XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

UNCERTAINTIES OF VICKERS HARDNESS TEST BLOCKS

Robert A. Ellis

David L. Ellis Co. Inc., Acton, MA, USA

Abstract – Uncertainties of Vickers hardness can be calculated for every individual Vickers hardness test block using the standardizing testing machine uncertainty components and the non- uniformity of the reference material. Unlike the Rockwell test for example, the test components can be directly related to the outcome of the uncertainty of the Vickers test. It can be shown in some cases that the reference uncertainty is larger than the accepted tolerances at the lower end of the hardness ranges.

Keywords: Uncertainties.

1. THE NEED FOR A METHOD TO DETERMINE REFERENCE BLOCK UNCERTAINTIES

Vickers Micro-indentation values are a mathematical computation of forces, linear measurements and geometric shapes of indenters. These equations and test procedures can be found in ASTM E-384 [1] and ISO 6507 [2] documents.

Since the inception of quality standards such as ISO 17025, uncertainties must be stated particularly on reference materials whether primary or secondary. Since reference standards are the building blocks of the test system, it is necessary to develop a method to determine the initial uncertainty.

Another consideration is whether tolerances are wide enough to accommodate the test uncertainties. An uncertainty to tolerance ratio of 4:1 is preferred but rarely met in hardness. In some cases, that ratio is less than one. Some adjustments of tolerances in loads and hardness ranges should be changed so that the value can be at least a value of one or greater.

A benefit of the Vickers procedure is that the test parameters can be directly related to the uncertainty of the test result [3]. In most cases, the linear measurement and non-uniform materials affect a Vickers reference material the most.

If a reference material were absolutely uniform, only the tester calibrating the standard would contribute uncertainty. Here, the components of force, linear measurement, resolution, and indenter angle can be determined for the tester whether it is a primary or secondary machine. These components can be monitored and assigned for the tester.

For every hardness number the tester components can be combined as per the GUM [4] [5]. For example, 36,25 µ at HV 0,5 equate to a hardness number of 706 HV 0,5. The components of the machine uncertainty can be determined by using the following method. Take the difference of hardness values determined when adding the uncertainty of each component; linear repeatability, resolution and indenter angles. The hardness number HV multiplied by the component of the force to determine the contribution of uncertainty by the force. In addition, the reference material will have uncertainty in the form of non-uniformity. Once the reference material has been calibrated, the non-uniformity of the reference standard can be combined with the tester combined tester uncertainties for a stated test block uncertainty. In general, non-uniformity of the reference material increases as the hardness decreases. This method is similar to a method proposed for the Rockwell test. However, that method considers the components a system and not separate [6].

The expanded uncertainty of the tester and the reference standard non-uniformity can be compared with the allowed tolerances. It can be found that at the low end of hardness ranges, the tolerance can fall below the reference test block uncertainty.

2. A METHOD FOR DETERMINING VICKERS REFERENCE BLOCK UNCERTAINTIES

The basis of this study is comprised of data from over 300 reference blocks calibrated in less than a year. The tester used for calibration was evaluated for several uncertainty components by statistics and other means. After determining the operational limits of the tester, this data became the values inserted for the tester uncertainty equations.

2.1. Errors used to determine tester uncertainty

Table 1. shows the uncertainty of the machine.

TABLE I. Machine Uncertainty for 700 HV 0,5

Type of Component	Value	
Repeatability Linear	0,11 µ m	Type A
Force	0,01 N (1,25 gf)	Type B
Resolution	0,06 µ m	Type B
Indenter Angles	5 minutes	Type B

Prior to determining the hardness test block uncertainty, the machine was monitored for repeatability and the tester had its forces verified with a load cell. In addition, a Vickers indenter with directly verified angles was used in the test.

2.2. Determining the tester uncertainty at given force and hardness level.

The hardness of Vickers is shown by the equation (1). While the tester errors may remain the same, their contribution of uncertainties at different forces and hardness ranges change. The component of uncertainty from the measurement of the diagonals is more significant at 700 HV than 200 HV. This is because that component becomes more significant as the size of the indent becomes smaller. Smaller indents are a result of higher hardness or lighter loads. The parameters associated with the measuring of diagonals are the dominant components of the uncertainty of the tester.

The Vickers hardness number of 705,59 HV 0,5 is determined by the equation by using a 500gf force and measured diagonal of 36,26 µm (2). Adding the indenter uncertainty components of repeatability, force, resolution and indenter yield a slightly different Vickers hardness number HV. These values can be determined by using equation (3), (5) and (6). Here the uncertainties of the components are added to the Vickers equation, which yields a resulting change of Vickers hardness numbers in HV. The HV component of force is a straight percentage of the HV value using a Type B uncertainty of the load cell (4).

Calculated value of Vickers hardness Number

$$HV = 2{,}0 \times 10^3 \times P \times \sin(\alpha/2)/d^2 \quad (1)$$

Where:

P = force, N (gf)
d = mean diagonal of indentation in µm
α = face angle of the indenter, nominal Vickers 136° 0'

$$HV = 2{,}0 \times 10^3 \times 500gf \times \sin(136°)/(36{,}25\mu m)^2 \quad (2)$$

$HV = 705{,}59$

Value with Repeatability uncertainty component

$$HV = 2{,}0 \times 10^3 \times 500gf \times \sin(136°)/(36{,}25\mu m+0{,}11\mu m)^2 \quad (3)$$

$HV = 701{,}32$

Value of force uncertainty component

$$HV = 0{,}0015 \times 2{,}0 \times 10^3 \times 500gf \times \sin(136°)/(36{,}25\mu m)^2 \quad (4)$$

$HV = 1{,}06$ HV

Value with resolution uncertainty component

$$HV = 2{,}0 \times 10^3 \times 500 \times \sin(136°)/(36{,}25\mu m+0{,}06\mu m)^2 \quad (5)$$

$HV = 703{,}26$

Value with indenter uncertainty component

$$HV = 2{,}000\cdot 10^3\cdot 500gf\cdot \sin(135°55'/2)/(36{,}25\mu m)^2 \quad (6)$$

$HV = 705{,}38$

Once the new Vickers hardness number has been calculated, the difference between the original Vickers number of 705,59 HV can be compared to those calculated using the uncertainty components (7), (8), (9) and (10). These different values are the individual uncertainty components in HV at that hardness range and force.

$$U_{Repeatability} = 705{,}59 - 701{,}32 = 4{,}27 \text{ HV} \quad (7)$$

$$U_{Force} = 1{,}06 \text{ HV} \quad (8)$$

$$U_{Resolution} = 705{,}59 - 703{,}26 = 2{,}33 \text{ HV} \quad (9)$$

$$U_{Indenter} = 705{,}59 – 705{,}38 = 0{,}21 \text{ HV} \quad (10)$$

Using a combined uncertainty (11) and expanded to K=2, the final expanded uncertainty value (12) of the tester is 9,96 HV at a hardness range of 706 HV 0,5.

$$U_c^2 = (4{,}27 \text{ HV})^2 + (1{,}06 \text{ HV})^2 + (2{,}33 \text{ HV})^2 + (0{,}21 \text{ HV})^2 \quad (11)$$

$U_c = 4{,}98$ HV

$$2\,U_c = 9{,}96 \text{ HV} \quad (12)$$

2.3. Non-uniformity of the reference block

To determine the final uncertainty value in HV of the test block the non-uniformity of the block will be combined to the tester uncertainty using equation (13). In this case a value of 4,0 HV for non-uniformity will be combined with the 4,98 HV of the tester. A final value of 10,18 HV will be assigned to the test block as an expanded uncertainty with K=2 (14).

$$U_c^2 = (4{,}98 \text{ HV})^2 + (4{,}0 \text{ HV})^2 \quad (13)$$

$U_c = 5{,}09$ HV

$$2\,U_c = 10{,}18 \text{ HV} \quad (14)$$

A computer is necessary to calculate reference standard uncertainties on a daily basis, as this operation can be tedious. It is convenient to use a spreadsheet template that has included all of the uncertainty components in the

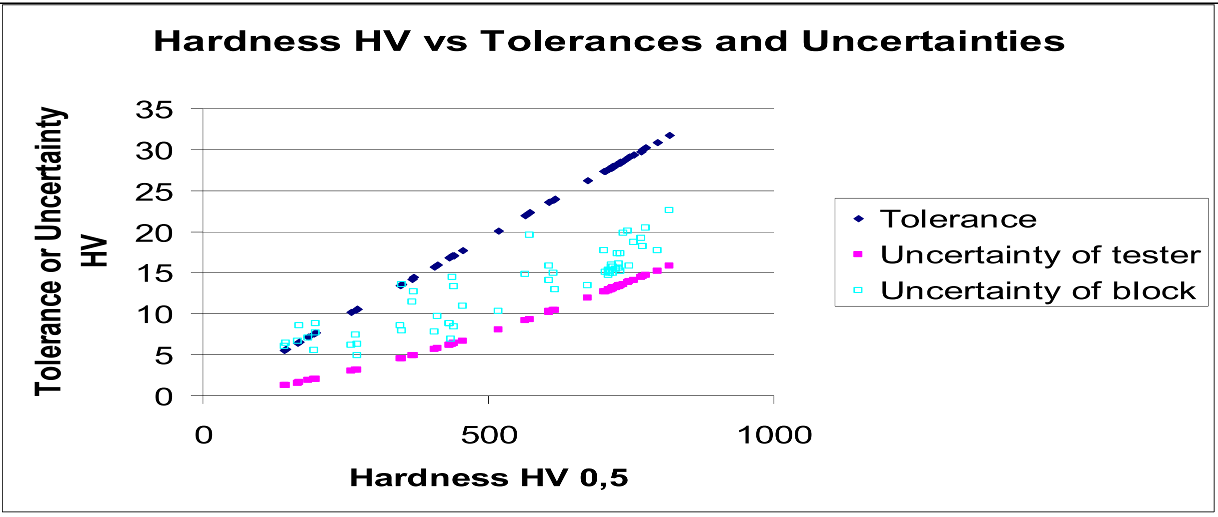

Fig .1

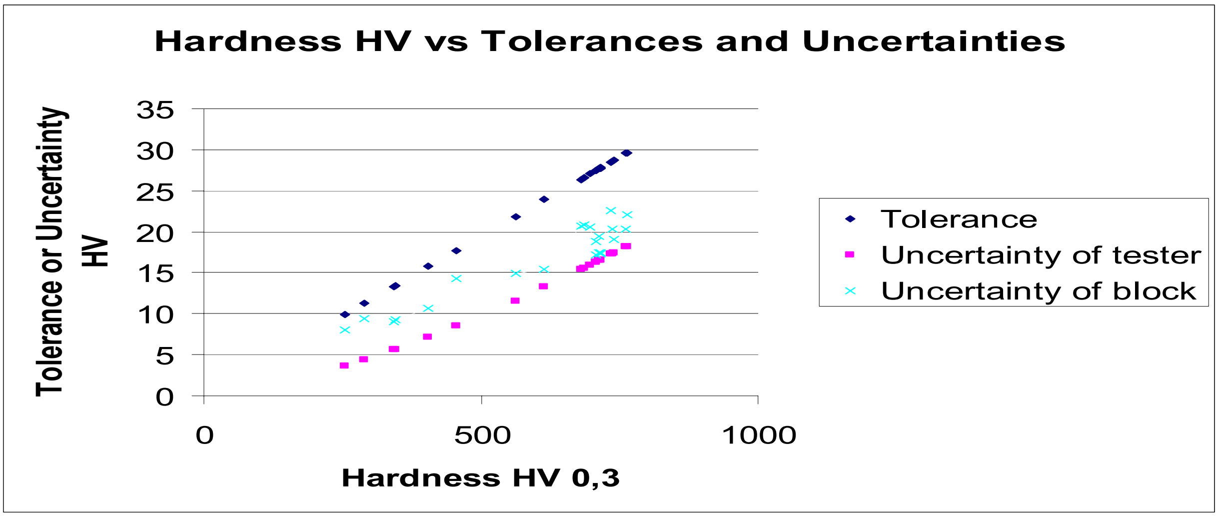

Fig. 2

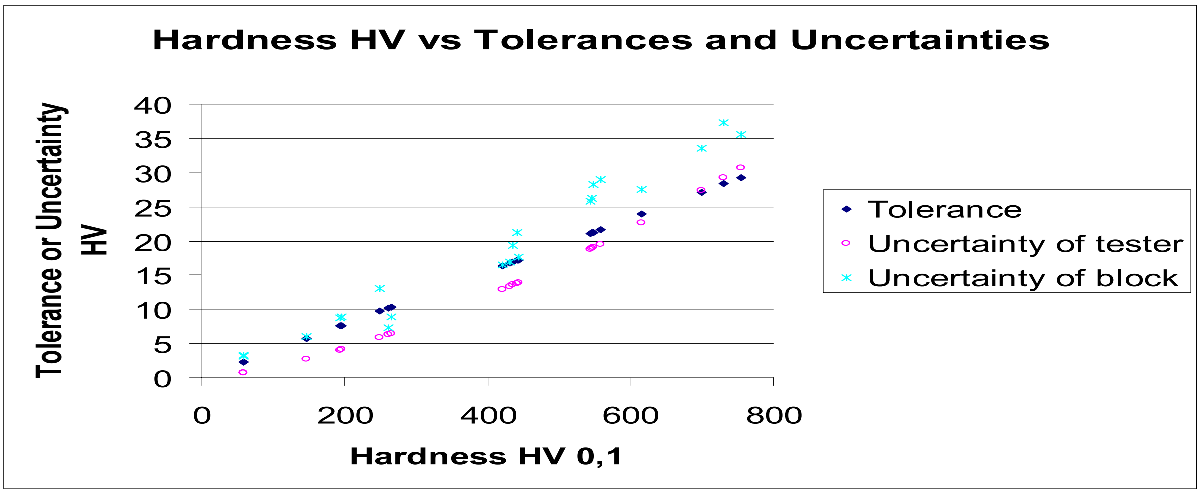

Fig. 3

necessary equations. Once a template has been designed, the values of force and individual diagonal readings can be entered and the uncertainty of the reference standard will be calculated by the spreadsheet. If it is decided that other components affect the reference uncertainty, they may be added to the template in the future using the same method as the previous components.

2.5. Accepted tolerances versus calculated uncertainties

While the standardizing testers calculated uncertainties of HV at the same force and hardness range may the same for two different standardized reference test blocks, the non-uniformity of the two blocks will most likely be different. The will result be most standardized reference blocks having somewhat unique uncertainty values. This scatter of uncertainties of the reference blocks at the same hardness level can be seen in Fig 1. This chart shows the uncertainties of the HV 0,5 hardness test. As the value of hardness decreases, the scatter is larger due varied non-uniformity. The upper line shows the tolerance allowed for the user of the block. The bottom line is the expanded uncertainty of the standardizing machine.

The charts on Fig. 2 and Fig. 3 shows uncertainties at HV0,3 and HV0,1 respectively. Here it can be seen that a similar pattern at HV0,5 is produced at HV0,3. While it can be seen that most of the uncertainties of reference standards remain below the tolerances, a four to one tolerance to uncertainty ratio is not possible. As the test force becomes smaller, the tester uncertainty approaches the tolerance.

In some cases, the uncertainties may be greater than the allowed tolerances. The chart Fig 1. showing HV0,1 indicates that the tester uncertainty is near the limit of the tolerances. At the lower force test, the uncertainty components affecting the measurement of the diagonal changes the HV value very quickly. In this case, the combined uncertainty of the non-uniformity of the block pushes the reference standard beyond the accepted tolerances. In the past, tolerances were established without current methods of statistics.

While the ISO 6507 document allows a larger tolerance than the ASTM E384, there are some cases where both documents are too restrictive for particular hardness levels and test forces. This can be found in the 100 to 200 HV hardness levels where materials other than steel must be used for the reference standard. For this reason it may be necessary to re-evaluated current test methods in use.

3. CONCLUSIONS

The uncertainty of a Vickers reference test block can be determined using the tester components and the non-uniformity of the test block. This uncertainty determination of the Vickers reference test block is necessary to meet the requirements of ISO 17025 and other quality systems. In some cases at the lower end hardness, the contribution of the non-uniformity of the block may give uncertainties higher than the accepted tolerances and will require some changes in these accepted values.

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Authors: Robert A. Ellis, David L. Ellis Company, Inc, Box 592 Acton, MA, 01742, USA, 978-897-1795 phone, 978-897-0844 fax, dlellisco@aol.com.