ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome X (Year 2012) – FASCICULE 3 (ISSN 1584 – 2673)

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THE AMBIENT TEMPERATURE AND QUALITY OF THE HARDNESS MEASUREMENT

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ABSTRACT: *Three appraisers carried out the calibration of hardness tester by Vickers and Brinell methods, using on standard (CRM) with defined both values of standard hardness and their uncertainty. The ambient temperature of laboratory varied in range 14.9 to 27.6°C at ten levels. The influence of the temperature on the results of calibration was evaluated by uncertainty, systematic and random errors whereby last two were determined by Youden plot.*
KEYWORDS: *temperature, hardness, uncertainty, error, appraiser*

INTRODUCTION

The temperature is ranked among one the most important influence quantities in metrology. As the influence quantity it does not affect only actually measured quantity, but affects also the relation between the indication and the measurement result. Ambient temperature affects measured and also affects other influence quantities (pressure, humidity…). It affects the dimensions of indenter, indentation measuring device, another parts of the hardness tester, the measures specimen, and last but not least the appraiser in hardness measurement. The parts of the tester and the specimen are made from construction materials (steel, glass), with various thermal dilatability. The standard permit to carry out the indirect calibration (23°C ± 5°C) [2, 4]and the hardness measurement (between 10°C and 35°C) in relative broad range of temperatures [1, 3].

The Vickers test is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond with vertex angle 136°. The diagonal of the resulting indention is measured under a microscope. The Vickers testing method is the most accurate and sensitive hardness test method. Thoroughly prepared surface before test is unavoidable. The Vickers test does not deteriorate the surface of final product as much as Brinell test.

The Brinell test uses a machine to press a tungsten carbide ball into the surface of the test specimen. The machine applies a test force proportional to the ball diameter and tested material. Among used hardness tests, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures, and any irregularities in the uniformity of the alloy and soft materials. Wide indentations, on the other hand, can impair the surface of specimen as was remarked above.

Like in any test of mechanical properties, there is obvious requirement for reliability of measurement results, which is unthinkable without sufficient quality of measurement process. Metrological confirmation shall be designed and implemented to ensure that the metrological characteristics of the measuring equipment satisfy the metrological requirements for the measurement process. Metrological confirmation comprises measuring equipment calibration and measuring equipment verification [5]. Calibration is checking of a measuring instrument against an accurate CRM (certified reference material, standard) to determine any deviation and correct for errors [6].

A perfect measurement would obtain the true value of a quantity, which is the value consistent with the definition of a given quantity. True values are, by nature, indeterminable because a perfect measurement cannot be performed. The final corrected result of a measurement is, at best, an estimate of the true value of the quantity that someone intended to measure. The measurement uncertainty is a parameter that characterizes the dispersion of the values that could reasonably be attributed to the measured value [7].

For indirect calibration of hardness tester against CRM according to the respective standard usually there is not a problem to keep the requirements for repeatability r_{rel} and maximum relative error E_{rel} of the tester. The problem arises after the determination of the maximum permissible deviation of the tester including its measurement uncertainty, which is equivalent to relative expanded uncertainty of calibration U_{rel}, whereas it is frequently higher than the value permitted by the standard. In such case, the measuring device is nonconforming and shall be removed from service [5].

The objective of the article is to analyze the influence of ambient temperature on the results of the hardness tester calibration by three appraisers using analysis of calibration characteristics, *uncertainty in particular and errors evaluated by Youden plot. One measured specimen in form of certified reference material (CRM) was used. The results were validated by analysis of variance (ANOVA).*

EQUIPMENT, SPECIMEN, TEMPERATURE AND METHOD

Universal hardness tester HPO 250 (usable for Vickers and Brinell method), product of VEB Werkstoffprüfmaschinen „Fritz Heckert"(East Germany) in 1982 was used as equipment. The magnification of measuring device was 70×, so the discrimination d = 0.001 mm (the value of the smallest graduation of screw micrometer drum).*

Table 1. The values of hardness and characteristics of calibration

appraiser		14.9	15.76	16.7	17.09	18.74	19.83	21.72	23.02	26.2	27.6
HBW2.5/187.5	A	258	250	247	253	253	253	257	247	245	248
	B	247	245	245	248	249	245	248	248	248	248
	C	248	248	245	247	247	249	247	246	249	245
HV10	A	281	279	281	296	288	275	286	278	287	275
	B	256	255	253	254	252	244	254	252	246	252
	C	285	290	288	281	287	289	292	270	285	289
HBW2.5/187.5 r_{rel}	A	1.91	2.29	1.97	0.84	1.47	2.1	1.16	2.39	3.1	1.77
	B	1.24	0.83	2.27	0.93	0.73	1.65	0.42	2.08	0.83	1.56
	C	1.56	0.83	2.38	1.66	1.14	2.39	1.76	0.83	2.08	1.24
HV10 r_{rel}	A	2.14	8.32	2.92	4.19	3.35	3.47	4.71	3.48	2.56	6.35
	B	3.16	1.85	2.21	2.59	2.58	3.63	2.22	3.5	1.11	1.47
	C	3.13	6.52	6.5	3.89	5.7	5.91	5.95	4.77	3.72	6.11
HBW2.5/187.5 E_{rel}	A	6.49	3.24	1.9	4.3	4.36	4.55	6.24	2.12	1	2.43
	B	1.78	1.06	1.12	2.2	2.91	1.11	2.33	2.56	2.55	2.25
	C	2.51	2.46	1.25	1.81	2.15	2.8	2.07	1.49	2.74	1.1
HV10 E_{rel}	A	14.83	13.97	14.9	20.89	17.72	12.62	17.13	13.77	17.54	12.49
	B	4.8	4.23	3.32	4.05	3.03	0	3.89	2.91	4.15	3.08
	C	16.53	18.54	17.99	15.13	17.58	18.13	19.32	10.62	16.64	18.2
HBW2.5/187.5 U_{rel}	A	8.78	5.67	4.19	6.02	6.44	6.95	8.02	4.57	3.99	4.63
	B	3.61	2.72	3.53	3.9	4.54	3.21	3.88	4.81	4.24	4.18
	C	4.51	4.13	3.71	3.84	3.93	5.69	4.26	3.2	4.97	2.97
HV10 U_{rel}	A	19.44	22.26	19.85	26.94	17.72	17.83	23.16	19.32	22.69	19.72
	B	9.7	8.63	8.03	8.7	3.03	5.09	8.42	8.29	8.41	7.4
	C	21.63	26.34	26.02	21.17	17.58	25.43	26.11	16.82	22.21	25.1

Table 2. The requests for the characteristics of calibration

	r_{rel}	E_{rel}	U_{rel}
HV10	2.0%	±3.0%	±3.0%
HBW2,5/187,5	2.0%	±2.0%	±2.0%

The certified reference material (CRM) in form of hardness reference block with specified hardness H_c = 242.4 HV10 and 242.4 HBW 2.5/187.5 and standard uncertainty u_{CRM} = ± 1.82 HV10 and 5.06 HBW 2.5/187.5 was used as a specimen for all measurements by both test methods: HBW2.5/187.5 and HV10. The tests were carried out at ambient temperature within the range of 14.9 to 27.6°C at ten levels. The laboratory with tester and CRM was tempered at least 12 hours. One measurement lasted about one hour. The temperature was measured on the anvil of tester (place of specimen) by two digital thermometers (Eurotron, TESTO) with discriminant d = 0.1°C. The temperature was calculated as average temperature from five values of both thermometers during calibration with standard deviation s between 0.2 and 0.3°C for particular calibrations except of No. 5 (average temperature 18.74°C, s = 0.6°C). The relative humidity was measured by Eurotron, it decreases with increasing temperature, fig. 1.*

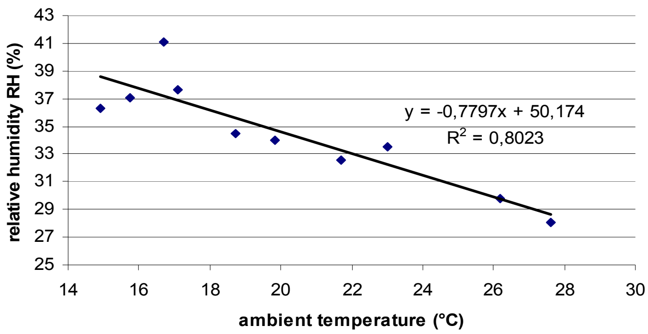

Figure 1. The relationship between ambient temperature and relative humidity

Table 3. The average value AVER, standard deviation s, outliers and p – value of normality test.

Method	HBW2.5/187.5				HV10			
Appraiser	A	B	C	A+B+C	A	B	C	A+B+C
AVER	251.08	247.08	246.72	248.2933	282.5	252.5	285.66	273.5533
s	5.735105	2.898557	3.505331	4.642301	11.00696	5.592451	12.90564	18.15723
outliers	0	0	0	0	0	0	0	0
normality (p)	0.5292	0.00713	0.11159	0.00009	0.74675	0.11904	0.48557	0.00014

All calibrations carried out three appraisers. The appraiser A is in his thirties and he is "beginner" in respect of the hardness measurement. The appraisers B and C are in their fifties; both are *approximately equally skilled "veterans". The indentations were along the radius (from the centre to the rim) of specimen in equidistant intervals with slewing of the CRM after each indentation. The appraisers performed the calibration (by five indentations by Brinell and Vickers methods) in random order. The force application time was 15 seconds. The values of particular appraisers - average hardness, the repeatability r_{rel}, the maximum error of testing machine E_{rel} and relative expanded uncertainty U_{rel} for particular calibrations are in tab. 1 and shall not exceed the values given in tab. 2 in accordance with standards [1, 3].*

RESULTS

The statistical outliers were detected by Grubbs' test (significance level α =0.05). Their presence would indicate measurement process suffering from special disturbances and out of statistical control. The normality was determined by Freeware Process Capability Calculator software (Anderson – Darling test, $p \geq 0.05$ for file with normal distribution. The normality and the outliers were determined for files involving values of one appraiser (n = 50 indentations) or three appraisers together (n = 150 indentations) measured by one method at all temperatures. As it can be seen in tab. 3 absence of outliers suggests that measurement process has avoided the gross errors.

Table 4. Two way ANOVA without repeatability, the influence of ambient temperature and appraiser on the characteristics of calibration, p-value

Method	HBW 2.5/187.5		HV10	
Factor	Appraiser	Temperature	Appraiser	Temperature
r_{rel}	0.001	0.469	5.7e-10	0.086
E_{rel}	0.058	0.180	0.001	0.282
U_{rel}	0.006	0.356	4.38e-11	0.344

In relation to fig. 2 decreasing tendency of measured hardness (average values of all three appraisers together) with increasing temperature is visible, but the correlation is weak (r = 0.3860 for HBW and r = 0.3167 for HV).

According to two factor ANOVA without repeatability the influence of ambient temperature on the characteristics of calibration (r_{rel}, E_{rel} and U_{rel}) is not statistically significant but the influence of particular appraiser is significant, tab. 4.

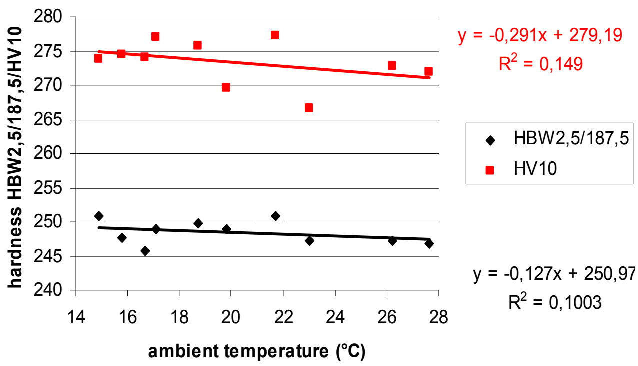

Figure 2. The relationship between the ambient temperature and the average measured hardness

The uncertainty is inversely proportional to the quality of measurement. The uncertainty of HV hardness moderate decreases with increasing of ambient temperature for all appraisers particularly and together, fig. 3. The influence of temperature on the uncertainty of HBW hardness of particular appraisers was ambiguous. The uncertainty of appraisers A and C decreased but in case of appraiser B increased with increasing of temperature, fig. 4.

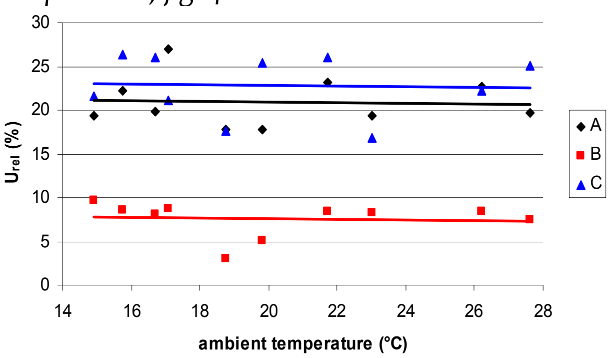

Figure 3. The relationship between the ambient temperature and expanded relative uncertainty of HV

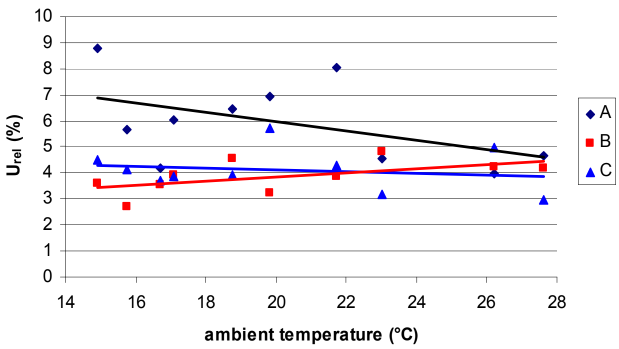

Figure 4. The relationship between the ambient temperature and expanded relative uncertainty of HBW

Youden plot (analysis) is used mostly in interlaboratory comparisons. Its advantage is unique ability to separate random and systematic errors (bias). Two values (HV and HBW hardness) are measured on one specimen by an appraiser at particular level of temperature. The axes in this plot are drawn on the same scale: the unit on the x-axis (HBW) has the same length as the unit on the y-axis (HV). Each point in the plot corresponds to the results of particular level of ambient temperature and is defined by a first response variable on the horizontal axis and a second response variable on the vertical axis. A horizontal median line is drawn parallel to the x-axis so that there are as many points above the *line as there are below it. A second median line is drawn parallel to the y-axis so that there are as many points on the left as there are on the right of this line. The intersection of the two median lines is called the Manhattan median. A 45-degree reference line is drawn through the Manhattan median. An error that is purely systematic (SE) will fall on the 45 degree line. The length of the vertical between the 45-degree reference line and the individual point corresponds with random error (RA) [8].*

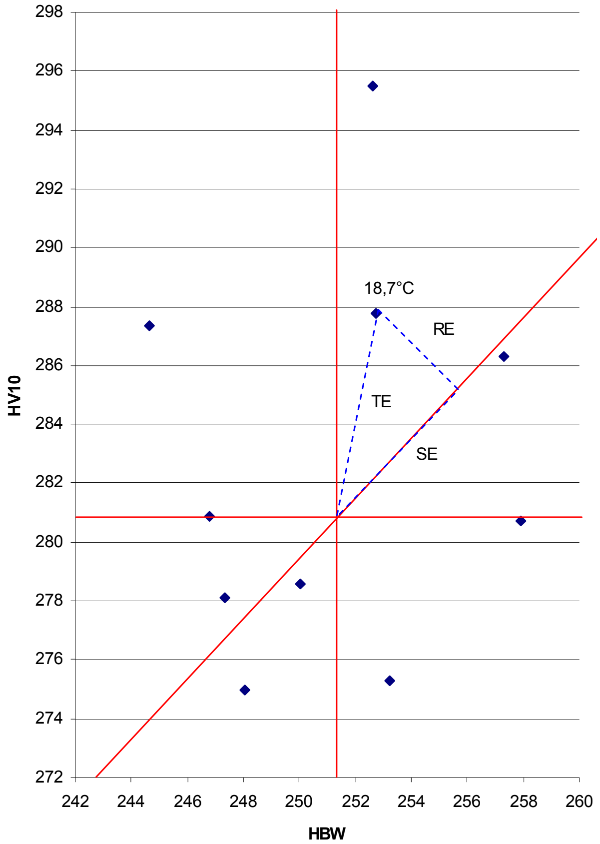

Figure 5. Youden plot of appraiser a (se is systematic error, re is random error and te is total error)

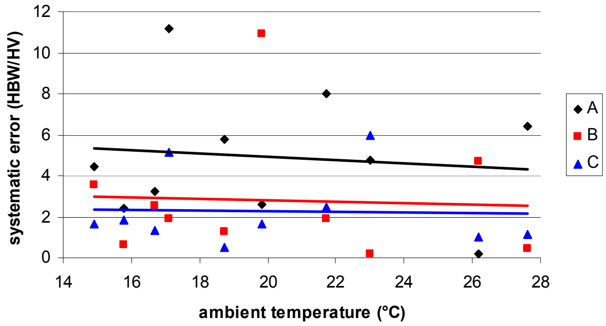

Figure 6. The relationship between the ambient temperature and systematic error

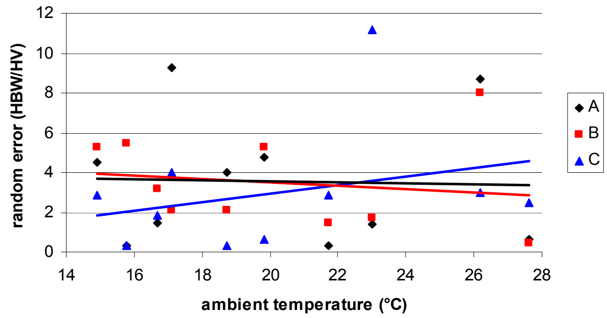

Figure 7. The relationship between the ambient temperature and random error

Youden plot for appraiser A is on the fig. 5. The plots of other appraisers were constructed in the same way. The absolute values of the systematic errors of all appraisers and random error of appraisers A and B moderate decreases with increasing ambient temperature, fig. 6 and fig. 7. The temperature increases random error of appraiser C on the contrary.

DISCUSSION

The quality of an appraiser work influences his/her competence, perception, skill discipline, vigilance and last but not least the ambient temperature - thermal environment. It may be said that the thermal environment differently affects quality of the work of individual appraisers and by means of them the qualitative characteristics (uncertainty, error) of calibration.

The thermal environment can be divided into three broad categories. The boundaries between these categories are not always obvious.

The first is thermal comfort, where appraiser feels either too hot or too cold, and do not perceive the temperature to be a problem. The second is thermal stress, where the thermal environment will cause clearly defined medical conditions, and can prove fatal. The third is thermal discomfort, which is the area between the first two. The conditions of analyzed measurement correspond to thermal comfort. There are main factors that influence how hot or cold appraisers feel:

1. *air temperature is how hot or cold the air around us is,*
2. *humidity,*
3. *radiant heat,*
4. *air speed,*
5. *physical activity have connection with heat, generated by appraiser's body,*
6. *clothing*
7. *other factors*

Age, state of health, body build and weight, use of prescribed medicines, substances such as alcohol [10] or illegal substances such as cannabis.

Thermal comfort has been described as "a condition of the mind which expresses satisfaction with the thermal environment". A person can be described as being "thermally comfortable" when they are not conscious of being either too hot or too cold.

A "thermally comfortable" environment is the ideal thermal environment for people to work in. Not only do people perform their work more efficiently, but they are less likely to make mistakes that could result in an accident.

Thermal comfort can be very subjective. Conditions that are very comfortable to one person can be uncomfortable to another. Factors that affect how hot or cold person feel in sedentary occupations [11]. Because of the range of temperatures (14.9-27.6°C) and relative humidity (27.6-41%) exceed recommended values (air temperature in summer 19-24°C and in winter 18-22°C; relative humidity 40-70%), the appraisers could be exposed to thermal stress during some measurements.

In the interest of the improvement the quality of the calibration and measurement is necessary to define the influence of ambient temperature on particular appraiser and to regulate the temperature of laboratory in accordance with him/her, or to use appropriate appraiser (for example with the best quality at upper limit of the range of temperatures) for particular temperature, firstly if the regulation of laboratory's temperature is technically or commercially difficult.

CONCLUSIONS

1. *The increasing of the temperature in laboratory increased in average the quality of measurement expressed as its uncertainty disregarding the method.*
2. *The quality of Vickers measurement, expressed as uncertainty increases with increased temperature for all appraisers.*
3. *The quality of Brinell measurement, expressed as uncertainty increases with increased temperature for most of appraisers.*
4. *The quality of measurement, expressed as the absolute value of the systematic error obtained by Youden plot increases with increased temperature for all appraisers.*
5. *The quality of measurement, expressed as random error obtained by Youden plot increases with increased temperature for most of appraisers.*
6. *The effect of appraisers on the measured value of hardness and the quality of measurement process is statistically significant.*

ACKNOWLEDGEMENTS

This work was supported by the Slovak Grant Agency for Science VEGA 1/0672/10

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