METROLOGY IN MEASUREMENT OF ROCKWELL HARDNESS SCALES

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Introduction:

In a context of Total Quality we must consider that the raw material (or just material) is a basic requirement for the manufacture of mechanical components of high quality or even any other product that depends on the quality of this material.

Inside of the universe of the mechanical manufacturing, after the siderurgical process of attainment of the raw materials, the verification of its qualities in mechanical properties is gotten by the measurement of its hardness.

The measurement methods, for the mechanical industry, more usual are the Rockwell, Vickers and Brinell.

Amongst the some scales of hardness, more specifically the scale of Hardness Rockwell, wants in this work to make the center of interest the metrologic aspect of the measurement, its importance and mainly the trustworthiness on the results of the measurement leadead by the increasing demand of quality for product and components. Also a basic aspect is to demonstrate the importance that gains the traceability of this matter, and in particular in Brazil how is this development currently.

Rockwell Hardness Measurement Scales

The method was idealized in 1919, for Stanley P. Rockwell, as a tool to get fast and more accurate values for control of hardness at the bearings plant where he worked. In pursuing its invention Charles H. Wilson complemented the test methods becoming it what today is the more widely used method for tests of acceptance and metallic control of metal processes and components.

The method created by Rockwell, initially as a home-made tool for measuring values of hardness, came through the times earning each time larger popularity and it ended up becoming a independent greatness matter inside of the field of the Metrology.

Simplicity in the operation of Rockwell hardness tester usually does not require greater abilities from operator, and the correlation with properties of other materials can determine important information on metallic materials, such as, strength, elasticity, plasticity, ductility and wearing resistance, and many other properties associates to needs of development of materials and equivalents for applications demanded in projects.

The hardness scale Rockwell consists of applying a load on a mensuring object intermediated by an indenter geometrically standardized, that should be a esphreconic Diamond Indenter or a Sphere (stell or Tugstein Carbide) with standartized diameter, than measure how long this penetrador was gone deep into the mensuring object. As dipper the penetration of the indenter in the mensuring object so lower is the hardness value in Rockwell scale. The application of load is done in two stages: a preliminary load and a suplementary load, or a test load, and after withdrawal the suplemental load, returns it the preliminary load, measuring then the sum penetrated for the indentor body enters the two stages of the preliminary load in mensurando.

The rockwell hardness test, can be used for materials of small thickness, and for such it uses lower loads to the test, thus searching to get results of measure from the object not suffering interferences from the hardness of the anvil on which it is supported, avoiding disguises of results from other influences due the thinnes of the mensurand. The table below shows the scales of Hardness Rockwell and their aplications loads and type of indenters.

Method		Superficial			Normal		
Pre-load		29,42 N (3kgf)			98,07 N (10 Kgf)		
Test Load		15	30	45	60	100	150
Diamond		15 N	30 N	45 N	[[A]]	D	C
Sphere (Ball)	1/ 16"	15 T	30 T	47 T	F	B	G
	1/8"	15 W	30 W	45 W	H	E	K
	1/4"	15 X	30 X	45 X	L	M	P
	1/2"	15 Y	30 Y	45 Y	R	S	V

Table 1 - Scales of Rockwell Hardness

Values of Hardness in Rockwell scale

The result of a measurement in hardness Rockwell is expressed as a simple value of scale of the Hardness Rockwell, without accompaniment of units, for value h given in mm.

For scales that use the Diamond indentor:

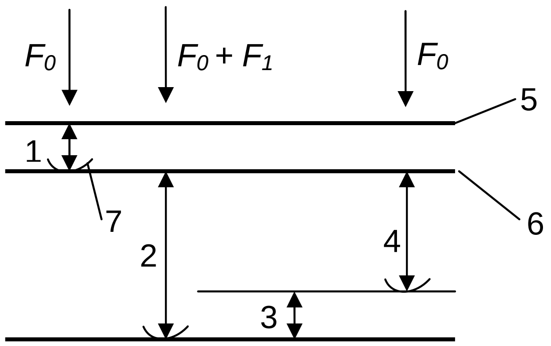
$$\text{Normal Rockwell Hardness} = 100 - \frac{h}{0{,}002mm}$$

$$\text{Superficial Rockwell Hardness} = 100 - \frac{h}{0{,}001mm}$$

For scales that use Balll Indenter

$$\text{Normal Rockwell Hardness} = 130 - \frac{h}{0{,}002mm}$$

$$\text{Superficial Rockwell Hardness} = 100 - \frac{h}{0{,}001mm}$$



1- Depth Penetration by Preliminary Force F_0
2- Increase indent Depth by total test Load F_1
3- Elastic Recovering after removing Total Test Load F_1
4- Permanent Indent Depth h
5- Mensurand Surface (Measuring object)
6- Reference surface for the measurement
7- Indenter Position (Depth position)

Diagram of Rockwell Hardness principle

What influences a Measurement of Hardness

TRACEABILITY, ERROR AND UNCERTAINTY

Currently the increasing industrial demand and strengthen of quality concepts, requirement of certifications and programs of recognition mutual and international, in the wave of the globalization and commanded mainly for the industry of mobility (automobile, aerospace and such kind of industries), is also increasing the concept of determination of the uncertainties associated to the results expressed as measurement value.
As briefly described in the method, many are the influences in the process of measurement of Hardness, the geometric form of indenter (Spheroconical Diamond or a Ball), the preliminary and Total loads of test, the measurement of the length on depth of penetration, beyond other parameters not demonstrated in the method, but that they are inherent of the proper method, such; the test forces speed at deposition, the time of permanence of these forces during the test, and many other practices recommended by standards or practical experiments. All these parameters become sources of errors with consequent influence in the result of the measurement of Hardness.

According to norm ISO 6508-1: 2005, and with the great efforts of Committee ISO TC 164, the main aspects to consider in the calculation of uncertainty in a measurement of Hardness Rockwell, are:
- Repeatability in performance of Hardness Testing Machine *(ms)*
- Reproducibility, including the drift of the equipment when determined, of the hardness testing Machine *(b)*
- Resolution of depth measuring device (display) *(b)*
- Uncertainty of the certified average value of the Reference Hardness Standards block used in the calibration of the Hardness Machine *(CRM)*
- Non uniformity in values of Hardness in the surface of the Hardness block , or other else in measuring process (object in measurement) *(CRM)*
- Bias in measurements in the hardness Machine refering to the Standard of hardness which the rastreabilidade is intended *(h)*
- Determination of the variations of measurements of the Hardness Machine (Repeatability during one exactly test) $(\bar{x})$
- Corrections for the measurement variations
- The remaining bias in the Hardness Machine after the corrections

Considering the coefficients of sensitivity for each one of the sources, the standardized uncertainties *(u)* and its influences in the results in values of hardness Rockwell, we have the expression that multiplied by a factor of confidence of *k=2 (*to *U=95%)* it will bring the Expanded Uncertainty *Ucorr (corrected):*

$$Ucorr = k \ . \ \sqrt{u_{CRM}{}^2 + u_H{}^2 + u_{\bar{x}}{}^2 + u_{ms}{}^2 + u_b{}^2}$$

The values associates to the sources of uncertainties, can vary for each type of equipment and must be determined empirically, or by technical informations from the manufacturer or another source of research that it has previously determined it.

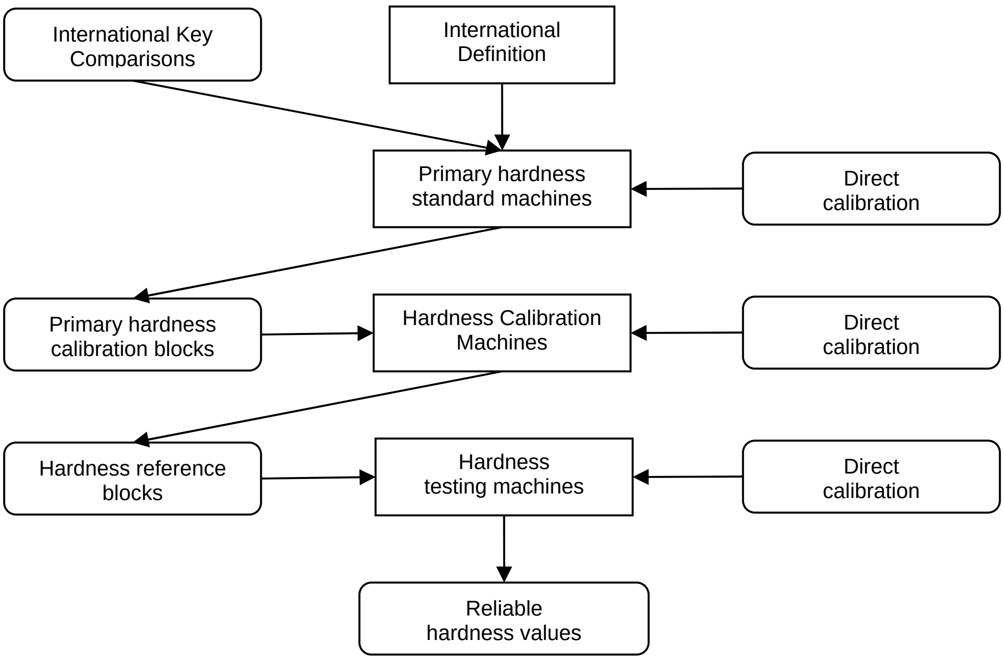
Traceability
The traceability is an important factor in a metrological chain for a measurement, perhaps the most important to determine the universality of a value gotten by measurement. It is what allows to express a result with a trustworthiness recognition, from there its obligatoriness for a calibration laboratory, without which an acreditation is invalidated.

We according to have for definition of Rastreabilidade (I CAME) International Vocabulary of Metrologia, adopted by INMETRO regulation Nº 029, of 10 of March of 1995, [[a]] define traceability as :

[*traceability/traçabilité, f]*

> *Property of the result of a measurement or the value of a standard to be related the established references, generally national or international standards, through a continuous chain of comparisons, all having established uncertainties.*
>
> *Comments:*
>
> *1) The concept is, generally express for the adjective **traceable**;*
>
> *2) A continuous chain of comparisons is called of **chain of traceability***

According to standard ISO 6508-1: 2005, the uncertainty is associated directly with the rastreabilidade chain, and presents in its attached G:
"…. It demonstrates the structure of the metrological chain of four levels, necessary to define and to spread hardness scales. The chain initiates in International Level using definitions for many hardness scales to allow te performing of international measurements comparations. Following of Primary Standardization Hardness Machines, as National Level, produce Blocks for Reference of Hardness values to Calibration Laboratories Level (accredited laboratories). Of course, the method of Direct Calibration and verification of these Hardness Machines must be lead with the highest possible accuracy."

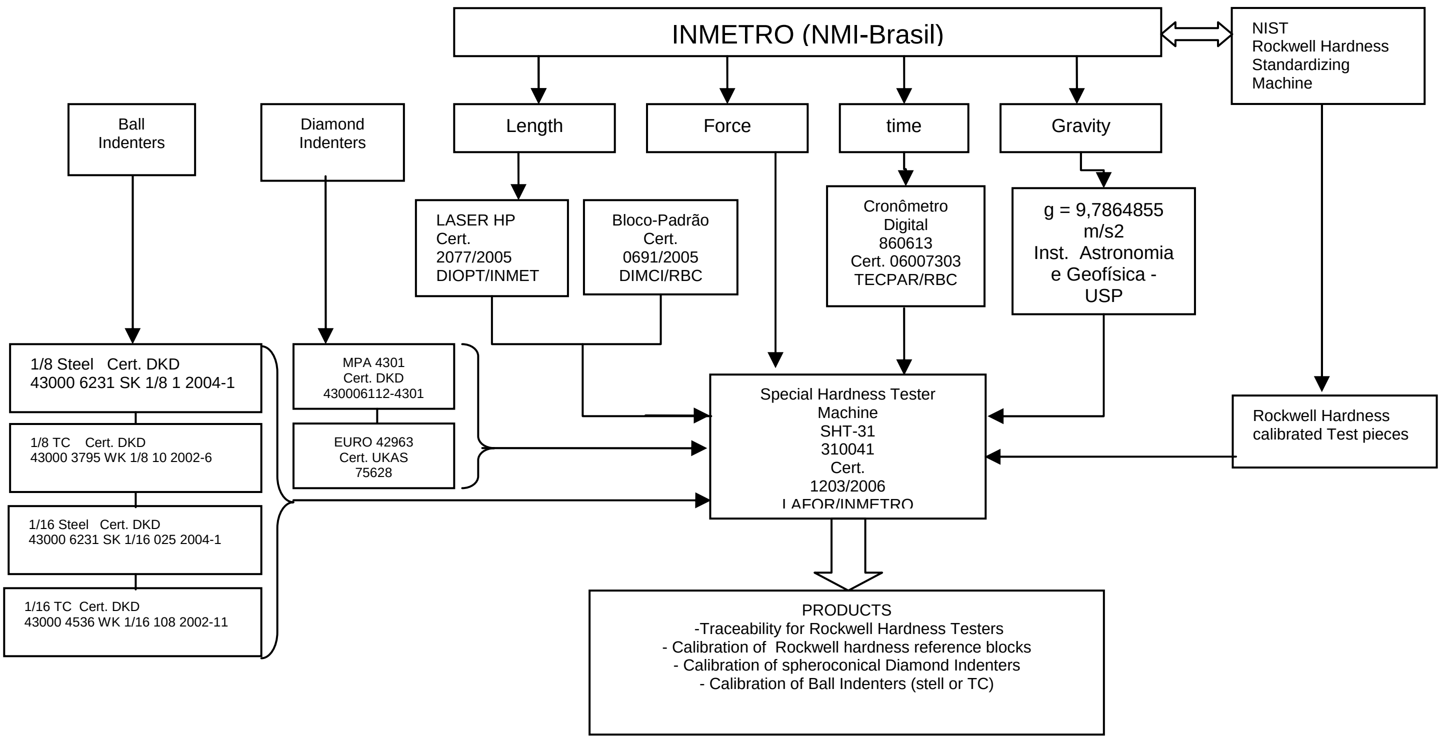


This Structure of the Metrological Chain for scales of Hardness, is a simple representation of the involved functions in the measurement of hardness scales.

As presented above, simply nominated as Direct Calibration, involves other metrological units that also must present a metrological chain, such as in the Dimensional area, Force, Time, Acceleration of the Gravity, and Geometrical units derived from length for definition and calibration of the Indenters (Diamond spheroconical Indenter; Stell or TC Balls).

In the figure below we demonstrate how is the structure to get metrological Chain, focused directly to the Level of Calibration Laboratory (as example the case of Mitutoyo Sul Americana Ltda), and the SHT-31 (Special Hardness Tester SHT-31) Machine for Calibration of Reference Hardness Blocks, which is, immediately below of the Standard of National Reference in Brazil (INMETRO).

ROCKWELL HARDNESS TRACEABILITY CHART
Mitutoyo Sul Americana

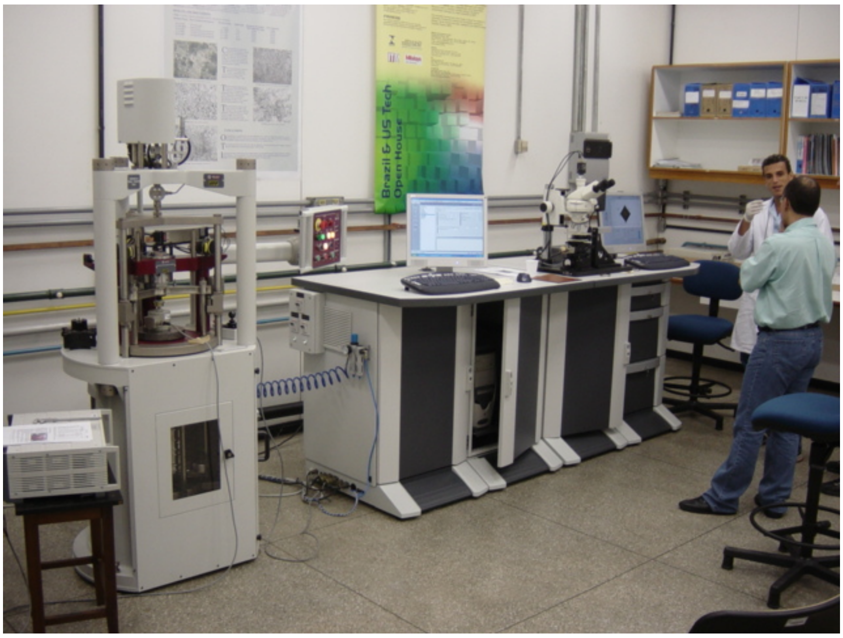


The chart above demonstrates the complexity and variety of derived units that must be kept under control to assure the metrological chain and consequentlly the traceability and reliability for hardness measurements. Also the needs to calibrate by direct method can be noted in the chart as well the Calibration of diamond or ball indenters.

The Hardness Metrological Chain in Brazil

The INMETRO, National Metrology Institute, withholds the equipment for Primary Standardization of Hardness scales, which was obtained in partnership via a project developed among the federal institute of Technology, a private University and local industry, which got support for financing the acquisition of this equipment.

The Primary Hardness Standardizing equipment is especially developed for NMIs (National Metrology Institutes) is the same holded by most advanced countries, such as U.S.A., Italy, UK, Germany, Canada, Australia etc.
The equipment just acquired and installed, have already started to calibrate blocks, defining and to implementing the Level of National Standard. It is an important and very onerous work, altoughth is adding a bigger value to the brazilian manufactured products.
We can see in the figures below the equipment already installed at INMETRO in Xerém, RIO DE JANEIRO, which is kept by the LAFOR – National Laboratory for Force and Hardness.

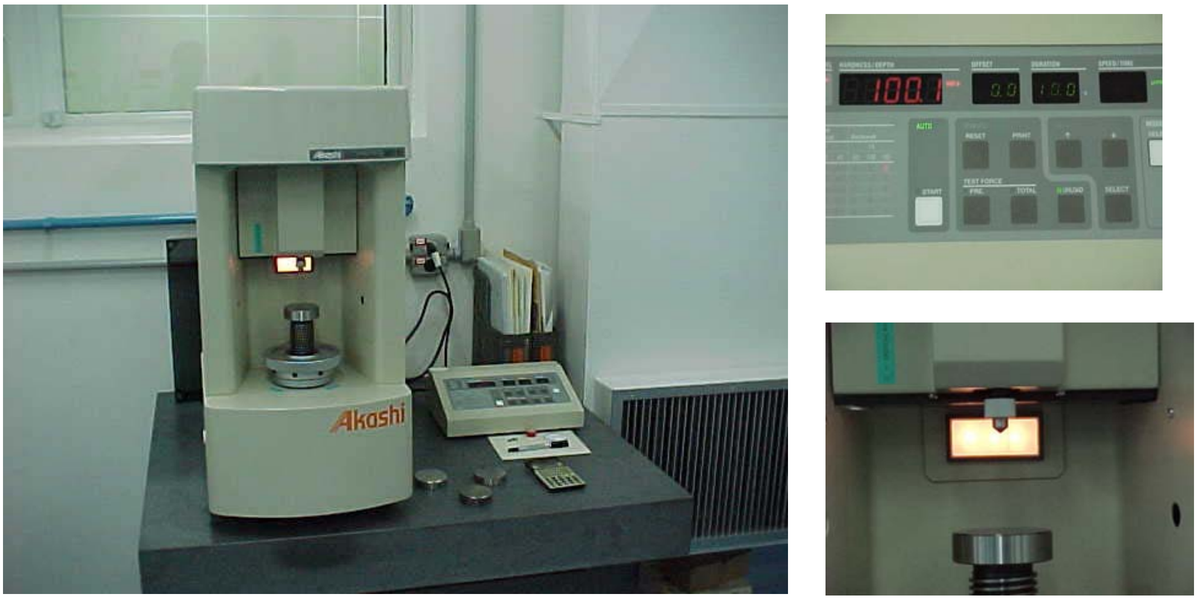


Hardness Primary Standartization Machine at LAFOR-INMETRO

Laboratory for Calibration of Reference Hardness blocks

At Mitutoyo, in Suzano-SP, the Laboratory of Metrology is accredited for Calibration of Hardness Referecne Blocks, besides IPT, that are today the two only laboratories qualified for that calibration service and accredited by INMETRO / CGCRE.
The Mitutoyo's calibration laboratory is accredited since 2002, and in the occasion INMETRO still didn't possess the Primary Standardization Machine for hardness, then the comparisons were made, under the coordination of INMETRO, comparing results with the equipment of NIST (National institute of Technology of USA) which owns a same equipment that today possesses INMETRO. Due this reason in the chart of traceability for Mitutoyo's calibration lab is mentioned the Primary Standardization machine of NIST, and that soon it will be modified, with the definitive operation starts of INMETRO's equipment.

The Hardness Calibration Machine holded by Mitutoyo's lab, which means second level in a metrological chain, is showed below.



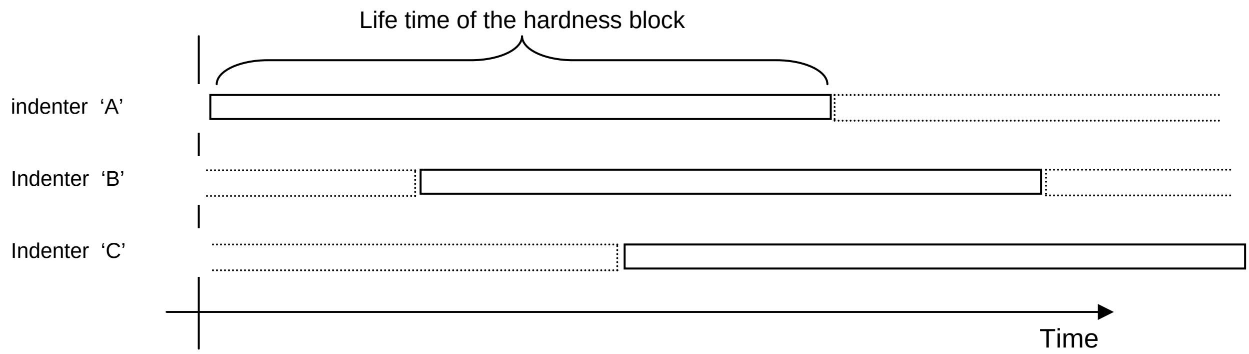
At left the Hardness Calibration Machine SHT-31.
At right and upper picture the SHT-31 operation panel, and
At right and lower picture details of Indenter and measurement anvil.

Control and Validation of the Hardness Calibration Method and Calibration Machine for Rockwell hardness scales (Maintenance of the Equipment of Calibration of Hardness)

To guarantee the results of the calibration process, several controls are made to allow continuous suitability of the proccess. These activities are:

a) *Control of Machine's Measurement performance*

This first control is constituted of a periodic attendance of the measurement acting, performed using 3 certified Diamond Indenters and 3 sets of reference hardness blocks, being each set composed by two blocks one of them with higher hardness value of the scale and other one with a lower values of the hardness scale being performed (e.g. HRC 60 and HRC 25). Each Indenter measurements corresponds exclusivelly to one set of test blocks, and measures are taken and ploted continually to verify the effectiveness of the measurement system along the time. These three sets of blocks are changed during their life time with a drift in it's life time of 1/3 of their own life, allowing a change for a new one without lossing the measurements among three sets and along the time. This kind of verification allows at any time a cross comparisons among Indenters and blocks, monitoring any change that could occours with any variable in the process.



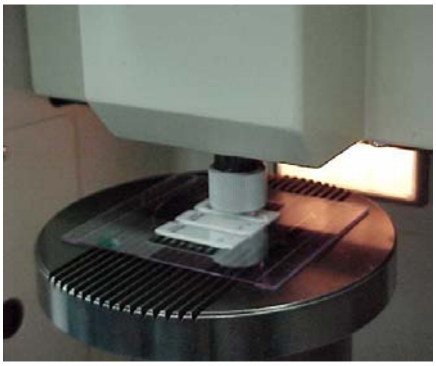
b -) Rigidity

The rigidity of the body of the equipment SHT-31 is also verified periodically checking its continuous suitability, initially apply the pre-load of 29.42 N seting zero to depth measuring device, and then afterwards applying the total load of 1.470 N on a flat plane and returning to the initial Pre-load of 29.42 N. The pointed value for the equipment corresponds to the value of rigidity of the body as it.

c -) Calibration of Depth Measurement System

As demonstrated by the illustration below the whole range of depth measurement is calibrated against gauge-blocks traceble to INMETRO / RBC, for that the SHT-31 its own becomes a comparador of high accuracy for the measurement.
As it has a Laser Holowscale's system on it's axis of loads application, eliminating Abbe's error in such configuration, the measurement it is made through a spherical measuring anvil instead an Indenter.

Depth measuring device calibration



Conclusion

This work inttended to focus the importance of Metrology applied to hardness measurement and the improvement in quality, considering all aspects involved in a hardness measurement and mainly the importance of a Structure in a Metrological Chain, regarding the hierarchy, and to push up the quality of our manufactured goods.
We are just begnning in the Hardness matter in brazil, if we compare with developed countries, which are more advanced on this matter. The OIML – International organization for metrology, in Europe, characterizes the Hardness as a to be monitored a unit for Legal Metrology, due to its importance in requirements of safety to mobility products and goods. There's a case were brazilian aircrafts were been proibited to landing on north America's territory untill we had to prove the hardness traceability needed to repair maintenances to aircrafts in Brazil.
It is still our incumbency to promote the metrology in Hardness to benefit brazilian industries and Technical Education, getting more perfect each time on products manufacture facing bigger qualitative requirements and safety, and nowadays why not say security too.