

Pilot Study on Leeb Interlaboratory Comparison Tests

Final report – 07th August 2025

CIPM / CCM / WORKING GROUP ON HARDNESS

Pilot Study code: CCM.H-P2

Pilot Laboratory: PTB / GERMANY

NMI PARTICIPANTS:

PTB/Germany; KRISS/Republic of Korea; NIM/China

OTHER PARTICIPANTS:

Proceq SA/Switzerland

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0 Document control

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1 Foreword

This report describes a CCM Pilot Study conducted by the CCM/Working Group on Hardness of systems used to calibrate hardness reference blocks for the Leeb hardness scales.

2 Introduction

In order to increase the acceptance of the Leeb rebound principle as hardness test method, it is necessary to carry out an interlaboratory comparison between national metrological institutes in order to validate the hardness scale and ensure its conformability. For this purpose, Korea Research Institute of Standards and Science, Republic of Korea (KRISS), National Institute of Metrology, China (NIM) and Physikalisch-Technische Bundesanstalt, Germany (PTB) carried out a round robin comparison. The Leeb hardness test method was invented by D. Leeb and M. Brandestini of the company Proceq SA, Switzerland in 1975. The company Proceq SA took part as an additional member for comparison purposes only, i.e. the Proceq results were compared to the reference value, but were not used to calculate the reference value. In this comparison PTB acts as pilot laboratory.

The objective of the comparison is to determine the capability of each institute to determine Leeb parameters based of their primary Leeb hardness setups.

3 Participants

Table with the name and contact data of the participants

Participant	Address	Contact information
Korea Research Institute of Standards and Science (KRISS)	<i>Naehyung Tak</i> 267 Gajeong-ro Yuseong-gu, Daejeon, 34113 Republic of Korea	Phone: +82-42-868-5327 Fax: +82-42-868-5393 Email: nhtak@kriss
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Physikalisch-Technische Bundesanstalt (PTB)	5.11: Hardness and Tactile Probing Methods <i>Febo Menelao</i> Bundesallee 100 38116 Braunschweig Germany	Phone: +49 531 592-5145 Fax: +49 531 592-69 5145 Email: febo.menelao@ptb.de
Non National Metrological Institute		
Proceq SA	<i>Christoph Frehner</i> Ringstr. 2 CH-8603 Schwerzenbach Switzerland	Phone: +41 43 355 3847 Fax: +41 43 355 3808 Email: christoph.frehner@proceq.com

4 Artifact

There are two sets of artifacts for the comparison of Leeb Hardness:

- One scale HLD artifact set consisting of 3 hardness test blocks of different hardness.
- One scale HLG artifact set consisting of 3 hardness test blocks of different hardness.

All test blocks conform to ISO 16859-3:

- scale HLD artifacts are cylindrical shape with a thickness of 56 mm, a diameter of 90 mm and a mass of 2.8 kg,
- scale HLG artifacts are cylindrical shape with a thickness of 70 mm, a diameter of 120 mm and a mass of 6.3 kg.

The blocks are manufactured by EuroProducts Ltd., Stourbridge, West Midlands, UK. Both artifact sets also contain one aluminum template each with circular holes numbered 1 through 10 and a line mark near the No. 10 recess (Figures 1 and 2). The circumference of each artifact block is labeled with equidistant marks A to H and S to Z. The marks A to H are used by the participating laboratories according to their assignment in Table 1. The remaining marks S to Z should be used only in the case individual measurements are invalid and require repeating. In this case, each laboratory should carry out only those measurements that require repeating with the template's mark aligned with the repeat mark S to Z the lab has been assigned with; all

remaining measurements of the 10 measurement series are to be carried out with the template aligned with the original mark A to H.

The two sets of artifacts, a set for scale HLD and a set for scale HLG, are transferred between the participants according to the timetable in which the date of measurement has been agreed upon between the participants. Each participant overtook the costs for transport, custom clearance and related administrative fees to the next participant.

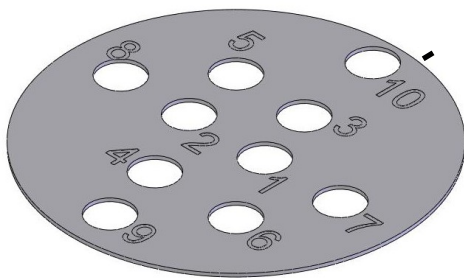


Figure 1: Template scale HLD artifacts (90 mm diameter aluminum template, 1.5 mm thick, with circular holes labeled 1 through 10; mark at number 10 recess to be aligned with marks on test block)

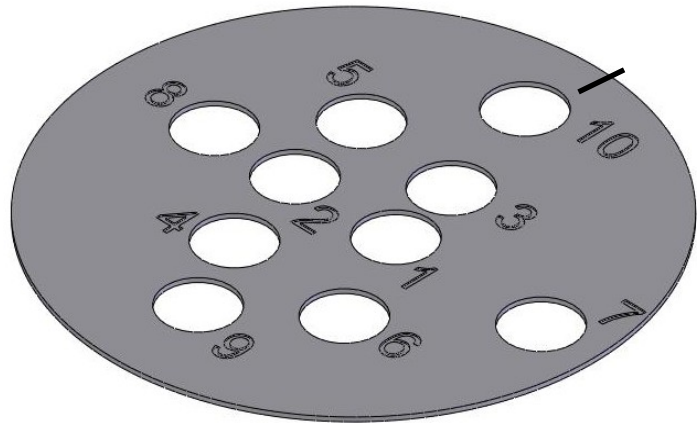


Figure 2: Template scale HLG artifacts (120 mm diameter aluminum template, 1.5 mm thick, with circular holes labeled 1 through 10; mark at number 10 recess to be aligned with marks on test block)

5 Measurement Procedure

5.1 Preparation Process

5.1.1 Unpacking, clean and inspect the artifact sets

The participating laboratories verified that all items as indicated in the packing checklist are contained in the artifact set. For cleaning and inspection, the rules of the technical protocol are fulfilled.

5.2 Measurement Process

5.2.1 Verification of the Leeb drop-tube equipment

Each participating laboratory carried out a functionality test according to the applicable international standard ISO 16859 for HLD and HLG. For this functionality test, the artifact test blocks were *NOT* being used.

5.2.2 Execution of the Leeb D drop-tube measurements

A measurement series consists of 10 readings which are to be taken on the polished test surface of the artifact blocks closest to the numbered marks on the test block circumference. Each participating laboratory carried out one measurement series on each artifact block. Each measurement was placed inside the holes in the respective Aluminum template placed on the test surface with the linear mark on the template being aligned with the mark A to H on the test blocks the laboratory has been assigned with.

The following steps are performed by each participant:

- Report environmental information in Form 1 (s. Appendix A)
- Use only the contents of the scale HLD artifact set, the national reference Leeb D drop tube with its associated electronic analysis equipment (e.g. Equotip 3 indicating device, EquoService PC software, etc.), and the national reference Leeb scale HLD impact body.
- Take the first of the three scale HLD artifacts, remove the protective stickers from *both* sides of the test block and place it underneath the Leeb D drop tube
- Place the Leeb D template form the artifact set with its mark aligned with the engraved mark on the test block circumference your laboratory has been assigned with.
- Orient the test block under the Leeb D drop tube for the impact to be carried out inside the number 1 recess in the template.
- Report the resulting HLD hardness reading to one decimal point accuracy in Form 1.
- Rearrange the test block for the number 2 recess in the template (with the template mark aligned with the mark on the test block your lab has been assigned with) to be centered underneath the D drop tube. Take and report the second reading. Proceed until all 10 impacts have been placed inside their respective holes in the template.
- If a given reading is invalid by requirements of the applicable national standard, repeat the invalid measurement by turning the template supplied with the D artifact set on the test block till the mark on the template is aligned with the repeat mark S to Z your lab has been assigned with. Rearrange the test block for the recess of the corresponding number of the invalid impact to be centered underneath the drop tube and carry out the impact. Continue with the measurement series only after the template has been turned back to the original mark A to H your lab has been assigned with.
- Remove the artifact from the setup, clean it with isopropanol and place one protective sticker on each polished surface.
- Proceed in the same fashion successively with the second and third test blocks of the scale HLD artifacts set.

Note: Any deviation from this concerted procedure must be reported.

The individual reports are added in Appendix A.

5.2.3 Execution of the Leeb G drop-tube measurements

A measurement series consists of 10 readings which are to be taken on the polished test surface of the artifact blocks closest to the numbered marks on the test block circumference. Each participating laboratory carried out one measurement series on each artifact block. Each measurement is placed inside the holes in the respective Aluminum template placed on the test surface with the linear mark on the template being aligned with the mark A to H on the test blocks the laboratory has been assigned with.

The following steps are performed by each participant:

- Report environmental information in Form 2
- Use only the contents of the scale HLG artifact set, the national reference Leeb G drop tube with its associated electronic analysis equipment (e.g. Equotip 3 indicating device, EquoService PC software, etc.), and the national reference Leeb G impact body.
- Take the first of the three scale HLG artifacts, remove the protective stickers from *both* sides of the test block and place it underneath the Leeb G scale drop tube
- Place the Leeb G template from the artifact set with its mark aligned with the engraved mark on the test block circumference your laboratory has been assigned with.
- Orient the test block under the Leeb G drop tube for the impact to be carried out inside the number 1 recess in the template.
- Report the resulting HLG hardness reading to one decimal point accuracy in Form 2.
- Rearrange the test block for the number 2 recess in the template (with the template mark aligned with the mark on the test block your lab has been assigned with) to be centered underneath the G drop tube. Take and report the second reading. Proceed in this fashion until all 10 impacts have been placed inside their respective holes in the template.
- If a given reading is invalid by requirements of the applicable national standard, repeat on the invalid measurement by turning the template supplied with the G artifact set on the test block till the mark on the template is aligned with the repeat mark S to Z your lab has been assigned with. Rearrange the test block for the recess of the corresponding number of the invalid impact to be centered underneath the drop tube and carry out the impact. Continue with the measurement series only after the template has been turned back to the original mark A to H your lab has been assigned with.
- Remove the artifact from the setup, clean it with isopropanol and place one protective sticker on each polished surface.
- Proceed in the same fashion successively with the second and third test blocks of the scale HLG artifacts set.

Note: Any deviation from this concerted procedure must be reported.

The individual reports are added in Appendix A.

6 Time Table of the Measurements

Table 1: Time table of measurements and test block mark assignment

Laboratory (Country)	Assigned test block marks	Time frame for measurements
Physikalisch Technische Bundesanstalt - PTB (Germany)	A, (Z for repeats)	May 2014
Proceq (Switzerland)	B, (Y for repeats)	June 2014
National Institute of Metrology - NIM (China)	C, (X for repeats)	July 2014
Korea Research Institute of Standards and Science – KRISS (Republic of Korea)	D, (W for repeats)	August 2014
Physikalisch Technische Bundesanstalt - PTB (Germany)	E, (V for repeats)	September 2014

The periods between times of measurement in the table are used for the shipping and custom clearance.

7 Data report

7.1 Measurement instrument and results

The instrument and the results obtained are reported in a report which was send to the pilot laboratory. The report of each institute is attached in Appendix A. The reports must include the set-up and the calculation of the measurement uncertainty budget.

8 Analyzing Method of Comparison Results

The comparison is performed and evaluated according to the ISO 16859-3 Metallic materials - Leeb hardness test - Part 3: Calibration of reference blocks, and calibration is conducted with scale *G* and *D* as reference. The pilot got all the data necessary from the participating institutes including uncertainty.

The comparison reference values X_{ref} were calculated from the results obtained from the NMI labs as the weighted mean X_i . The calculation formulas used are listed as follows.

$$X_{ref} = \frac{\sum_{i=1}^n u(x_i)^{-2} \cdot x_i}{\sum_{i=1}^n u(x_i)^{-2}} \quad (1)$$

$$u(x_{ref}) = \left(\sum_{i=1}^n u(x_i)^{-2} \right)^{-\frac{1}{2}} \quad (2)$$

$$E_n(x_i) = \frac{x_i - x_{ref}}{\sqrt{U(x_i)^2 + U(x_{ref})^2}} \quad (3)$$

Where:

x_i : measured value of participating institute

$u(x_i)$: standard uncertainty of x_i

x_{ref} : weighted mean of measurements of all participants

$u(x_{\text{ref}})$: standard uncertainty of x_{ref}

$E_n(x_i)$: normalized deviation ratio

The minus sign in the denominator of E_n formula (3) is used if the value of the NMI has been taken into account for the calculation of the reference value. Otherwise the “+” sign is used, because there is no correlation.

In the tables 2 to 5 all results are listed. \bar{x} is the mean value from 10 measurements, σ_x is the calculated standard deviation, $u_{\bar{x}}$ the uncertainty of the mean value calculated from the standard deviation, u_{MS} the uncertainty of the instrument. Therein the contributions are taken into account which result from the calibration of the system. The system calibration the deviation of the mass of the impact body, the radius of the indenter ball, the impact velocity, the resolution of the measurement system.

9 Measurement Data and Data Calculation

9.1 The measurement results of the laboratories

The measurement results of the laboratories are shown in Table 2 to 5

Table 2: Measurement data of PTB, NMI of Germany

	HLD1	HLD2	HLD3	HLG1	HLG2	HLG3
1	739.8	596.7	451.5	631.7	533.4	383.5
2	741.3	598.4	448.0	632.7	532.5	380.5
3	740.8	596.7	449.0	632.6	530.4	380.2
4	739.2	596.1	446.7	632.9	527.5	378.7
5	737.0	593.8	445.5	630.9	526.0	380.0
6	739.3	595.6	448.0	630.8	524.6	378.3
7	738.8	593.9	447.2	629.9	526.8	376.0
8	737.7	591.3	444.4	630.4	522.7	376.5
9	740.2	592.6	446.9	630.8	522.2	375.7
10	738.1	593.5	445.3	629.1	521.0	376.8
$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$	739.2	594.9	447.3	631.2	526.7	378.6
$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.37	2.19	2.05	1.27	4.30	2.47
$u_x = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.46	0.73	0.69	0.43	1.44	0.83
u_{MS}	3.33	2.68	2.01	1.26	1.05	0.76
$U = 2 \cdot \sqrt{u_{MS}^2 + u_x^2}$	6.72	5.55	4.25	2.66	3.57	2.25

Table 3: Measurement data of NIM, NMI of China

	HLD1	HLD2	HLD3	HLG1	HLG2	HLG3
1	740.4	598.6	449.1	634.5	534.2	385.0
2	739.6	595.4	448.9	636.2	530.1	381.9
3	738.4	593.9	445.9	634.3	528.7	380.9
4	741.3	597.2	448.2	631.6	527.6	381.6
5	737.9	595.7	445.7	634.9	526.8	380.2
6	741.7	594.2	445.4	636.5	525.9	379.0
7	741.1	592.2	442.6	634.7	525.1	379.0
8	739.9	594.2	444.6	635.0	526.2	377.4
9	737.6	592.3	444.3	634.6	525.3	375.8
10	736.0	592.8	444.7	634.2	525.4	377.5
$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$	739.4	594.6	445.9	635.1	527.5	379.8
$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.86	2.11	2.14	0.83	2.85	2.67

$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.62	0.71	0.72	0.28	0.96	0.89
u_{MS}	3.70	2.97	2.23	3.18	2.64	1.90
$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	8.13	6.54	4.90	6.99	5.80	4.18

Table 4: Measurement data of KRISS, NMI of South Korea

	HLD1	HLD2	HLD3	HLG1	HLG2	HLG3
1	741.5	601.3	452.0	632.0	532.0	385.0
2	741.3	600.1	451.1	633.0	530.0	383.0
3	741.3	600.0	447.7	633.0	529.0	382.0
4	739.1	599.7	449.6	630.0	529.0	381.0
5	740.2	599.3	448.0	631.0	526.0	378.0
6	740.9	600.0	448.1	631.0	528.0	379.0
7	739.8	598.0	446.2	629.0	527.0	380.0
8	743.0	598.1	446.8	630.0	525.0	378.0
9	740.0	598.0	447.0	630.0	525.0	379.0
10	740.0	597.4	446.1	627.0	525.0	377.0
$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$	740.7	599.2	448.3	631.0	527.6	380.2
$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.1	1.3	2	1.8	2.4	2.5
$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.4	0.4	0.7	0.6	0.8	0.8
u_{MS}	2.3	2	1.9	2.6	2.5	2.5
$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	4.7	4.1	4	5.3	5.3	5.3

Table 5: Measurement data of Proceq, Switzerland

	HLD1	HLD2	HLD3	HLG1	HLG2	HLG3
1	738.7	596.2	451.7	634.6	534.5	389.9
2	739.5	595.7	450.2	636.2	531.7	387.3
3	740.2	594.9	448.0	633.0	530.1	386.6
4	740.1	594.5	448.6	634.4	527.8	385.5
5	738.5	593.9	447.2	633.4	527.2	384.2
6	738.6	593.2	446.4	633.1	525.7	382.9
7	738.9	593.7	445.7	631.8	526.3	381.5
8	737.9	592.9	446.3	631.0	527.2	381.7
9	737.2	592.5	446.6	629.5	524.3	381.4
10	736.4	592.9	445.8	629.0	523.2	381.4
$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$	738.6	594.0	447.7	632.6	527.8	384.2

$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.20	1.26	2.00	2.31	3.43	2.99
$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.40	0.42	0.67	0.77	1.15	1.00
u_{MS}	2.94	2.39	1.83	0.85	0.74	0.61
$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	5.94	4.85	3.90	2.30	2.74	2.35

9.2 Calculation of the stability of the hardness reference blocks

The pilot laboratory (PTB) has measured the blocks at the start and at the end of the comparison. The differences between the last and the first measurement results are listed in the table 6.

Table 6: Drift of the hardness blocks

Block	HLD1	HLD2	HLD3	HLG1	HLG2	HLG3
Deviation	-0.7	1.4	1.4	0.6	0.3	0.8

The deviations for all blocks are smaller than the measurement uncertainties of the pilot laboratory. The hardness reference blocks are stable over the comparison. A possible drift is negligible.

9.3 Calculation of the reference values

From the above tables the reference value and its uncertainty are calculated in a first step by using equation (1) and (2) for the data from the NMI, only. The values from Proceq are used for comparison mean, only. Afterwards the E_n value has been calculated. In the case that the E_n value is larger than 1 the related data is removed from the calculation of the reference value. Thereby the largest is removed first, and the calculation is repeated with the restricted set of data. Since this was not necessary here, all NMIs are included to the reference value. The following tables show the calculated data for HLD1 to HLD3 and HLG1 to HLG3.

Table 7: Data and calculated reference value and its uncertainty for HLD1 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	$x_i - x_{ref}$	Correlated *)	Abs(E_n)
PTB	739.2	6.72	3.36	0.089	65.48	-0.86	-1	0.15
NIM	739.4	8.13	4.07	0.060	44.71	-0.66	-1	0.09
KRISS	740.7	4.7	2.35	0.181	134.12	0.64	-1	0.20
$x_{ref} =$	740.06	$u_{ref}(k=1) =$	1.74				*) correlated ==> -1 no correlation ==> +1	
		$u_{ref}(k=2) =$	3.48					
Proceq	738.5	5.94	2.97	0.113	83.72	-1.56	1	0.23

Table 8: Data and calculated reference value and its uncertainty for HLD2 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	x_i-x_{ref}	Correlated *)	Abs(E_n)
PTB	594.9	5.55	2.78	0.130	77.22	-2.19	-1	0.46
NIM	594.6	6.54	3.27	0.094	55.60	-2.45	-1	0.42
KRISS	599.2	4.1	2.05	0.238	142.58	2.15	-1	0.76
$x_{ref} =$	597.05	$u_{ref}(k=1) =$	1.47					*) correlated ==> -1
		$U_{ref}(k=2) =$	2.94					no correlation ==> +1
Proceq	594.0	4.85	2.43	0.170	101.02	-3.01	1	0.53

Table 9: Data and calculated reference value and its uncertainty for HLD3 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	x_i-x_{ref}	Correlated *)	Abs(E_n)
PTB	447.3	4.25	2.13	0.221	98.93	-0.06	-1	0.02
NIM	445.9	4.90	2.45	0.166	74.14	-1.41	-1	0.33
KRISS	448.3	4	2.00	0.250	112.08	0.99	-1	0.32
$x_{ref} =$	447.31	$u_{ref}(k=1) =$	1.25					*) correlated ==> -1
		$U_{ref}(k=2) =$	2.50					no correlation ==> +1
Proceq	447.7	3.90	1.95	0.263	117.73	0.34	1	0.07

Table 10: Data and calculated reference value and its uncertainty for HLG1 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	x_i-x_{ref}	Correlated *)	Abs(E_n)
PTB	631.2	2.66	1.33	0.564	355.69	-0.38	-1	0.26
NIM	635.1	6.99	3.49	0.082	52.05	3.54	-1	0.54
KRISS	631.0	5.3	2.65	0.142	89.85	-0.56	-1	0.12
$x_{ref} =$	631.56	$u_{ref}(k=1) =$	1.13					*) correlated ==> -1
		$U_{ref}(k=2) =$	2.25					no correlation ==> +1
Proceq	632.6	2.30	1.15	0.756	478.34	1.04	1	0.32

Table 11: Data and calculated reference value and its uncertainty for HLG2 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	x_i-x_{ref}	Correlated *)	Abs(E_n)
PTB	526.7	3.57	1.79	0.314	165.19	-0.38	-1	0.16
NIM	527.5	5.80	2.90	0.119	62.67	0.41	-1	0.08
KRISS	527.6	5.3	2.65	0.142	75.13	0.51	-1	0.11
$x_{ref} =$	527.09	$u_{ref}(k=1) =$	1.32					*) correlated ==> -1
		$U_{ref}(k=2) =$	2.64					no correlation ==> +1
Proce	527.8	2.74	1.37	0.533	281.21	0.71	1	0.19

Table 12: Data and calculated reference value and its uncertainty for HLG3 including E_n values

	x_i	$U_i(k=2)$	$u_i(k=1)$	$1/u_i^2$	x_i/u_i^2	x_i-x_{ref}	Correlated *)	Abs(E_n)	
PTB	378.6	2.25	1.12	0.793	300.31	-0.43	-1	0.34	
NIM	379.8	4.18	2.09	0.229	87.04	0.75	-1	0.20	
KRISS	380.2	5.3	2.65	0.142	54.14	1.15	-1	0.23	
$x_{ref}=$	379.05	$u_{ref}(k=1)=$	0.93					*) correlated ==> -1	
		$U_{ref}(k=2)=$	1.85					no correlation ==> +1	
Proceq	384.2	2.35	1.18	0.724	278.31	5.19	1	1.74	

All values from the NMIs fulfill the E_n criteria in the first run. The E_n criteria from Proceq company are too high for the HLG-3 block.

The figures 1 to 6 shows the result of the laboratories including the reference value x_{ref} and uncertainty of the reference value $U(x_{ref})$ of the different hardness block.

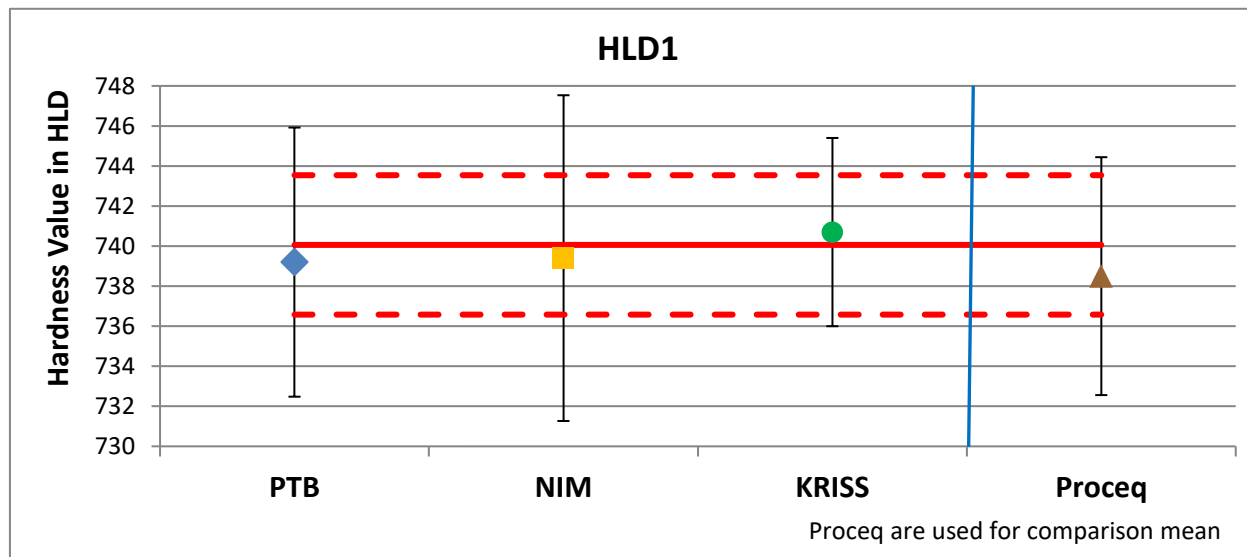


Figure 1: Measurement values x_i and its uncertainty $U(k=2)$ including reference value X_{ref} (red line) and upper and lower limit due to the uncertainty of the reference value U_{ref} (dashed red line) for HLD1 block. Proceq are used for comparison mean.

The descriptions are according in the following figures 2 to 6.

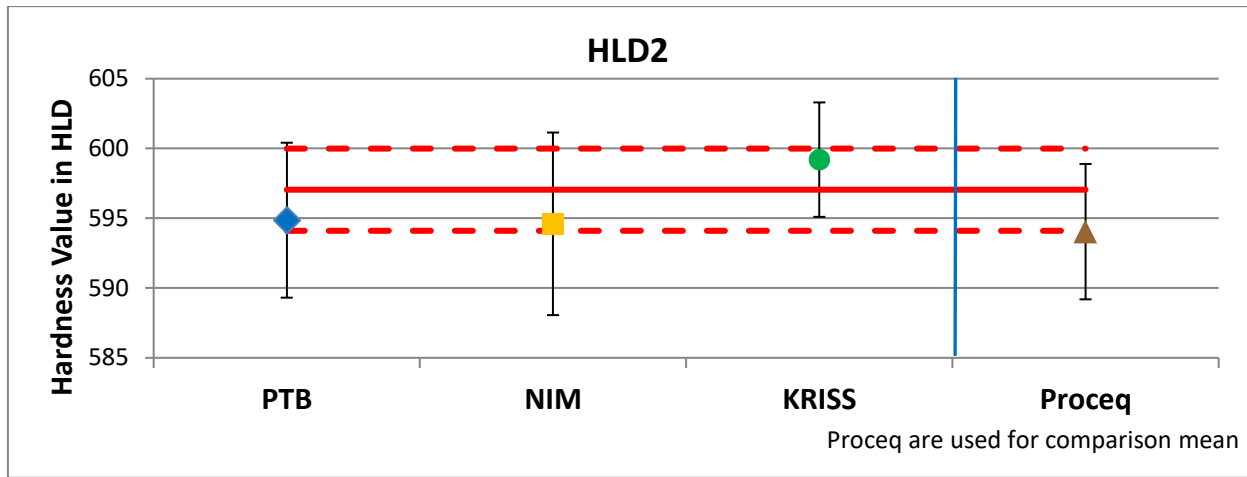


Figure 2: Measurement values for HLD2 block

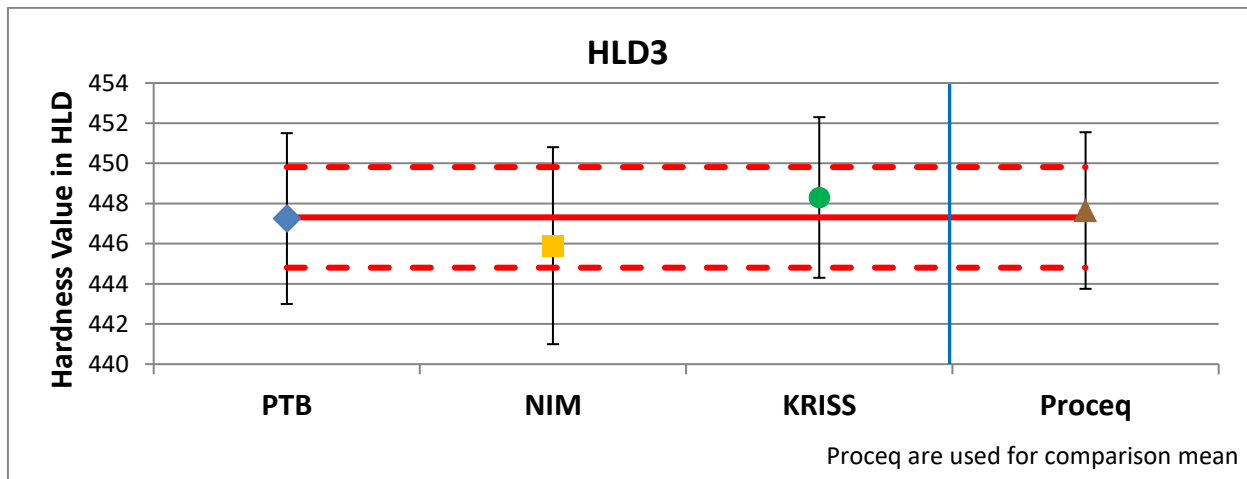


Figure 3: Measurement values for HLD3 block

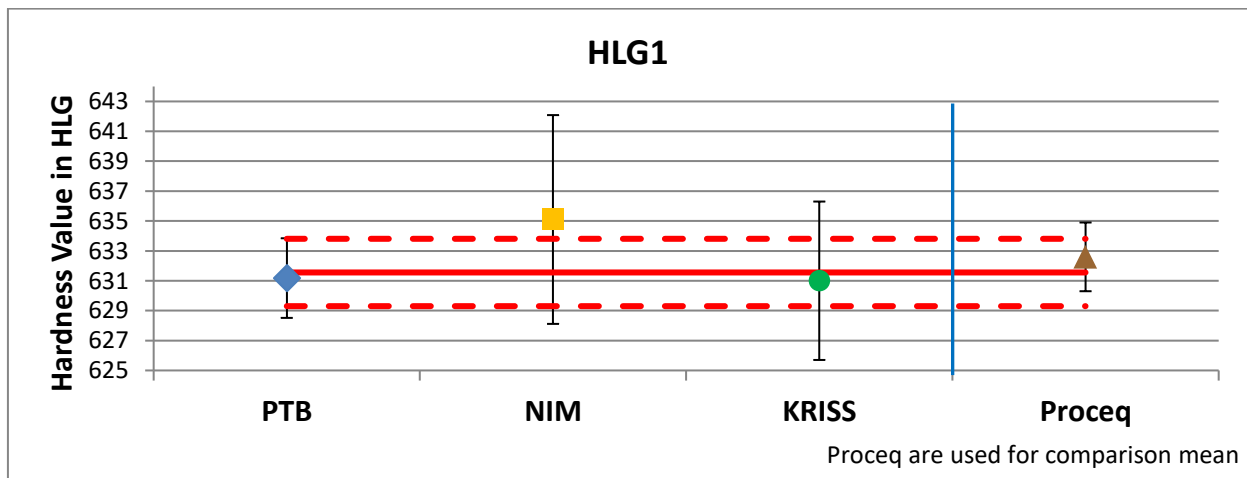


Figure 4: Measurement values for HLG1 block

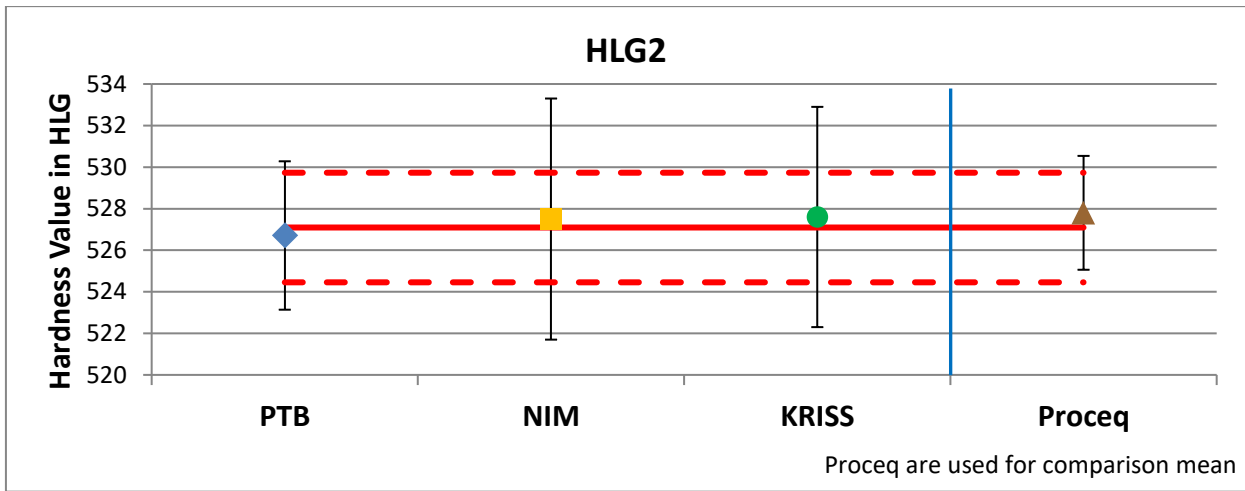


Figure 5: Measurement values for HLG2 block

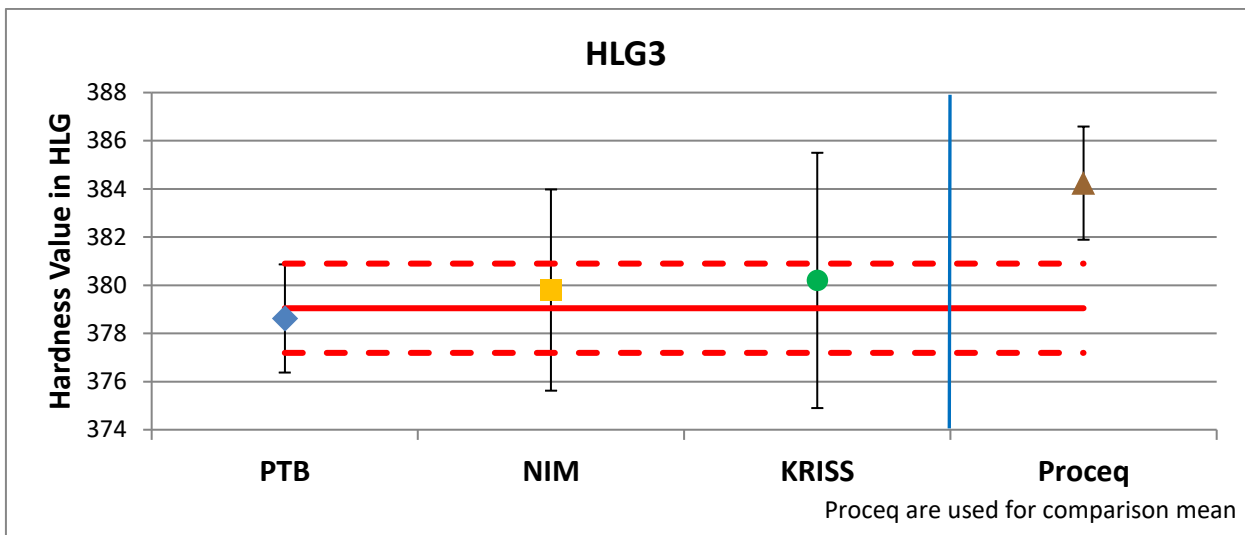


Figure 6: Measurement values for HLG3 block

Appendix A: Reports from the participants

Report Form 1 (Leeb D drop-tube measurements)

Metrology Information

Laboratory	PTB
Manufacturer of primary reference instrument	Proceq
Model of primary reference instrument	D drop-tube
Serial Number of primary reference instrument	E301-001-0067-06/4K
Hardness indication system	
Serial Number of Impact Body	ID40-001-0001-07/2E

Environment & General Information

Measurement place	Hardness Laboratory of PTB
Measurement date and time	03.05.2014
Temperature	20.0 °C
Relative Humidity	45 %
Measured by	Febo Menelao

Results of Measurements: Artifact D-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	
A	1	739.8		1		
	2	741.3		2		
	3	740.8		3		
	4	739.2		4		
	5	737		5		
	6	739.3		6		
	7	738.8		7		
	8	737.7		8		
	9	740.2		9		
	10	738.1		10		

Mean Value	$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$	739.22
Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.37
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.46
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	3.33
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	6.72

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
A	1	596.7		1		
	2	598.4		2		
	3	596.7		3		
	4	596.1		4		
	5	593.8		5		
	6	595.6		6		
	7	593.9		7		
	8	591.3		8		
	9	592.6		9		
	10	593.5		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			594.86
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.19
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.73
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.68
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			5.55

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
A	1	451.5		1		
	2	448.0		2		
	3	449.0		3		
	4	446.7		4		
	5	445.5		5		
	6	448.0		6		
	7	447.2		7		
	8	444.4		8		
	9	446.9		9		
	10	445.3		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			447.25
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.05
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.69
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.01
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			4.25

Please fill in all fields not shaded in grey.

Report Form 2 (Leeb G drop-tube measurements)

Metrology Information

Laboratory	PTB
Manufacturer of primary reference instrument	Proceq
Model of primary reference instrument	D drop-tube
Serial Number of primary reference instrument	E301-001-0067-06/4K
Hardness indication system	
Serial Number of Impact Body	IG40-001-0001-07/2E

Environment & General Information

Measurement place	Hardness Laboratory of PTB
Measurement date and time	04.05.2014
Temperature	20.0 °C
Relative Humidity	45 %
Measured by	Febo Menelao

Results of Measurements Artifact G-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	
A	1	631.7		1		
	2	632.7		2		
	3	632.6		3		
	4	632.9		4		
	5	630.9		5		
	6	630.8		6		
	7	629.9		7		
	8	630.4		8		
	9	630.8		9		
	10	629.1		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			631.18

Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.27
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.43
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	1.26
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	2.66

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
A	1	533.4		1		
	2	532.5		2		
	3	530.4		3		
	4	527.5		4		
	5	526.0		5		
	6	524.6		6		
	7	526.8		7		
	8	522.7		8		
	9	522.2		9		
	10	521.0		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			526.71
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			4.30
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			1.44
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			1.05
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			3.57

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
A	1	383.5		1		
	2	380.5		2		
	3	380.2		3		
	4	378.7		4		
	5	380.0		5		
	6	378.3		6		
	7	376.0		7		
	8	376.5		8		
	9	375.7		9		
	10	376.8		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			378.62
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.47
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.83
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.76
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			2.25

Please fill in all fields not shaded in grey.

Report Form 1 (Leeb D drop-tube measurements)

Metrology Information

Laboratory	NIM
Manufacturer of primary reference instrument	Proceq
Model of primary reference instrument	D drop-tube
Serial Number of primary reference instrument	Equotip 3 E301-005-1040-08/3K
Hardness indication system	
Serial Number of Impact Body	BD01-003-0002

Environment & General Information

Measurement place	Hardness Laboratory of NIM
Measurement date and time	03.02.2015 15:06
Temperature	23.0°C
Relative Humidity	15%
Measured by	Ming YE

Results of Measurements: Artifact D-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	
C	1	740.4		1		
	2	739.6		2		
	3	738.4		3		
	4	741.3		4		
	5	737.9		5		
	6	741.7		6		
	7	741.1		7		
	8	739.9		8		
	9	737.6		9		
	10	736.0		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			739.4HLD
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			1.86HLD

Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.62HLD, 0.08%
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	0.50%
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	1.0%

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
C	1	598.6		1		
	2	595.4		2		
	3	593.9		3		
	4	597.2		4		
	5	595.7		5		
	6	594.2		6		
	7	592.2		7		
	8	594.2		8		
	9	592.3		9		
	10	592.8		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			594.6HLD
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.11HLD
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.71HLD, 0.12%
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.5%
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			1.0%

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
C	1	449.1	X	1		
	2	448.9		2		
	3	445.9		3		
	4	448.2		4		
	5	445.7		5		
	6	445.4		6		
	7	442.6		7		
	8	444.6		8		
	9	444.3		9		
	10	Show error		10	444.7	
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			445.9HLD
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.14HLD
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.72HLD, 0.16%
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.5%
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			1.0%

Please fill in all fields not shaded in grey.

Report Form 2 (Leeb G drop-tube measurements)

Metrology Information

Laboratory	NIM
Manufacturer of primary reference instrument	Proceq
Model of primary reference instrument	G drop-tube
Serial Number of primary reference instrument	3 E301-005-1040-08/3K
Hardness indication system	
Serial Number of Impact Body	BG01-003-0006

Environment & General Information

Measurement place	Hardness Laboratory of NIM
Measurement date and time	03.02.2015 15:57
Temperature	23.0° C
Relative Humidity	15%
Measured by	Ming YE

Results of Measurements Artifact G-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	
C	1	634.5		1		
	2	636.2		2		
	3	634.3		3		
	4	631.6		4		
	5	634.9		5		
	6	636.5		6		
	7	634.7		7		
	8	635.0		8		
	9	634.6		9		
	10	634.2		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			635.1HLG
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			0.83HLG

Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.28HLG, 0.04%
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	0.5%
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	1.0%

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
C	1	534.2		1		
	2	530.1		2		
	3	528.7		3		
	4	527.6		4		
	5	526.8		5		
	6	525.9		6		
	7	525.1		7		
	8	526.2		8		
	9	525.3		9		
	10	525.4		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			527.5HLG
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.85HLG
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.96HLG, 0.18%
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.5%
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			1.1%

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
C	1	385.0		1		
	2	381.9		2		
	3	380.9		3		
	4	381.6		4		
	5	380.2		5		
	6	379.0		6		
	7	379.0		7		
	8	377.4		8		
	9	375.8		9		
	10	377.5		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			379.8HLG
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.67HLG
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.89HLG, 0.23%
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.5%
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			1.1%

Please fill in all fields not shaded in grey.

Report Form 1 (Leeb D drop-tube measurements)

Metrology Information

Laboratory	KRISS
Manufacturer of primary reference instrument	SYSCO Korea
Model of primary reference instrument	None(Prototype impact device for the Leeb Hardness Tester)
Serial Number of primary reference instrument	C011515
Hardness indication system	Oscilloscope with Leeb Hardness Calculation Program
Serial Number of Impact Body	'03-02

Environment & General Information

Measurement place	KRISS Hardness Test Lab.
Measurement date and time	March 02, 2015
Temperature	23 °C
Relative Humidity	48%
Measured by	NAEHYUNG TAK

Results of Measurements: Artifact D-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	
D	1	741.5		1		
	2	741.3		2		
	3	741.3		3		
	4	739.1		4		
	5	740.2		5		
	6	740.9		6		
	7	739.8		7		
	8	743.0		8		
	9	740.0		9		
	10	740.0		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			740.7

Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.1
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.4
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	2.3
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	4.7

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
D	1	601.3		1		
	2	600.1		2		
	3	600.0		3		
	4	599.7		4		
	5	599.3		5		
	6	600.0		6		
	7	598.0		7		
	8	598.1		8		
	9	598.0		9		
	10	597.4		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			599.2
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			1.3
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.4
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.0
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			4.1

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
D	1	452.0		1		
	2	451.1		2		
	3	447.7		3		
	4	449.6		4		
	5	448.0		5		
	6	448.1		6		
	7	446.2		7		
	8	446.8		8		
	9	447.0		9		
	10	446.1		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			448.3
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.0
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.7
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			1.9
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			4.0

Please fill in all fields not shaded in grey.

Report Form 2 (Leeb G drop-tube measurements)

Metrology Information

Laboratory	KRISS
Manufacturer of primary reference instrument	Proceq
Model of primary reference instrument	EQUOTIP 2
Serial Number of primary reference instrument	923-0072
Hardness indication system	EQUOTIP 2
Serial Number of Impact Body	IG51-010-0162

Environment & General Information

Measurement place	KRISS Hardness Test Lab.
Measurement date and time	March 04, 2015
Temperature	23 °C
Relative Humidity	48%
Measured by	NAEHYUNG TAK

Results of Measurements Artifact G-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	
D	1	632		1		
	2	633		2		
	3	633		3		
	4	630		4		
	5	631		5		
	6	631		6		
	7	629		7		
	8	630		8		
	9	630		9		
	10	627		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			631

Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.8
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.6
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	2.6
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	5.3

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
D	1	532		1		
	2	530		2		
	3	529		3		
	4	529		4		
	5	526		5		
	6	528		6		
	7	527		7		
	8	525		8		
	9	525		9		
	10	525		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			527.6
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.4
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.8
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.5
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			5.3

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
D	1	385		1		
	2	383		2		
	3	382		3		
	4	381		4		
	5	378		5		
	6	379		6		
	7	380		7		
	8	378		8		
	9	379		9		
	10	377		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			380.2
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.5
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.8
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.5
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			5.3

Please fill in all fields not shaded in grey.

Report Form 1 (Leeb D drop-tube measurements)

Metrology Information

Laboratory	PROCEQ SA
Manufacturer of primary reference instrument	PROCEQ SA [E]
Model of primary reference instrument	Equotip DropTube D/G
Serial Number of primary reference instrument	ID40-001-0002 / IG50-001-0002
Hardness indication system	E301-001-0008 (Equotip3)
Serial Number of Impact Body	D14mE / G15oE

Environment & General Information

Measurement place	Bahnstrasse 23, Schwerzenbach CH - 2nd Floor - LabRoom
Measurement date and time	05.12.2014
Temperature	22
Relative Humidity	51.40%RH
Measured by	Romain Coury

Results of Measurements: Artifact D-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	
B	1	737.9		1	738.7	Initial T0 Value was too low.
	2	739.5		2		
	3	740.2		3		
	4	740.1		4		
	5	738.5		5		
	6	738.6		6		
	7	738.9		7		
	8	737.9		8		
	9	737.2		9		
	10	736.4		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			738.6

Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	1.20
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.40
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	2.94
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	5.94

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
B	1	596.2		1		
	2	595.7		2		
	3	594.9		3		
	4	594.5		4		
	5	593.9		5		
	6	593.2		6		
	7	593.7		7		
	8	592.9		8		
	9	592.5		9		
	10	593.9		10	592.9	Low A value
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			594.04
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			1.26
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.42
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			2.39
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			4.85

Please fill in all fields not shaded in grey

Results of Measurements: Artifact D-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLD	Assigned Repeat Test Block Mark	Template Recess	Reading in HLD	Comments
B	1	451.7		1		
	2	450.2		2		
	3	448		3		
	4	448.6		4		
	5	447.2		5		
	6	446.4		6		
	7	445.7		7		
	8	446.3		8		
	9	446.6		9		
	10	445.8		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			447.65
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.00
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			0.67
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			1.83
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			3.90

Please fill in all fields not shaded in grey.

Report Form 2 (Leeb G drop-tube measurements)

Metrology Information

Laboratory	PROCEQ SA
Manufacturer of primary reference instrument	PROCEQ SA [E]
Model of primary reference instrument	Equotip DropTube D/G
Serial Number of primary reference instrument	ID40-001-0002 / IG50-001-0002
Hardness indication system	E301-001-0008 (Equotip3)
Serial Number of Impact Body	D14mE / G15oE

Environment & General Information

Measurement place	Bahnstrasse 23, Schwerzenbach CH - 2nd Floor - LabRoom
Measurement date and time	05.12.2014
Temperature	22
Relative Humidity	51.40%RH
Measured by	Romain Coury

Results of Measurements Artifact G-1

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			Comments
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	
B	1	634.9		1	634.6	Low A value
	2	636.2		2		
	3	633		3		
	4	634.4		4		
	5	633.4		5		
	6	633.1		6		
	7	631.8		7		
	8	631		8		
	9	629.5		9		
	10	629		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			632.6

Standard deviation	$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$	2.31
Measurement Uncertainty series of 10 readings, confidence level 68%	$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$	0.77
Measurement Uncertainty of the instrument by the measured hardness k=1	u_{MS}	0.85
Combined Uncertainty k=2	$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$	2.30

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-2

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
B	1	534.5		1		
	2	531.7		2		
	3	530.1		3		
	4	527.8		4		
	5	527.2		5		
	6	525.7		6		
	7	526.3		7		
	8	527.2		8		
	9	524.3		9		
	10	523.2		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			527.8
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			3.43
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			1.15
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.74
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			2.74

Please fill in all fields not shaded in grey.

Results of Measurements Artifact G-3

1 st attempt measurements			Repeat Measurements (use ONLY if 1 st attempt is rejected)			
Assigned Test Block Mark	Template Recess	Reading in HLG	Assigned Repeat Test Block Mark	Template Recess	Reading in HLG	Comments
B	1	389.9		1		
	2	387.3		2		
	3	386.6		3		
	4	385.5		4		
	5	384.2		5		
	6	382.9		6		
	7	381.5		7		
	8	381.7		8		
	9	381.4		9		
	10	381.4		10		
Mean Value			$\bar{x} = \frac{\sum_{i=1}^{10} x_i}{10}$			384.24
Standard deviation			$\sigma_x = \sqrt{\frac{1}{9} \sum_{i=1}^{10} (x_i - \bar{x})^2}$			2.99
Measurement Uncertainty series of 10 readings, confidence level 68%			$u_{\bar{x}} = \frac{1.06 \cdot \sigma_x}{\sqrt{10}}$			1.00
Measurement Uncertainty of the instrument by the measured hardness k=1			u_{MS}			0.61
Combined Uncertainty k=2			$U = 2 \cdot \sqrt{u_{MS}^2 + u_{\bar{x}}^2}$			2.35

Please fill in all fields not shaded in grey.

Appendix B: Additional investigations into the results obtained

If all measured values of a hardness reference block are placed in a measured value number hardness diagram, it is noticeable that the hardness of almost all hardness reference blocks decreases towards the edge. The following diagrams (Diagram B.1 to Diagram B.4) illustrate this.

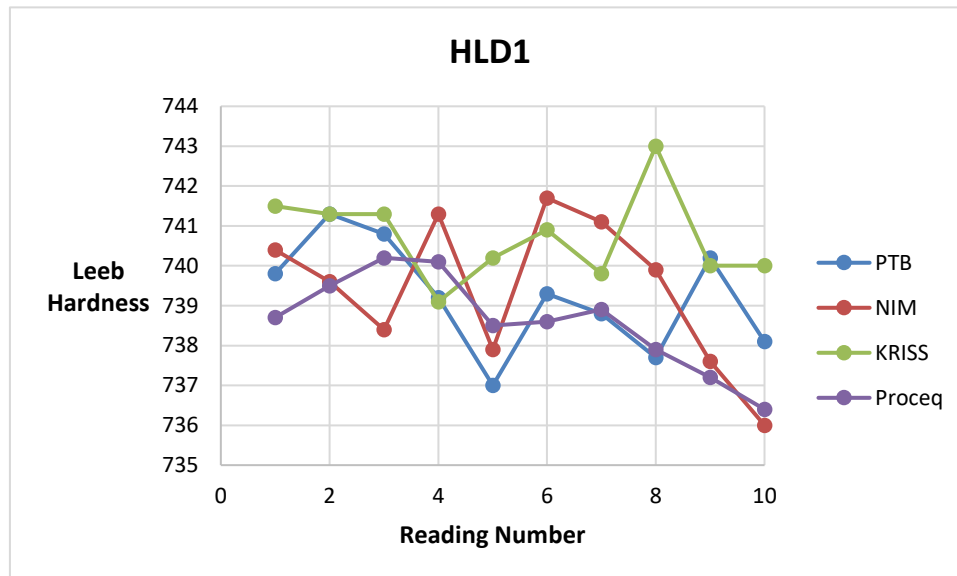


Diagram B.1: Dependence of the hardness on the number of the indentation from block HLD1



Diagram B.2: Dependence of the hardness on the number of the indentation from block HLD3

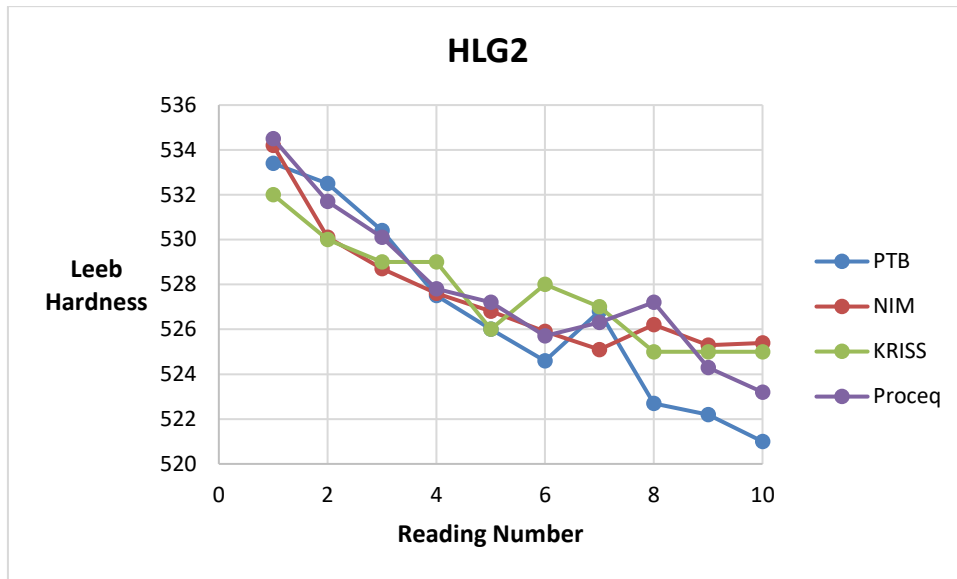


Diagram B.3: Dependence of the hardness on the number of the indentation from block HLG2

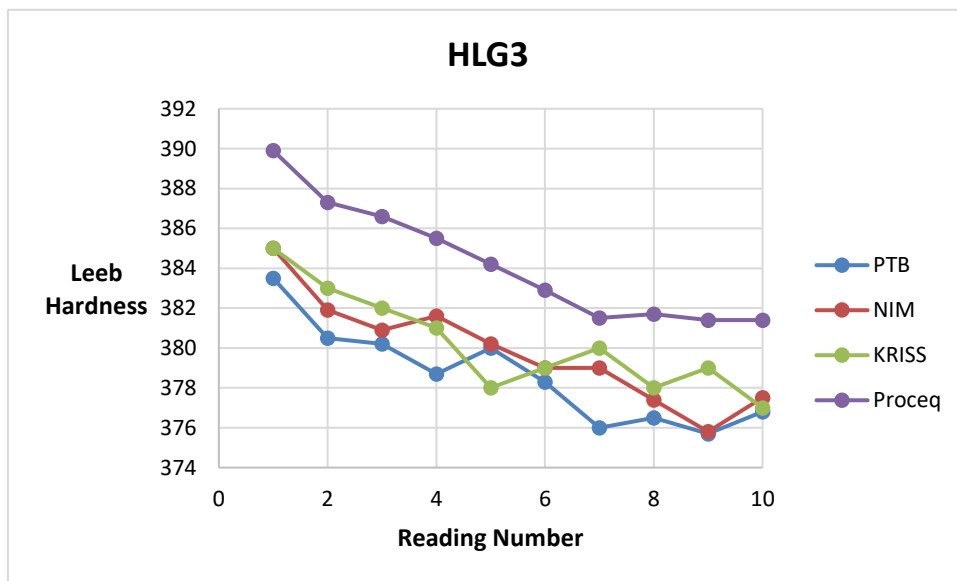


Diagram B.4: Dependence of the hardness on the number of the indentation from block HLG3

As the hardness indents from the centre have moved further towards the edge, it is possible that the Leeb hardness measurement method has a strong influence on the edge. This seems to be independent of the scale, as both measured scales (HLD and HLG) show this influence. To check whether the Leeb hardness measurement method is responsible for the course of the hardness on the hardness reference blocks, a second hardness method was used on the blocks. The Vickers hardness measurement method was selected as this method can cope with all hardnesses of the blocks. It is also very well known how the edge influence is with this method. With this method, it is sufficient to have an edge distance or a distance between 2

hardness indentations of at least 3 times the Vickers hardness indentation. HV 1 was defined as the load level. Diagram B.5 shows the course of the Vickers hardness on the hardness reference blocks.

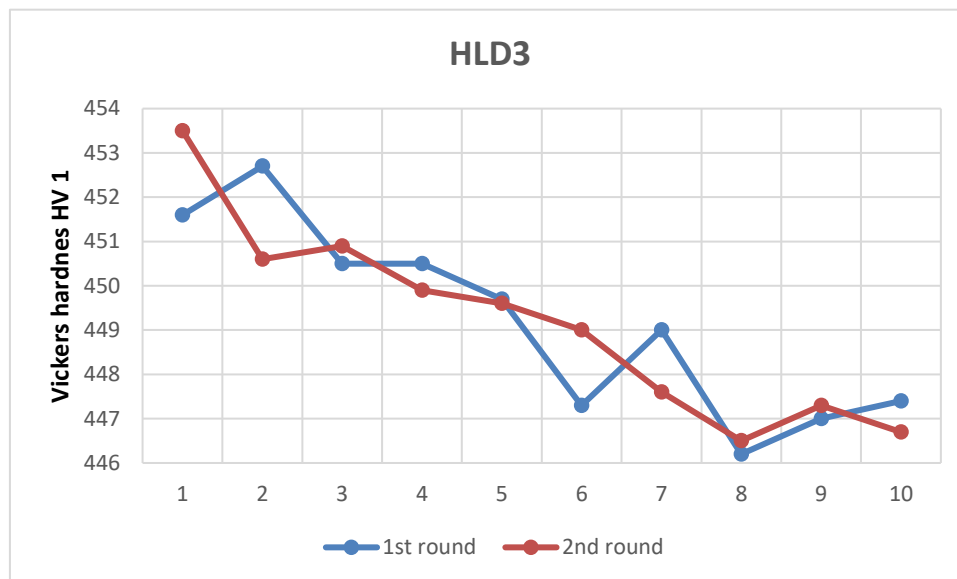


Diagram B.1: Dependence of the hardness on the number of the indentation by Vickers measurements from block HLD3

Measurements were taken close to the corresponding Leeb hardness, so that measuring point 1 of the Vickers method is next to measuring point 1 of the Leeb method. The same procedure was followed for Vickers indentations 2 to 10. It can be clearly seen that the Vickers hardness and the Leeb hardness show the same curve. The diagonal length of the Vickers indentation was approx. 100 μm . As the indentations between the Leeb and Vickers indentations were at least 1 mm apart and this also applied to the edge of the sample, the Vickers hardness values show no edge influence. It can therefore be assumed that the hardness curve of the Leeb hardness method is not due to an edge effect. Rather, it can be assumed that the hardness reference block exhibits a hardness gradient.

This gradient may have arisen due to the huge mass of the hardness reference block. For example, when tempering the hardness reference block after hardening, the temperature could have been applied for much longer, resulting in a reduction in hardness towards the edge.

It is also noticeable that the gradient can reach a value of 10 Leeb units. With such a large gradient, it is no longer ensured that the same hardness value is determined between the calibrating institute and the user of the hardness reference block, depending on the measuring points used. Up to 1 % of the Leeb value was specified as the measurement uncertainty of the participating institutes. For the hardness reference block tested (HLD3) with an average hardness value of 450 HLD and an assumed measurement uncertainty of 1 % (4.5 HLD), the measured values would no longer overlap if one participant measured mainly in the centre and

another participant mainly at the edge. This effect is even greater with the HLG method, as the measurement uncertainty here is approx. 0.5 %.