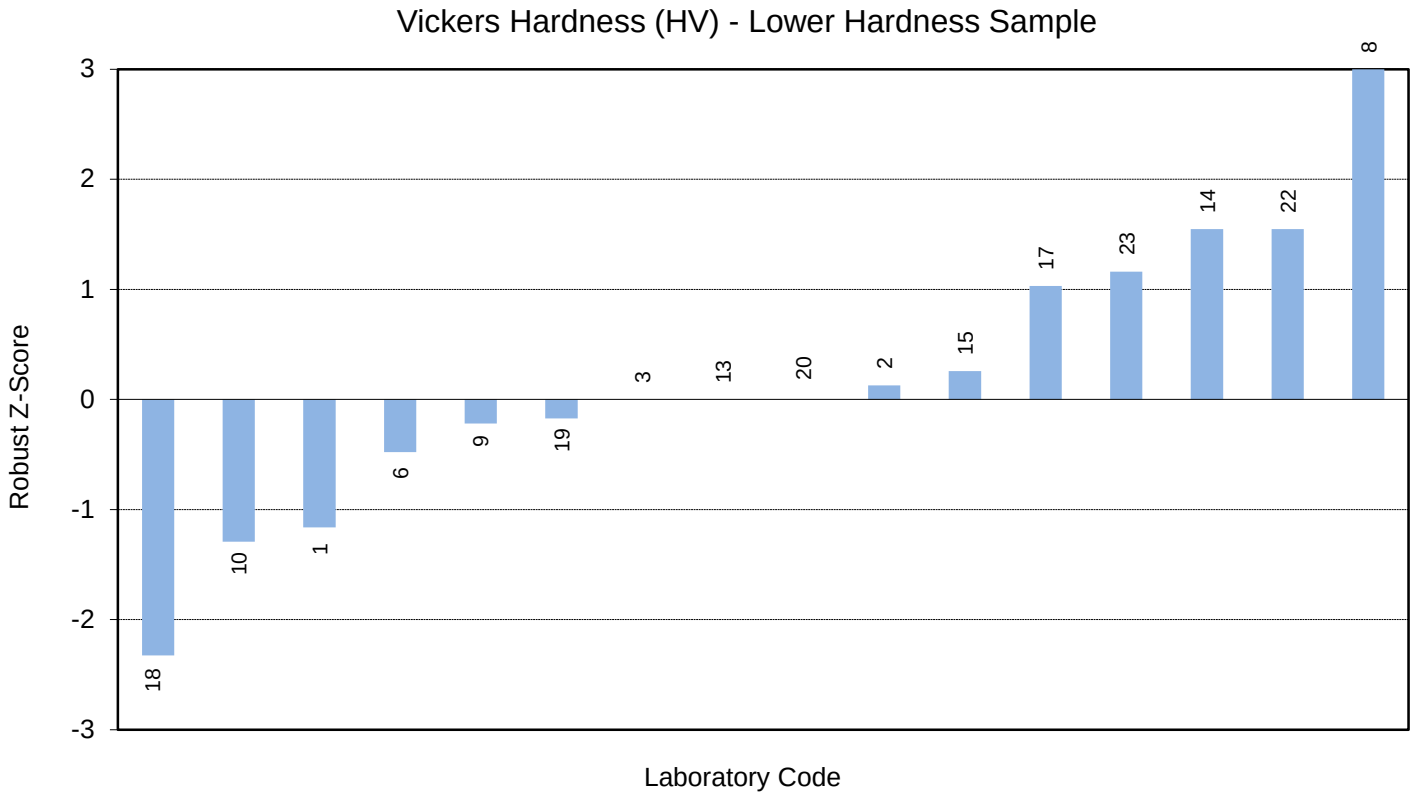
Summary Statistics

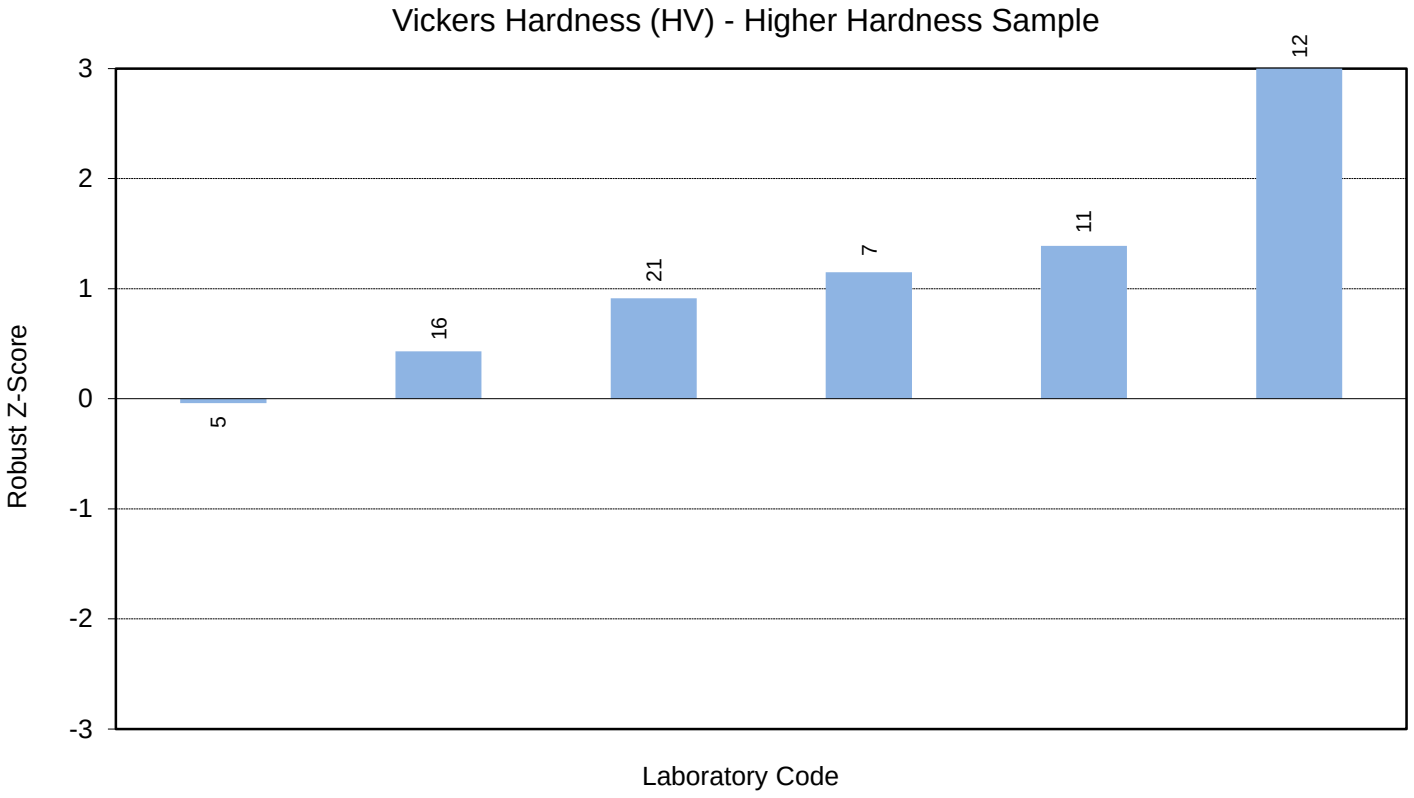
Statistic	Average Result
Number of Results	12
Median	283.3
Normalised IQR	8.4
Uncertainty (Median)	3.0
Robust CV	3.0%
Minimum	277
Maximum	309
Range	32

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. The results for all test methods were pooled for analysis.
3. Summary statistics and z-scores have been calculated for the average results reported.
4. The summary statistics and z-scores were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd (see Appendix B).

A2.3


Vickers Hardness (HV) - Lower Hardness Sample
Robust Z-Score
3
2
1
0
-1
-2
-3
18
10
1
6
9
19
3
13
20
2
15
17
23
14
22
8
Laboratory Code


Vickers Hardness (HV) - Higher Hardness Sample
Robust Z-Score
3
2
1
0
-1
-2
-3
5
16
21
7
11
12
Laboratory Code

Section A3

Rockwell B Hardness

Rockwell B Hardness (HRB) – Lower Hardness Sample – Results and Z-Scores

Lab Code	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
1	18	90.8	90.6	91.6	91.0	-	-2.27
3	15	92.1	92.2	92.5	92.3	3.1	-0.43
4	23.5	93.5	92.8	92.7	93.0	0.8	0.57
6	23.5	91.8	93.8	92.2	92.6	-	0.00
8	24	90	94	93	92.3	4	-0.43
9	22	94	95	94.5	94.5	-	2.70
10	23	90.7	91.9	89.6	90.7	1.17%	-2.70
13	21	93.5	93.8	94.6	94.0	1.5	1.99
14	22	92.7	92.8	92.6	92.7	0.7	0.14
15	21	92.9	93.2	93.8	93.3	1.0	0.99
17	21	90	90	91	90.3	2.0	-3.27 **§**
18	22.4	92.2	92.0	92.1	92.1	95%	-0.71
19	19.2	92.8	93	93	92.93	1.5	0.47
20	23	92.3	92.1	92.9	92.4	2%	-0.28
22	22	94.2	94.5	93.7	94.1	-	2.13

Summary Statistics

Statistic	Average Result
Number of Results	15
Median	92.60
Normalised IQR	0.70
Uncertainty (Median)	0.23
Robust CV	0.8%
Minimum	90.3
Maximum	94.5
Range	4.2

Notes:

1. **§** denotes an outlier (i.e. |z-score| ≥ 3.0).
2. The results for all test methods were pooled for analysis.
3. Summary statistics and z-scores have been calculated for the average results reported.

Rockwell B Hardness (HRB) – Higher Hardness Sample – Results and Z-Scores

Lab Code	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
21	23.1	104.5	106.5	104	105.0	1.59	1.87

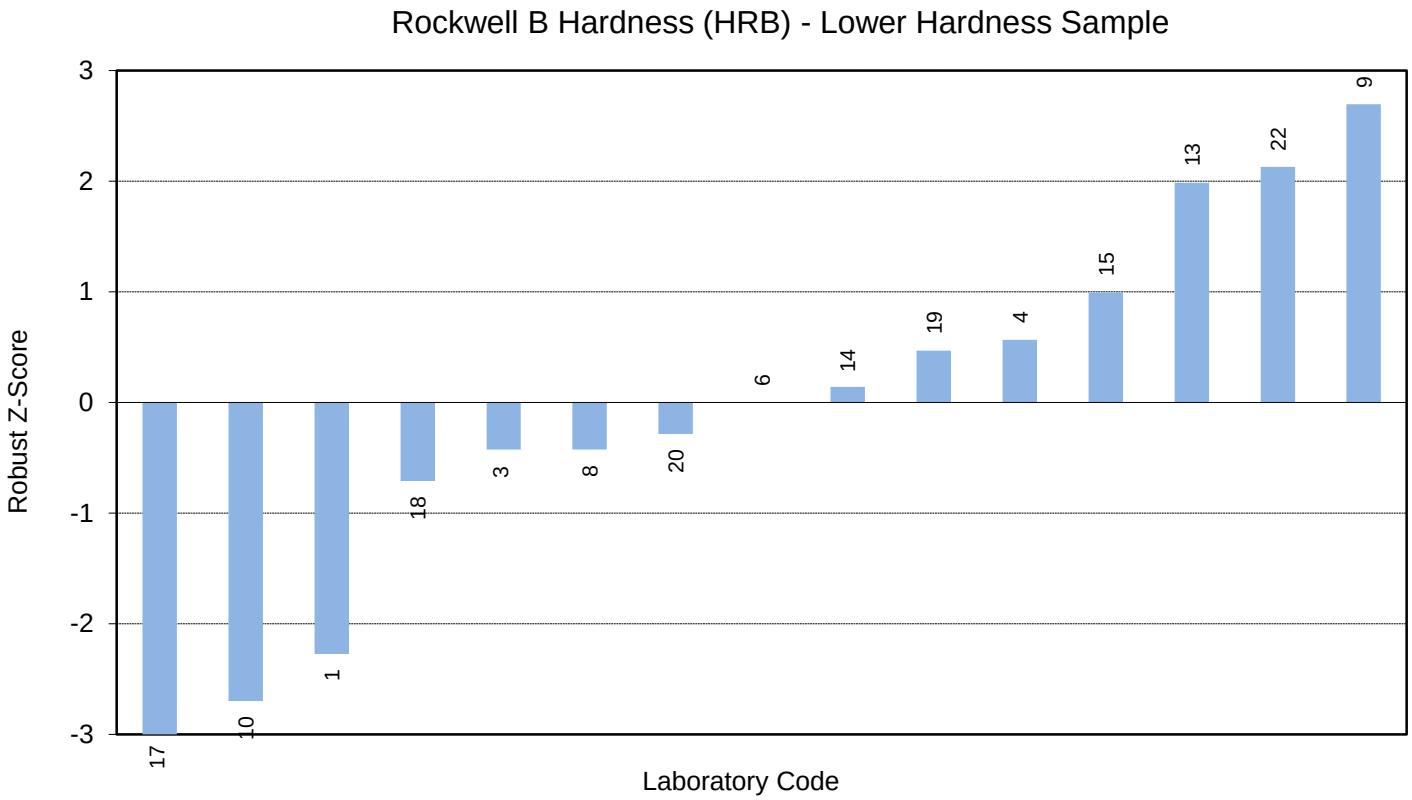
Summary Statistics

Statistic	Average Result
Number of Results	7
Median	102.70
Normalised IQR	0.77
Uncertainty (Median)	0.36
Robust CV	0.7%
Target SD	1.23
Target CV	1.2%
Minimum	101.8
Maximum	105.0
Range	3.2

Notes:

1. Summary statistics and z-scores have been calculated for the average result reported.
2. The summary statistics and z-scores were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd (see Appendix B).
3. A target CV was used to calculate the robust z-scores. The target CV chosen was 1.2%.
4. The target SD (standard deviation) was obtained by multiplying the target CV by the median. This target SD was used to calculate the z-scores. For more information on the use of target CVs to calculate z-scores, please see the Guide to Proficiency Testing Australia (2019).
5. As only one result was submitted for Rockwell B hardness for the higher hardness sample, an ordered z-score chart has only been included for the lower hardness sample for Rockwell B testing.

A3.3


Rockwell B Hardness (HRB) - Lower Hardness Sample
Robust Z-Score
3
2
1
0
-1
-2
-3
17
10
1
18
3
8
20
6
14
19
4
15
13
22
9
Laboratory Code

Section A4

Rockwell C Hardness

Rockwell C Hardness (HRC) – Higher Hardness Sample – Results and Z-Scores

Lab Code	Temp. (^{o}C)	Test 1	Test 2	Test 3	Average	MU (±)	Z-Score
12	22.0	28.7	30.3	29.8	29.6	1.6	0.00

Summary Statistics

Statistic	Average Result
Number of Results	7
Median	29.60
Normalised IQR	0.17
Uncertainty (Median)	0.08
Robust CV	0.6%
Minimum	29.4
Maximum	30.1
Range	0.6

Notes:

1. Summary statistics and z-scores have been calculated for the average result reported.
2. The summary statistics and z-scores were calculated by including results that were obtained from testing by ARL Laboratory Services Pty Ltd (see Appendix B).
3. As only one result was submitted for Rockwell C hardness for the higher hardness sample, an ordered z-score chart has not been included.

Section A5

Methods Used and Surface Preparation

A5.1

Methods Used

Lab Code	Brinell Hardness	Vickers Hardness
1	AS 1816.1	AS 1817.1
2	AS 1816: 2007	AS 1817: 2003
3	AS 1816.1, ISO 6506-4, ASTM E10	AS 1817.1, ASTM E92
4	-	-
5	-	ISO 6507-1
6	ISO 6506-1	ISO 6507-1
7	-	ASTM E92: 2016
8	AS 1816	AS 1817
9	AS 1816.1	AS 1817.1
10	ISO 6506-1	ISO 6507-1
11	-	AS 1817.1
12	AS 1816.1	AS 1817.1
13	AS 1816.1: 2007	AS 1817.1: 2003
14	-	AS 1817.1
15	AS 1816.1	AS 1817.1
16	ASTM E10	ASTM E92
17	-	ISO 6507-1: 2018
18	-	AS 1817.1: 2003
19	AS 1816.1	AS 1817.1
20	AS 1816.1: 2007	AS 1817.1: 2007
21	ISO 6506-1	ISO 6507-1
22	ASTM A370	AS 1817.1
23	AS 1816.1	AS 1817.1

Methods Used (continued)

Lab Code	Rockwell B Hardness	Rockwell C Hardness
1	AS 1815.1	-
2	-	-
3	AS 1815.1, ASTM E18	-
4	JIS Z 2245: 2016	-
5	-	-
6	ISO 6508-1	-
7	-	-
8	AS 1815	-
9	AS 1815.1	-
10	ISO 6508-1	-
11	-	-
12	-	AS 1815.1
13	AS 1815.1: 2007	-
14	AS 1815.1	-
15	AS 1815.1	-
16	-	-
17	ISO 6508-1: 2016	-
18	AS 1815.1: 2007	-
19	AS 1815.1	-
20	AS 1815.1: 2007	-
21	ISO 6508-1	-
22	AS 1815.1	-
23	-	-

A5.3

Surface Preparation

Lab Code	Preparation Details
1	The test sample surface was polished using SiC abrasive paper 2000 grit.
2	Diamond polish 3µ.
3	Polished surfaces that had to be tested to P1200 grit in accordance with AS 2205.5.1. Finer surface finish will allow an accurate measurement.
4	-
5	Wet and dry on bench polisher to 1200 grit to give more uniform surface.
6	No surface preparation performed.
7	No surface preparation performed.
8	No surface preparation performed.
9	No surface preparation performed.
10	No surface preparation performed.
11	Wet ground using silicon carbide abrasive papers to a #1200 grit surface finish.
12	Polished to a mirror finish.
13	Metallographic preparation, wet abrasion on silicon carbide papers 180 → 240 → 320 → 600 → P1200. Testing at P1200 finish.
14	Polished with fine sand paper.
15	Vickers Hardness: Polished to a 3 µm diamond finish.
16	Finish polishing.
17	Polished to 600 grit.
18	No surface preparation performed.
19	Polished to 1 micron finish.
20	No surface preparation performed.
21	No surface preparation performed.
22	No surface preparation performed.
23	Polished to 1200 grit with wet grinder.

APPENDIX B

Homogeneity Testing

HOMOGENEITY TESTING

Before the samples were distributed to participants, eight of the lower hardness samples were randomly selected and tested for homogeneity by ARL Laboratory Services Pty Ltd. Six hardness measurements were made around the testing area, for each of the eight samples, for Brinell, Vickers and Rockwell B hardness. The results of the homogeneity testing are displayed below:

Homogeneity Testing Results – Lower Hardness Sample

Brinell HBW 10/3000

Result 1	Result 2	Result 3	Result 4	Result 5	Result 6	Average
187	186	185	185	183	187	185.5
185	185	186	186	184	185	185.2
183	187	185	183	184	186	184.7
185	185	186	185	184	185	185.0
184	183	185	184	185	186	184.5
185	185	184	186	187	186	185.5
185	185	185	185	186	188	185.7
186	185	187	186	184	184	185.3

Vickers HV 10

Result 1	Result 2	Result 3	Result 4	Result 5	Result 6	Average
200	199	195	197	197	197	197.5
198	202	203	196	199	202	200.0
196	203	198	200	204	203	200.7
202	199	204	201	202	200	201.3
199	202	204	199	203	204	201.8
203	198	205	205	201	202	202.3
202	204	204	205	205	203	203.8
204	204	200	199	204	203	202.3

Rockwell B HRB

Result 1	Result 2	Result 3	Result 4	Result 5	Result 6	Average
93.3	92.5	90.5	91.2	92.2	90.8	91.75
92.0	88.7	92.4	90.5	87.8	90.4	90.30
93.4	92.4	88.7	91.3	92.0	92.3	91.68
92.8	91.6	90.7	90.5	90.4	92.5	91.42
90.5	91.9	92.7	91.7	93.5	92.5	92.13
90.2	92.6	92.2	92.1	92.5	93.6	92.20
92.9	93.2	91.3	92.0	93.6	92.3	92.55
92.0	91.4	91.3	91.2	91.7	93.5	91.85

In addition, six of the higher hardness samples were randomly selected and tested for homogeneity by ARL Laboratory Services Pty Ltd. Three hardness measurements were made around the testing area, for each of the six samples, for Brinell, Vickers, Rockwell B and Rockwell C hardness. The results of the homogeneity testing are displayed below:

Homogeneity Testing Results – Higher Hardness Sample

Brinell HBW 10/3000

Result 1	Result 2	Result 3	Average
278	282	272	277.3
272	275	276	274.3
280	277	275	277.3
282	277	279	279.3
276	270	280	275.3
277	281	289	282.3

Vickers HV 10

Result 1	Result 2	Result 3	Average
285	276	283	281.3
276	279	281	278.7
287	281	283	283.7
279	282	280	280.3
284	276	279	279.7
280	279	273	277.3

B1.3

Rockwell B HRB

Result 1	Result 2	Result 3	Average
102.0	102.3	102.8	102.37
102.6	103.6	103.4	103.20
102.9	103.7	102.8	103.13
103.1	101.9	101.8	102.27
101.8	101.6	101.9	101.77
102.4	102.6	103.1	102.70

Rockwell C HRC

Result 1	Result 2	Result 3	Average
30.2	29.6	29.7	29.83
28.6	30.0	30.1	29.57
30.1	29.9	28.9	29.63
30.1	29.9	30.2	30.07
29.5	29.9	28.9	29.43
28.7	29.9	30.0	29.53

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

The results of the homogeneity testing for the higher hardness samples were included with the participants' results in order to calculate summary statistics and z-scores.

APPENDIX C

Instructions to Participants
and
Results Sheet

PROFICIENCY TESTING AUSTRALIA

Hardness Testing Of Metals Proficiency Testing Program Round 18, June 2020

Instructions to Participants

To ensure that the results of this program can be analysed correctly, participants are asked to adhere carefully to these instructions.

1) The sample for this hardness testing program consists of a steel sample, approximately 60 mm in diameter and 30 mm thick. The sample has a number labelled on the circumference.

2) The sample is to be tested for Brinell, Vickers and Rockwell 'B' hardness. Although both surfaces of the test sample are polished, the testing area is enclosed with a 0.5 mm groove. Participants may wish to improve the surface to provide a better testing surface.

3) The sample should be treated as a routine laboratory sample. All testing, recording and reporting is to be performed in accordance with your routine test methods.

4) Please use the attached Result Sheet to record and report your results to Proficiency Testing Australia. Please also report the method used for testing (*e.g.* AS 1816.1, ISO 6506.1, etc. for Brinell hardness testing, AS 1817.1, ISO 6507.1, etc. for Vickers hardness testing, AS 1815.1, ISO 6508.1, etc. for Rockwell HRB hardness testing).

6) Do not discard the hardness test sample until you have received the final report. You may be asked to carry out a retest or to return the sample to Proficiency Testing Australia for retesting at the laboratory that performed the homogeneity tests.

7) 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, thus ensuring the confidentiality of your results.

8) Laboratories 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 $k \approx 2$).

9) 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 **Monday 20 July 2020**. Results reported later than this date may not be analysed in the final report.

C2.1

PROFICIENCY TESTING AUSTRALIA

Hardness Testing Of Metals Proficiency Testing Program

Round 18, June 2020

RESULTS SHEET

Laboratory Code: ☐

Sample I.D.	Scale	Report to nearest	Test Temp ºC	Results					Standard (AS, ISO, etc.)
				Test 1	Test 2	Test 3	Average	MU (±)	
	Brinell (/ /) (mm/kg/s)	1 BHN							
	HV ( ) Insert load used	1 HV							
	HRB	0.1 HRB							

Did you carry out surface preparation on the obverse surface of the sample for the hardness tests? Yes / No

If Yes, please give details of preparation.

……

……

……

……

……

……

Print Name: _____

Signature: _____

Date: _____

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