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WORLDWIDE ACTIVITIES AROUND HARDNESS MEASUREMENT - ACTIVITIES IN CCM/CIPM, IMEKO/TC5, OIML/TC10 AND ISO/TC164 -

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Abstract – All of hardness testing methods now in use were invented about a century ago but it was after the World War II that the international conformity of the test results was required and that the standardization of the testing methods and testing machines was investigated and promoted. In this paper, the historical role of four international organizations, CIPM, IMEKO, OIML and ISO for the progress of the standardization of hardness testing and on the development of the metrological standards of hardness is reviewed together with some remark on the discussions related to the definition of hardness as a quantity. Then a few comments on the feature and metrological meaning of hardness standards are described.

Keywords: Hardness standards, IMEKO, CIPM

1. INTRODUCTION

While the word "hardness" in general is a concept expressing the resistance to deformation or fracture, scientists and engineers tried to express hardness quantitatively. With the progress of metal products in the beginning of the 20th century, hardness testing methods now in practical use were invented one after another. As is well known, they are Brinell (invented in 1900), Shore (in 1906), Rockwell (in 1919) and Vickers hardness test (in 1925). There were many other testing methods but the above four (including Knoop hardness as a variation of Vickers) have survived until now for the evaluation, inspection and certification of metals and metal products.

Even in the above hardness testing methods, the hardness numbers are expressed according to the conventional definitions based on the respective testing methods. Although a physical interpretation of conventionally defined hardness was smartly analysed by Prof. D. Tabor [1], it does not satisfy the requirements of metrologists for the technological definition of hardness as a quantity. Nevertheless, the usefulness of hardness testing had been widely recognized in laboratories and factories for examining the property of metals and for controlling the production and processing of metals.

With the recovery of industry after the World War II, hardness testing came into wide use and the conformity of test results obtained at different factories or plants by different machines was questioned everywhere. Thus the standardization of hardness testing machines became an urgent problem in industry and the establishment of the national and international standards were considered seriously in every industrialized countries. In Japan, Hardness Research Association (presently Material Testing Research Association) consisting of experts from industry, academia and government was created in 1956 to investigate the problem. However, the compatibility of the standard must be confirmed on the platform of the concerned international organizations which is described in the following.

2. STANDARDIZATION OF HARDNESS TEST

2.1. Activity of ISO

The first step for the standardization of hardness was to clarify the definition of the testing method and testing machines and to develop document standards for each hardness scale. As hardness testing is one of material testing methods, its standardization on the international platform was first discussed in such group dealing with the industrial standards of metal products as ISO/TC17 (Technical Committee 17 "Steel" of International Organization for Standardization). The author attended the meeting of Subcommittee of TC17 for the mechanical testing of steel, held in 1959 in London, where almost all leading researchers on hardness testing in Europe were present. In Japan, a similar investigation was made by Hardness Research Association to formulate drafts for Japan Industrial Standards (JIS).

Later, in 1975, a restructuring of ISO/TCs took place and a new TC164 was formed to deal with testing of metals to unify the efforts of standardization of testing methods common for various metals. By chance, the author was appointed as the Chair of this TC in 1986 and worked for the coordination of ISO standards on hardness until 1993. The formulation of the ISO standards on hardness now consists of three parts for each testing method, the standard on testing method, on the testing machine and on the reference test block for the calibration of testing machines. The definition of hardness scale is given in the standard of testing method, while tolerances for each of influencing factors are specified together with respective uncertainties.

During the past three decades, ISO/TC164/SC3 (Hardness testing of metals) has formulated ISO standards for three major hardness scales by introducing more precise specifications on the testing machines and conditions. At the same time, new standards for Knoop and universal hardness had been worked out by the Committee. The feature of ISO standards on hardness testing is, in author's view, its intrinsic role for industrial application, because the standardization of the testing is always the motive force for their formulation. However, another important and unique role of ISO standards is to clarify the definition of hardness scales, which is to be used as the basis of the establishment of hardness standards. From this reason, it is desired to keep closer coordination among four international organizations (ISO, OIML, IMEKO and CIPM) concerned with hardness testing.

2.2. Activity in OIML

Another international organization dealing with document standards for metrology is International Organization of Legal Metrology (OIML) established by Convention concluded in 1955. Japan entered into the Convention of OIML in 1961. Although hardness or hardness testing is not always subject to legal regulations in all countries, it used to be an item for study by some of OIML members and is now under investigation by TC10/SC5. The specifications in OIML documents (Recommendations) for hardness testing mostly follow those in ISO standards but are distinguished by the inclusion of legal aspects.

Contrary to ISO standards, OIML documents are featured by their verification-oriented character. In other words, they are documents for inspection bodies, which are often national metrology institutes (NMIs). In fact, many NMIs were traditionally involved in the preparation and formulation of OIML Recommendations. Under the above circumstances, OIML/TCs and SCs (it used to be Pilot Secretariat or Reporting Secretariat until 1992) were useful platform to carry out joint study and intercomparison of measurement of such quantities as hardness, which were out of the scope of Metre Convention until late 1990s.

In response to the request from industry in 1950s, some metrology institutes in Europe challenged to establish hardness standard, by building a standard testing machine for Vickers or Rockwell hardness. The most advanced was the Rockwell standard machine developed by Dr. K. Meyer in Material Prüfungsamt (MPA) in Dortmund, Germany [2]. The National physical Laboratory, UK, where I was staying as a guest researcher, completed the construction of Vickers standard hardness testing machine in 1958 [3] and later built Rockwell standard machine, too. A common feature of these machines was the dead-weight loading for indenting and a precise optical microscope (later an electronic micrometer) for indentation measurement.

In the National Research Laboratory of Metrology, Japan, (presently part of the NMIJ), Prof. K. Yamamoto, the former Director-General, and Dr. H. Yano developed a new Rockwell standard hardness testing machine with a single lever for loading [4]. It was already noted that the shape of the indenter was the most influential factor to the test results and the precise measuring method of the shape was also developed by these laboratories and was used for selecting standard indenters. The idea of metrology institutes on the standard of hardness was to realize an accurate testing machine and indenters exactly following the definition and fulfilling specifications for each component. When metrology institutes established their hardness standards, they were inclined to confirm the conformity of their standards with the others including testing machines in practical use. Thus, Mr. Meyer of the MPA made an intercomparison of Rockwell C hardness in 1957, which was the first international comparison of hardness. In 1960s, the NRLM organized another international comparison of Rockwell C hardness and the result was reported by Prof. K. Yamamoto at the meeting of OIML Working Group Y3 in Vienna on October 18-21, 1966 [5]. It was an epoch-making instance that OIML could provide a platform for the international comparison of metrological standard. Since then, a similar comparison was performed in other items and OIML proved to be useful for supporting joint activity of NMIs.

2.3. Activity in IMEKO

Hardness test has been one of the topics in the World Congress of International Measurement Confederation (IMEKO) since its foundation, although it is not a major topic and the number of presentations is not very many. When I participated in the 4th Congress in Warsaw in 1967, three papers are accepted in the session of hardness. The speakers were Mr. K. Meyer from Germany, Dr. F. Petik from Hungary and myself [6]. The Table 1 shows the summary of the World Congress in the past together with the participation from Japan.

Table 1 Past World Congress of IMEKO.

Year	Venue	Number of participation		
		Total	Japan	Papers
1958	Budapest	?		
1961	Budapest	~ 800	3	0
1964	Stockholm	~600	6	6
1967	Warsaw	882	7	9
1970	Versailles	711	16	10
1973	Dresden	1150	3	6
1976	London	430	16	
1979	Moscow	~1500		
1982	Berlin (W)	637	35	25
1985	Prague	~1000	33	
1988	Houston	~27000*	~50	
1991	Beijing	~3000	~50	
1994	Turin	550	55	
1997	Tampere	~800	85	
1999	Osaka	641	353	165
2000	Vienna			
2003	Dubrovnik	~600		
2006	Rio de Jan.	823		

(Data for blank cell are not available.)

*: The number denotes the attendees for ISA show held together with IMEKO Congress.

It should be noted that the creation of IMEKO Technical Committee 5 on Hardness chaired by Dr. F. Petik was approved at the General Council of IMEKO held in Dresden in 1973 and the first round table meeting was organized in the Congress in London in 1976 [7]. Unfortunately, the author could not attend the Congress though being a member of the Committee and presented a paper.

In the meantime, European researchers and engineers were having interchanges on hardness testing even before IMEKO provided a forum on it. The initiative was taken by German specialists and the first international workshop on hardness was organized by German institution, VDI (Verein Deutscher Ingenieure), in Bremen in 1952. The 2nd workshop was held again in Bremen in 1955 and the 3rd one in Dortmund in 1959 by the effort of Mr. K. Meyer of MPA which was the centre of hardness studies in Germany at that time. Although I contributed a paper on my early work on a pendulum type rebound hardness testing apparatus in the 2nd Workshop, I could not attend the meeting itself. I also missed to participate in the 3rd Workshop which was held just after my return from the National physical Laboratory, Teddington, but a few Japanese experts joined in the meeting to introduce several advanced studies achieved by Japanese industry, universities and research institutes including the NRLM. As all the contributed papers from Japan were written in English, Mr. K. Meyer of the MPA kindly translated them into German to be printed in the special VDI issue for the Workshop [8]. It may be said that this workshop was the first occasion that the overall progress of studies on hardness test and standards in Japan was introduced in Europe.

The 4th Workshop was also in Dortmund in 1965 and in 1970, the 1st IMEKO Symposium on Hardness was held in Dortmund again, as the 5th VDI's event succeeding the above mentioned four workshops.

Since IMEKO/TC5 was created in 1973, it has been organizing specialized symposia from time to time and round-table discussions on the occasion of IMEKO Congress. Table 2 shows the list of symposia organized by TC5.

TABLE 2. HARDMEKO Symposia

No	Year	Venue	Country
1	1970	Dortmund	Germany
2	1978	Stuttgart	Germany
3	1986	Fellbach	Germany
4	1990	Heidelberg	Germany
5	1992	Prague	Czech
6	1995	Düesseldorf	Germany
7	1998	Beijing	China
8	2002	Celle	Germany
9	2004	Washington	USA
10	2007	Tsukuba	Japan

Although IMEKO is not an organization to make decisions on standard nor to arrange intercomparisons, it has been playing a very important role to discuss about the problems concerning the definition of hardness, the method of realization of hardness standards, the uncertainty of each testing method, novel testing methods and apparatus together with their applications for the scientific research on new materials and for the control of production process etc.

2.4. Metre Convention (CIPM/CCM)

The International Committee of Weights and Measures (CIPM) founded by Metre Convention has been making efforts to establish and disseminate International System of Units (SI) as a unique unit system based on physical laws and principles since the 9th General Conference of Weights and Measures in 1948. As the result, such conventional quantity as hardness was out of scope of the Committee's activity for many years. However, the situation and the position of the CIPM changed in 1990s. In 1993, a new Consultative Committee for Amount of Substance (CCQM) was created to deal with the standard of chemical quantities. In this field, some quantities are not clearly defined on the physical basis but still their standard is required. The CIPM had to alter its traditional views on the domain of its responsibility. In the same year, the role of the CIPM on the accreditation and certification of measurement was discussed in its annual session for the first time and in the following year, the Committee decided to take up the problem of the traceability in the next General Conference.

In 1995, the 20th General Conference of Weights and Measures resolved to ensure the world-wide traceability by international comparison of metrological standards. By reflecting to the proposal from Italian member of the CIPM, the author proposed at the 86th Session of the CIPM in 1997 to create an ad-hoc working group on hardness to consider international comparisons of hardness standards. The proposal was approved and the first meeting of the group, chaired by the author, was held in June 1998 at NIST, Gaithersburg. The questionnaire circulated among NMIs beforehand clearly revealed their keen interest in the hardness standards and in the intercomparison of their standards and the working group started to collect the past data and to prepare for the new key comparisons. With the progress of these activities, the ad-hoc group was approved by the CIPM as a full working group (CCM/WGH) of the Consultative Committee for Mass and Related Quantities (CCM) in its 88th Session in 1999 [9]. Dr. A. Germak, Italy, has been nominated as the Chair since the Working Group started on ad-hoc basis.

There were some discussions in the CIPM whether it should look after the problems of such conventional quantities as hardness scales. However, the following explanation by the author was eventually accepted:

"Although the definition of hardness scale is certainly conventional in the sense of the use of arbitrarily chosen formula, (1) the testing method is defined by a combination of physical quantities expressed by SI units, (2) the standard of hardness is established and maintained in most of NMIs and (3) the traceability to the standard of NMIs is demanded in industry and elsewhere."

I was convinced that it was a timely decision for hardness standards to be included in the key comparison data-base (KCDB) for the mutual recognition arrangement (MRA) started in 1999.

3. DISCUSSION ON HARDNESS AS A QUANTITY AND ITS STANDARD

A few decades ago, the concept of hardness as a quantity was not necessarily understood by other researchers than metrologists but nowadays it is widely accepted that hardness, at least, of metals could be an object to be measured and be expressed in number on a technically universal scale, although it is not yet defined according to physical laws. In fact, "hardness" is recognized as one of the quantities, defined as "property of a phenomenon, or substance, to which a magnitude can be assigned" by International Vocabulary of Basic and General Terms in Metrology (VIM) [10]. The VIM also refers to Rockwell hardness as an example of "ordinal quantity defined by a conventional measurement procedure, for which a total ordering relation with other quantities of the same kind is defined, but for which no algebraic operations among those quantities are defined".

Relating to the concept of the quantity, the definition of metrological standard of hardness may call for numerous discussions. When the standardization of hardness testing machines was an urgent issue in Japan, there were two different views on the standard of hardness. The first one was to rely on the (imported) testing machines from original manufacturer and to take their average readings as the standard. It was justified by the fact the manufacturer was the originator of the hardness scale and was keeping their standard by the average of a number of testing machines. This system will work properly if the manufacturer is dominant for the same type of testing machine but it was not the case.

An alternative view is to produce a standard testing machine together with the standard indenter, which exactly follows the definition of hardness. The realization of the definition needs precise specifications for the test force, dimension and shape of indenters, testing conditions etc. expressed by the combination of physical quantities. Most of the NMIs and other testing laboratories now takes the latter view and are developing their standard testing machines and standard indenters for establishing their standards by "specified procedure".

There may be another way of realizing or materializing the standard of hardness in the future. From metrological point of view, the method for realizing the standard of a quantity is, of course, based on its definition but relies largely on the specifications for the procedure. It is not necessarily unique for hardness standards but common even for well defined physical quantities. To consider the real meaning of metrological standards, it may be useful to classify the primary standards of practical use. The author's view is as follows:

Category A: An artefact represents the standard of the quantity (ex.: Prototype kilogram).

Category B: A specific standard reference material represents the standard of the quantity (ex.: Silicon single crystal as the density standard).

Category C: Standard apparatus or instrument generates the standard of the quantity (ex.: Dead weight force standard).

The modern standard of hardness is considered to be included in the category C. However, there are a few other examples. The standard of original Shore hardness was told to be a roll for the steel mill, which corresponds to Category A. The standard belonging to category B could be practical for Mohs's hardness and even for other conventional hardness scales in the future.

Even the standard is of Category A or B, the standard value of hardness has to be transferred to testing machines or reference test blocks by means of a testing machine. As the result, the same consideration on the specifications of testing machines and the conditions of testing as those in Category C seems to be required for all sorts of standards and it must be the task given to the metrologists in charge of standards.

4. CONCLUSION

When one is given a task to create the standard of hardness, he will be embarrassed at first but will soon notice that the standard of derived quantities or even of base quantities is not differing to that of hardness in its nature and in the methodology for realizing it. In other words, hardness standard is the most appropriate model for considering the meaning of standard and the technical methodology for attaining the traceability. In that sense, the author feels very happy to have tackled the development of the standard of hardness in his young period and thanks to his leader, Prof. Kentaro Yamamoto, and his colleagues Drs. N. Hida, H. Yano, H. Imai et al., who worked together in the former NRLM.

REFERENCES

[1] D. Tabor, "The Hardness of Metals", *Oxford University Press*, London, 1951.

[2] K. Meyer, "Das Erreichen der Vergleichbarkeit der Härtemesswerte –ein Problem der Werkstoff-Prüftechnik von Internationaler Bedeutung", VDI Berechte, Nr. 11, pp. 103-122, 1957.

[3] R. S. Marriner, F.C.P. Mason, "A New Standard Hardness Testing Machine", Machinery, pp. 1-6, 1957.

[4] K. Yamamoto, H. Yano, N. Yajima, "Studies on the standard indentation hardness tester", Report of NRLM, Vol. 7, No. 2, pp.10-14, 1958.

[5] K. Yamamoto, H. Yano, "International comparison of Rockwell C hardness done by the NRLM", Bulletin of NRLM, No. 13, pp.10-31, Oct. 1966.

[6] K. Iizuka, "Realization of the Standard of Shore Rebound Hardness Scale", Acta IMEKO, pp. 333-347, 1967.

[7] Proceedings of the Round-Table Discussion on Hardness Testing, 7th IMEKO London (edited by W. Weiler), PTB, May. 1976.

[8] VDI Berichte Nr. 41, Düsseldorf, 1961.

[9] Procès-Verbaux de la 88e Session, CIPM, BIPM, 1999.

[10] International Vocabulary of Basic and General Terms in Metrology, 3rd edition, ISO (in preparation).

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