Accuracy of Portable Hardness Testers

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Hardness tests enable to determine one of the main mechanical properties of the material, namely hardness. For hardness testing, it is possible to use either conventional desk hardness testers or the currently increasingly used portable hardness testers. The paper is focused on determination of the accuracy and reliability of static (desk) and dynamic (portable) hardness testers. The paper deals with the measurement of hardness of calibration hardness plates by 4 different methods (Brinell, Vickers, Rockwell and Leeb) with using 5 different hardness testers (3 desk and 2 portable). The hardness values measured by the different hardness testers were compared to the reference hardness listed in the calibration hardness plates and consequently, the accuracy of these measurements was evaluated. The aim of the work has been to determine the accuracy and reliability of portable hardness testers in comparison with desk hardness testers.

Keywords: Hardness, Brinell, Vickers, Rockwell, Leeb

1　Introduction

Hardness is a mechanical property of a material defined as the resistance of a material to the permanent deformation of its surface caused by the effect of a geometrically defined body. In the hardness test, the surface of the test material is mechanically loaded by the pressure of the foreign body from the hard material and the result of this action is quantitatively expressed as the hardness value. Due to their simplicity and applicability even when other tests cannot be used, hardness tests are advantageous and widely used. The metal is not damaged in this test as in most mechanical tests, because only a small volume on the surface of the tested metal is affected [1-3].

Nowadays, several methods for hardness testing are used in practice. Hardness tests are divided:

- according to the principle (indentation, rebound, scratch and pendulum methods),
- according to the speed of the loading force (static and dynamic methods),
- according to the purpose of hardness measurement (macro and microhardness tests) [4-6].

According to the principle, indentation and rebound methods are most widely used. The principle of indentation methods consists in pushing the indentor (ball, pyramid, cone) of steel, carbide or diamond into the test material, where the criterion for determination of hardness is the size of the indentation (Brinell, Vickers, Rockwell and Knoop method). The principle of rebound methods consists in rebounding of the falling body of a certain shape and weight from the test material, where the criterion for determination of hardness is the height of rebound (Shore method) or the energy loss (Leeb method) [7,8].

In static methods, the test material is loaded slowly, continuously, with a uniformly increasing load (Brinell, Vickers, Rockwell and Knoop method); in dynamic methods, the load increases suddenly, by impact (Leeb method).

For laboratory hardness testing, there are usually used desk hardness testers which use static methods. For exterior hardness testing, there are increasingly used universal portable hardness testers that use dynamic methods. These hardness testers enable the measured hardness to be converted to all common hardness scales (HB, HV, HRB, HRC, HS) as well as the orientation tensile strength R_m [9-15]. For this reason, the paper deals with comparing the accuracy and reliability of static (desk) and dynamic (portable) hardness testers.

2　Experimental material and methods

Hardness tests were carried out at the Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina.

The following methods were used for experiments (hardness tests) – 3 static methods (Brinell, Vickers and Rockwell) and 1 dynamic method (Leeb).

Five hardness testers were used for experiments:

- for Brinell hardness test – desk hardness tester CV-3000LDB;
- for Vickers hardness test – desk hardness tester HPO250/AQ;
- for Rockwell hardness test – desk hardness tester RR-1D/AQ;
- for Leeb hardness test – portable hardness testers TH170 and TH1100 (Fig. 1).

Fig. 1 *Portable hardness testers used for experiments – TH170 and TH1100*

Four hardness calibration plates were used as experimental material for hardness tests:

- for Brinell hardness test – hardness plate with reference hardness 97.4 HBW 5/250;
- for Vickers hardness test – hardness plate with reference hardness 710 HV 30;
- for Rockwell hardness test – hardness plate with reference hardness 64.4 HRC;
- for Leeb hardness test – hardness plate with reference hardness 778 HLD.

The following conditions were used for hardness tests:

- for Brinell hardness test (according to STN EN ISO 6506-1) – carbide ball with diameter D = 5 mm, test load F = 250 kp (2452.5 N), loading time t = 10 s => HBW 5/250/10;
- for Vickers hardness test (according to STN EN ISO 6507-1) – diamond regular quadrilateral pyramid, test load F = 30 kp (294.3 N), loading time t = 10 s => HV 30/10;
- for Rockwell hardness test (according to STN EN ISO 6508-1) – diamond cone, test load F = 150 kp (1471.5 N), loading time t = 6 s => HRC;
- for Leeb hardness test (according to STN EN ISO 16859-1) – carbide ball with diameter D = 3 mm => HLD.

Each calibration hardness plate was subjected to n = 5 measurements using a desk hardness tester and another n = 5 measurements using portable hardness testers. The average value $\bar{H}$ and standard deviation s_H [16,17] were calculated from the measured values H_i according to the formulas:

$$\bar{H} = \frac{\sum_{i=1}^{n} H_i}{n} \qquad (1)$$

$$s_H = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (H_i - \bar{H})^2} \qquad (2)$$

Where:
n ... number of measurements [–],
H_i … measured values of hardness [–].

From the average hardness $\bar{H}$ and reference hardness H_{ref} listed on the calibration hardness plate, the measurement inaccuracy N was calculated according to the formula

$$N = \frac{\bar{H} - H_{ref}}{H_{ref}} \cdot 100 \quad [\%]$$

Where:
$\bar{H}$ ... average hardness [–],
H_{ref} … reference hardness from the calibration hardness plate [–].

3 Experimental results and discussion

The results of hardness measurement on the hardness plate for Brinell hardness test are given in Tab. 1. Desk hardness tester CV-3000LDB and portable hardness testers TH170 and TH1100 were used for measurement.

Tab. 1 *Results of Brinell hardness test*

| Hardness tester	CV-3000LDB		TH170	TH1100
Measurement No	d (mm)	HBW5/250/10	HB (HLD)	HB (HLD)
1	1.78	98	91	95
2	1.80	95	92	91
3	1.78	98	96	93
4	1.79	96	97	90
5	1.80	95	92	89
$\bar{H}$		96.4	93.6	91.6
s_H		1.52	2.70	2.41
N (%)		−1.03	−3.90	−5.95
reference hardness H_{ref} from the calibration hardness plate => 97.4 HBW 5/250				
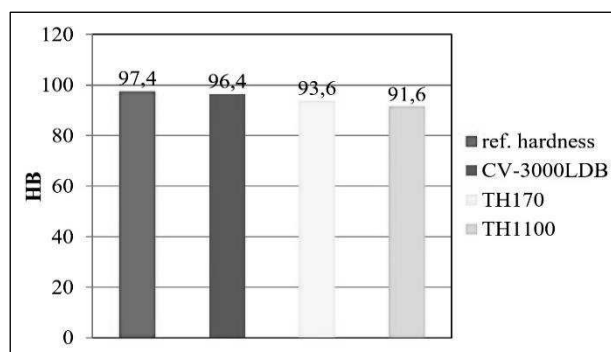
Fig. 2 *Comparison of measured Brinell hardness with the reference hardness*

A comparison of the results of Brinell hardness test is shown in Fig. 2. The hardness measured by the desk hardness tester differs from the reference hardness minimally (–1.03 %). The hardness determined by the portable hardness testers differs from the reference hardness by –3.90 %, respectively –5.95 %. The values measured by the desk hardness tester show less inaccuracy than the values measured by the portable hardness testers (Tab. 1).

The results of hardness measurement on the hardness plate for Vickers hardness test are given in Tab. 2. Desk hardness tester HPO250/AQ and portable hardness testers TH170 and TH1100 were used for measurement.

Tab. 2 *Results of Vickers hardness test*

| Hardness tester	HPO250/AQ		TH170	TH1100
Measurement No	d (mm)	HV30/10	HV (HLD)	HV (HLD)
1	0.275	736	742	703
2	0.275	736	706	698
3	0.276	730	731	689
4	0.274	741	735	691
5	0.274	741	740	707
$\bar{H}$		736.8	730.8	697.6
s_H		4.55	14.52	7.67
N (%)		+3.77	+2.93	−1.75
reference hardness H_{ref} from the calibration hardness plate => 710 HV 30				
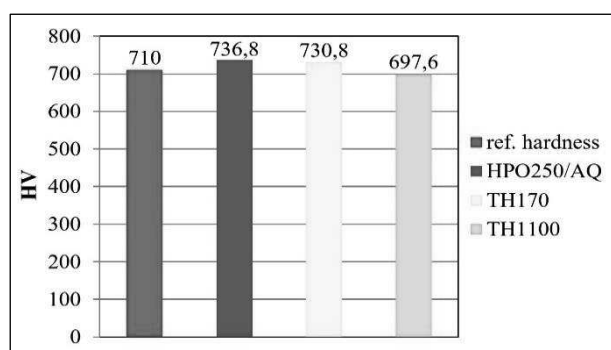
Fig. 3 *Comparison of measured Vickers hardness with the reference hardness*

A comparison of the results of Vickers hardness test is shown in Fig. 3. The hardness measured by the desk hardness tester differs from the reference hardness by +3.77 %. The hardness determined by the portable hardness testers differs from the reference hardness by +2.93 %, respectively –1.75 %. The values measured by the portable hardness testers show less inaccuracy than the values measured by the desk hardness tester (Tab. 2).

The results of hardness measurement on the hardness plate for Rockwell hardness test are shown in Tab. 3. Desk hardness tester RR-1D/AQ and portable hardness testers TH170 and TH1100 were used for measurement.

Tab. 3 *Results of Rockwell hardness test*

| Hardness tester	RR-1D/AQ	TH170	TH1100
Measurement No	HRC	HRC (HLD)	HRC (HLD)
1	64.1	62.4	60.4
2	64.8	58.6	59.0
3	64.6	61.6	60.9
4	64.5	60.5	60.1
5	64.7	63.2	60.3
$\bar{H}$	64.5	61.3	60.2
s_H	0.27	1.79	0.71
N (%)	+0.22	−4.81	−6.52
reference hardness H_{ref} from the calibration hardness plate => 64.4 HRC			
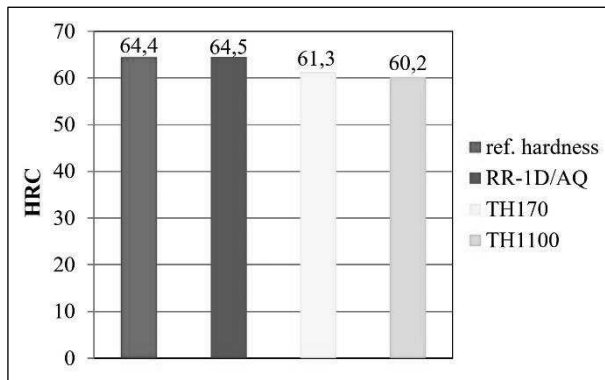
***Fig. 4** Comparison of measured Rockwell hardness with the reference hardness*

A comparison of the results of Rockwell hardness test is shown in Fig. 4. The hardness measured by the desk

hardness tester differs from the reference hardness minimally (+0.22 %). The hardness determined by the portable hardness testers differs from the reference hardness by –4.81 %, respectively –6.52 %. The values measured by the desk hardness tester show less inaccuracy than the values measured by the portable hardness testers (Tab. 3).

By comparing the desk hardness testers, it was found that the lowest inaccuracy N (percentage deviation between measured and reference hardness) was achieved by the hardness tester RR-1D/AQ for Rockwell hardness test (+0.22 %), followed by the hardness tester CV-3000LDB for Brinell hardness test (–1.03 %) and finally by the hardness tester HPO250/AQ for Vickers hardness test (+3.77 %).

The results of hardness measurement on the hardness plate for Leeb hardness test are given in Tab. 4. Portable hardness testers TH170 and TH1100 were used for measurement.

***Tab. 4** Results of Leeb hardness test*

Hardness tester	TH170	TH1100
Measurement No	HLD	HLD
1	777	784
2	781	784
3	785	785
4	782	780
5	780	783
$\bar{H}$	781.0	783.2
s_H	2.92	1.94
N (%)	+0.38	+0.64
reference hardness H_{ref} from the calibration hardness plate => 778 HLD		

A comparison of the results of Leeb hardness test is shown in Fig. 5. The hardness determined by the portable hardness testers differs from the reference hardness by less than 1% (+0.38 %, respectively +0.64 %) (Tab. 4).
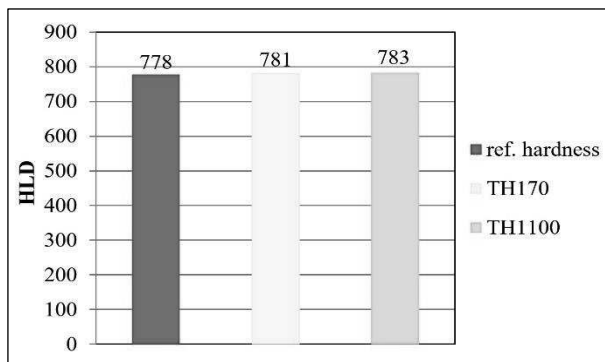
***Fig. 5** Comparison of measured Leeb hardness with the reference hardness*

Using portable hardness testers, the lowest inaccuracy N was achieved for Vickers hardness test (+2.93 % by the hardness tester TH170, respectively –1.75 % by the hardness tester TH1100), followed by Brinell hardness test (–3.90 % by the hardness tester TH170 and –5.95 % by the hardness tester TH1100) and by Rockwell hardness test (–4.81 % by the hardness tester TH170 and –6.52 % by the hardness tester TH1100). For the Leeb hardness test,

the inaccuracy of measurement was minimal in both cases (+0.38 %, respectively +0.64 %).

By comparing the portable hardness testers, it was found that the hardness tester TH170 was more accurate for Brinell hardness test (inaccuracy –3.90 %), Rockwell hardness test (–4.81 %) and Leeb hardness test (+0.38 %); the hardness tester TH1100 was more accurate only for Vickers hardness test (–1.75 %).

In the case of Brinell hardness test, the desk hardness tester CV-3000LDB was significantly more accurate (inaccuracy –1.03 %) than the portable hardness testers. Similarly, for Rockwell hardness test, the desk hardness tester RR-1D/AQ was significantly more accurate (+0.22 %) compared to the portable hardness testers. Only for Vickers hardness test, the portable hardness testers TH170 and TH1100 were more accurate (+2.93 %, respectively –1.75 %) compared to the desk hardness tester HPO250/AQ. In this case, it would be necessary to calibrate the desk hardness tester to increase its accuracy.

4 Conclusion

The hardness tests carried out with using desk and portable hardness testers showed that more accurate values of hardness were obtained using desk hardness testers. The accuracy and reliability of portable hardness testers was lower than that of desk hardness testers. This accuracy can be influenced by different method of measur-

ing and by the need to convert the measured Leeb hardness to other hardness scales. On the other hand, portable hardness testers have several advantages, such as measuring hardness outside the laboratory, measuring large and heavy test specimens (that cannot be measured with desk hardness testers), measuring hardness in different directions, lower cost of hardness testing, etc.

Acknowedgement

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