Traceability in Measurement for Rockwell, Brinell and Vickers hardness

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Abstract - The establishment of traceability in hardness measurement is still under discussion at the ISO TC 164 SC 3 subcommittee on hardness testing. Two paths for establishing traceability are proposed for Rockwell hardness measurement in ISO 6508-1. One way is to take a route to SI units through direct calibration of machine components; the other way is to take a route to the hardness measurement standard through indirect calibration of machine performance. This confusion is partly caused by the characteristics of hardness; i.e., a procedure dependent property. In this paper, methods for the establishment of traceability for Rockwell, Brinell, and Vickers hardness measurements are discussed based on the concepts defined in the international vocabulary of metrology (VIM).

I. Introduction

Hardness is one of the most widely used material property for quality control of heat treated machine components and structural materials. Because of its simple and quick test process, its application is expanding with the development of new equipments such as Leeb hardness and an instrumented indentation tester. However, there is still confusion about the way to establish traceability in hardness measurement. More precisely, it was initiated with the publication of EA guidelines about the uncertainty evaluation in hardness measurement[1]. This approach is based on the uncertainty evaluation of a hardness testing machine by combining all of the uncertainties of machine components. In this case, the calibration and uncertainty evaluation of each machine component should be carried out before combining the uncertainties. This approach is known as direct calibration.

Since machine performance can not be guaranteed even after the calibration of the machine components, hardness standard blocks are used to check the overall machine performance after the calibration of machine components. This process is called indirect calibration or indirect verification.

With the introduction in the 1990s of the concepts of traceability and uncertainty, there was a discussion about the right path to take for the establishment of traceability in hardness measurement and uncertainty evaluation. Unfortunately, there has been no definitive conclusion about this problem

until this time; both ways of establishing traceability are described in the ISO 6508-1[2]. In this paper, it will be suggested that the EA guidelines for the uncertainty evaluation of a hardness testing machine, i.e., direct calibration, is applicable for the NMI level and indirect calibration is the right path for the traceability regarding hardness values. This argument is based on the definitions of calibration, traceability, calibration hierarchy, measurement standard, etc., as described in the VIM version 3[3].

II. Material property and traceability

Material properties such as strength, hardness, wear, fatigue, corrosion, creep, etc., are very important engineering properties. Usually the process to measure these properties is understood as testing and is considered a different category as compared to measurement. The results of testings are usually used for making the decision of pass or fail regarding material quality which has led many people to think that testing and measurement are different from each other. Nowadays, as the concept of measurement expands, testing is understood as a part of measurement. To make a decision of pass or fail we should measure material properties first.

Material properties can be grouped into two areas[4]: intrinsic properties and procedural properties. Intrinsic properties, such as elastic constant, heat conductivity, etc., are procedure independent. For example, to measure Young's modulus, two methods are available. One method is to calculate Young's modulus from the slope of the stress-strain curve. The other method is to obtain Young's modulus from the difference in the ultrasonic sound velocity in materials. Even if the principles of the methods used are totally different, the results are comparable. In contrast, procedural properties, such as strength, hardness, ductility, etc., are procedure dependent. In other words, if the measurement procedure changes, then the result also changes. Most important engineering properties are procedural properties. Hardness also belongs to procedural properties and can be known from unique units such as HRC, HRA, HBW, HV, etc. This is the main reason why the hardness values obtained with different procedures are not comparable with each other. Table 1 shows the list of material properties of both groups.

Table 1.Examples of intrinsic properties and procedural properties of materials.

Intrinsic properties	Young's modulus, shear modulus, Poisson's ratio, sound velocity, thermal conductivity, thermal diffusivity, emissivity, electrical resistivity, electrical conductivity, optical transmissivity, etc.
Procedural properties	ductility, yield strength, tensile strength, hardness, friction coefficient, fatigue, creep rate, corrosion rate, diffusion rate, fracture toughness, etc.

We are measuring quantity and its object lies in comparison. We obtain data and compare them with other peoples' reports or

regulations to see whether or not it satisfies requirements.

According to VIM version 3, quantity is defined as the "property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference"[3]. Here, it is worthy to note the definition of reference. In note 2 of this clause, "a reference can be a measurement unit, a measurement procedure, a reference material, or a combination of such". Therefore, procedure-dependent properties of materials can be grouped into the second category of quantity, a number and a reference procedure. Also, it can be said that testing procedural properties of materials is a part of the measurement as far as it is expressed in numbers and a reference procedure.

According to this definition of quantity, the so-called hardness units, such as HRC, HRA, HV, HRB etc., are not units but symbols of procedure. Actually, the main reason for using this kind of special unit system for hardness is because of procedure-dependentcharacteristics. Hardness values obtained with different procedures are not comparable to each other in practice. To avoid any mistake of comparing hardness data obtained with different procedures, a unique unit and name symbolizing a measurement procedure was introduced. In this sense, the unit used for expressing yield strength, ultimate tensile strength, and fracture strength of materials - MPa - may misguide users as an intrinsic property and comparable with other data even though it is a procedure-dependent property[4]. For example, yield strength is expressed by the unit MPa, but if a testing condition such as strain rate changes, the data are not comparable even though the yield strength data are expressed in the same MPa unit.

The next question is how to establish an unbroken traceability chain regarding procedure dependent properties. Let us examine the definition of traceability in VIM. Clause 2.41 of VIM defines metrological traceability[3], the "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty." Note that the measurement result should be related to a REFERENCE. For the case of procedure dependent material properties, the reference will be a reference procedure. Further explanation can be found in Note 1 of this clause, describing 'reference' as a definition of unit or a measurement procedure.

Traceability is connected by an unbroken chain of calibration. In other words, calibration hierarchy is necessary. For the procedural property, the reference is a measurement procedure. Considering the calibration hierarchy, it can be understood that we need a primary reference procedure with lower uncertainty. Specifically for hardness, a Working Group on Hardness (WGH) under a Consultative Committee on Mass and related quantities (CCM) is now working to develop a primary reference procedure; that of the Rockwell hardness

measurement is available at this time. In the SI unit system, the basic SI units and derived unit systems naturally show the path of traceability since the seven basic SI units are the starting point and provide the fundamental uncertainty.

According to the 5.1 of VIM, measurement standard is defined as the "realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference"[3]. Therefore, the hardness testing machine that can realize the primary reference procedure with stated hardness value and associated measurement uncertainty becomes the measurement standard of hardness and can be called as the primary hardness measurement machine.

III. Calibration hierarchy of hardness value

To establish the traceability in hardness value, we need an unbroken chain of calibration and uncertainty evaluation with a hardness unit. This means that the calibration on a hardness value is the key element in calibration hierarchy. Since the hardness value is obtained by the operation of a hardness machine, the calibration of the hardness value can be understood as a calibration of machine performance. The so-called direct calibration is actually a verification of machine components and thus cannot be called a calibration because it is not used on hardness value but on SI units.

Reproduction of data is possible only when the machine components satisfy the requirements and the machine operates in good condition. To make sure of this, verification of the machine components is necessary; this has been misunderstood as a calibration. Specifically, verification of machine components is to check the performance of the load cell, the depth measuring device, the timer, etc., and these results do not contribute to the uncertainty evaluation of hardness value.

Calibration of a hardness machine is, strictly speaking, calibration of the procedure since hardness value is realized by the procedure. This is one of the reason why a primary reference procedure with lower uncertainty in hardness value is necessary to establish calibration hierarchy. The unbroken chain of calibration in hardness value can be connected via hardness reference blocks with specified hardness value and uncertainty. This has been called an indirect calibration or indirect verification, without clear definition. Actually, this is the calibration on hardness value.

Fig. 1 shows the traceability chain of the Rockwell hardness value[5]. The measurement standard of the Rockwell hardness value is realized by the primary hardness machine with primary reference procedure. Using this primary hardness standard machine, a primary hardness reference block with hardness reference value and uncertainty can be produced. This primary hardness reference block is applied

for the calibration of the hardness testing machine of the calibration laboratory. The hardness machine of the calibration laboratory is used for the calibration of hardness reference blocks that are manufactured by the commercial hardness reference block producers.
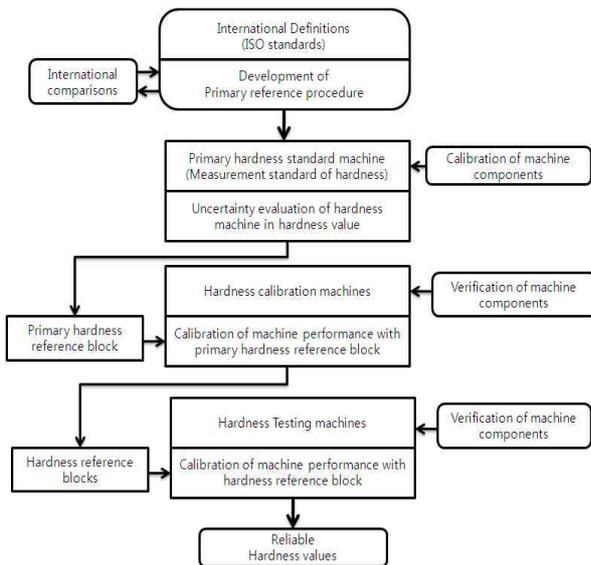

Fig. 1. Traceability in Rockwell hardness

For the uncertainty evaluation of the primary hardness testing machine, which lies on the top of the traceability system in hardness, a process based on machine components is necessary. This is described in the EA guidelines [1]. Uncertainties of individual machine components in SI units are evaluated and converted into hardness values by multiplying the sensitivity coefficients. By combining all of the uncertainties of machine components, we can evaluate the uncertainty in hardness value of the primary hardness machine.

Since the primary procedure is not perfect, there can be some unexpected deviations in hardness measurement data, even in those reported by NMIs. For this reason, international comparison among NMIs is necessary to figure out a reasonable and internationally agreed upon uncertainty range of primary hardness testing machines.

For the Rockwell hardness machine, the traceability can be understood straightforwardly since the force application and hardness value reading are done at the same time. However, for the Brinell and Vickers hardness testing, indentation by force application is followed separately by indent measurement. This may cause a confusion on the traceability. The main point of the guideline for the calibration hierarchy is that we are dealing with hardness value, not SI traceable units.

To establish the traceability in Brinell hardness, the first job will be the development of a primary reference procedure with lower uncertainty. In this primary procedure, not only the load application cycle but also the diameter measurement process should be included. It is expected that CCM-WGH will start in a short time to develop a primary reference procedure for Brinell hardness. After the primary reference procedure becomes available, NMIs should develop a primary reference machine that can realize the primary reference procedure. Using this primary hardness machine, the measurement standard of Brinell hardness is realized and NMIs can assign hardness value and uncertainty to the primary reference block.

The calibration laboratory uses this primary reference block to calibrate their machines after the verification of machine components as well as the indent diameter measuring device. By this process, it is possible to evaluate the uncertainty of the machine performance and the diameter measuring device all together. Using this calibration machine and diameter measuring device, secondary blocks can be calibrated as has been done for Rockwell hardness.

The reference indent is necessary for the verification of the diameter measuring device. Note that this is not the calibration process but the verification process. Vickers hardness is the same as the Brinell hardness case. It is recommended that the ISO standards about the traceability, uncertainty evaluation and calibration hierarchy of Brinell and Vickers hardness be amended according to the definitions described in VIM. The traceability of instrumented indentation hardness can be established in the same way. At this time, international comparison among NMIs is in progress and the results can be used for the development of a primary reference procedure.

IV. Conclusion

With the change of the definition of quantity, procedure-dependent properties of materials became the subject of measurement and should be covered under the international structure of metrology. In other words, traceability in hardness measurement is important in order to guarantee the comparability of hardness data. Since the measurement standard of hardness is realized by the NMIs, based on primary reference procedure and primary reference machine, traceability in hardness value and calibration hierarchy start from this measurement standard. It is recommended that all other ISO standards related with the measurement of procedural properties should be amended according to the concept proposed in VIM.

References

1. European co-operation for Accreditation, *EA guidelines on the estimation of uncertainty in hardness measurements* EA-10/16rev.00 (2001)
2. ISO 6508-1, *Metallic materials–Rockwell hardness test–Part1: test methods* (2005)
3. *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms*, JCGM 200:2012
4. Munro R. G. *Data evaluation theory and practice for materials properties,* NIST Special Publication 960-11 (Washington, NIST) (2003)
5. G. W. Bahng, et. al., "Establishment of traceability in measurement of mechanical properties of materials", Metrologia, vol. 47, pp. S32-S40 (2010)