BRINELL HARDNESS: IMAGE ANALYSIS AND UNCERTAINTY

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Abstract: In the present work, all steps involved in the measurement of Brinell hardness indentations were studied, with the main purpose of evaluating the contribution of each step to the total uncertainty of the process. For the measurement of the indentations an expert system using digital image processing was developed. This automatic procedure can be very helpful as it reduces by orders of magnitude the time needed to perform the measurements and makes the process more reproducible by reducing the influence of the human operator.

Keywords: Brinell Hardness, Uncertainty Evaluation, Digital Image Processing.

1   INTRODUCTION

The present work is part of a large project that has been under development since 1996, with the main purpose of establishing a national metrological system for hardness scales, with procedures and standards that are traceable to metrological institutes recognized worldwide. One of the stages of this project aims at developing and certifying Brinell hardness standardized blocks in Brazil (HBW 2,5/187,5). A partnership between the Brazilian National Institute for Metrology, Standardization and Industrial Quality (INMETRO) and two technological institutions, Instituto de Tecnologia of the Catholic University of Rio de Janeiro (ITUC/PUC-Rio) and Instituto Nacional de Tecnologia of the Ministry of Science and Technology (INT/MCT) was established.

The certification procedure requires the analysis of all steps involved in the hardness measurement allied to the determination of the contribution of each step to the global uncertainty of the process. The uncertainty sources can be divided in two main groups:

1) uncertainty due to the indentation imprinting. In this group the main sources of uncertainty are the applied force, the imprinting duration and the diameter of the indenter [1].
2) uncertainty due to the measurement of the indentation itself. Sources of uncertainty in this group are the formation of the indentation image in an optical microscope, and the specific method for measuring the indentation geometry.

In this work we concentrate on the second group, describing a measurement method based on digital image analysis and the careful uncertainty and error analysis that was developed.

Hardness and micro-hardness values are normally obtained by measuring some linear parameter of indentations imprinted in the surface of a sample. For instance, the Brinell Hardness Number (BHN) is obtained from the diameter of a circular indentation.

Even though hardness is actually dependent on a complex combination of the area and depth of the indentation, the analysis of the standard expressions shows that the linear parameters measured are actually transformed into area values. Thus the Brinell expression is

$$BHN = \frac{2P}{pD\left[D - \sqrt{D^2 - d^2}\right]} \tag{1}$$

where P is the load, D is the indenter diameter and d is the indentation diameter.

The probable reason behind the use of linear dimensions is the difficulty in measuring areas with traditional techniques. Common hardness equipment normally requires the operator to perform the measurements manually with the aid of a microscope and a linear measuring device. This procedure suffers from the typical limitations of traditional metallography: lack of accuracy, poor repeatability and strong dependence on operator experience. Direct area measurements are impossible in these systems.

Digital image processing techniques can be very helpful in this context. With the correct combination of image acquisition devices, processing and analysis, the area of the indentation can be quickly and accurately obtained and the corresponding hardness values quickly reported. The system can be further improved by providing analysis rules that allow it to automatically eliminate spurious

image features and identify only the indentations. In this manner, a fully automatic system can be implemented.

2 EXPERIMENTAL PROCEDURE AND IMAGE ANALYSIS

Micrographs of indentations previously imprinted on standard blocks were obtained on a Zeiss Axioskope optical microscope with a video camera attached to a digitizer board. The digitized images were processed with the KS400 [2] package with customized macros.

Figure 1 shows the complete sequence involving the following steps:

1. Image formation in the optical microscope with focus and illumination adjustments.
2. Image digitization through the video camera and frame grabber.
3. Automatic image segmentation using the Otsu Method [3].
4. Shape recognition based on a circular form factor (CFF) to isolate the circular indentation from spurious features left behind by the segmentation step. The CFF is defined as [4]

$$CFF = \frac{4pA}{P^2} \tag{2}$$

where A is the area and P is the perimeter of the object. CCF equals 1 for a perfect circle and will decrease for other shapes.

5. Measurement of the equivalent circular diameter d of the indentation based on its area A.
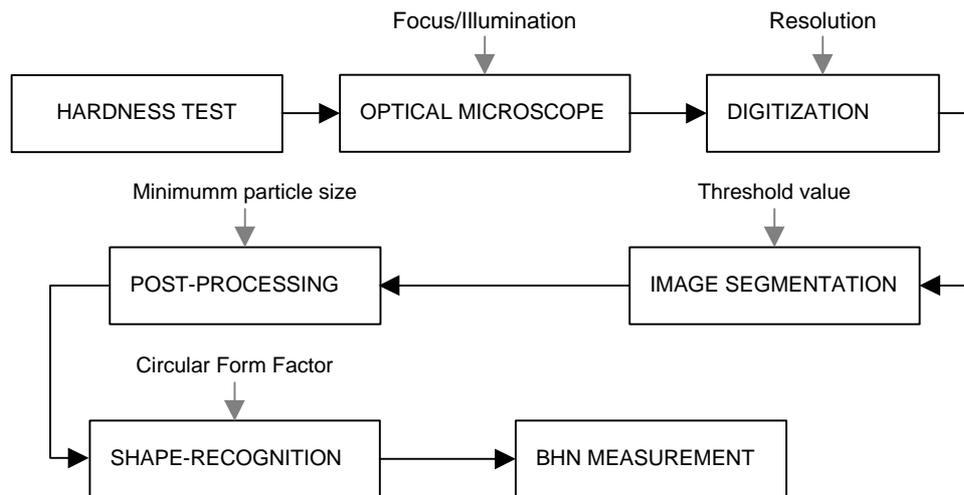6. Measurement of the Brinell hardness value.

Focus/Illumination   Resolution

| HARDNESS TEST | → | OPTICAL MICROSCOPE | → | DIGITIZATION |

Minimumm particle size   Threshold value

| POST-PROCESSING | ← | IMAGE SEGMENTATION |

Circular Form Factor

| SHAPE-RECOGNITION | → | BHN MEASUREMENT |

Figure 1. Flowchart showing the complete sequence and the variables involved in each step of the analysis.

3 UNCERTAINTY ANALYSIS

The whole sequence was then analyzed to identify the sources of uncertainty and the sources of systematic error. From the list of steps above, it becomes clear that there are only two parameters, namely focus and illumination, that generate uncertainty because they require a possibly different choice for each measurement, even if of the same field. The other parameters do not involve any kind of choice and thus cannot contribute to the uncertainty but rather to a possible systematic error.

It is well known [5] that the compound uncertainty of a measurement due to two independent influence variables can be expressed as

$$U = 2 * \sqrt{\left(\frac{\partial d}{\partial F} \cdot \Delta F\right)^2 + \left(\frac{\partial d}{\partial I} \cdot \Delta I\right)^2} \tag{3}$$

where U is the compound uncertainty within two standard deviations; d is the measured parameter

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(the indentation diameter); ΔF is the standard deviation of the first influence variable, (the focus value, measured as the z position of the sample under the optical microscope); ΔI is the standard deviation of the second influence variable, (the illumination value measured as units on the lamp control knob of the microscope); $\partial d/\partial F$ and $\partial d/\partial I$ are, respectively, the sensitivities of d to focus and illumination variation.

To obtain ΔF, the following procedure was repeated 20 times:
- the sample was visually brought into focus,
- the z position of the sample holder was measured with a highly accurate caliper,
- the sample was grossly defocused and again focused and
- ΔF was calculated as the standard deviation of the 20 z values obtained.

The sensitivity $\partial d/\partial F$ was obtained by measuring the diameter for 20 images obtained with 20 different values of focus systematically varied around the optimal value.

ΔI and $\partial d/\partial I$ were similarly measured. The illumination intensity was simply measured from the numbers in the intensity control knob of the microscope. The whole procedure required 80 images.

4 RESULTS AND DISCUSSION

The image processing sequence is depicted in Figures 2 to 5. The original grayscale image was automatically segmented leading to a binary image with the indentation and small and large spurious features. The small particles were eliminated based on area. The large shape on the right is an ink mark and was kept in the image to highlight the shape recognition capabilities of the procedure. The system then checked the circular form factor for every remaining object in the image and eliminated objects with CFF<0.8. In Figure 5, the program has recognized the circular indentation and ignored the large irregular feature.
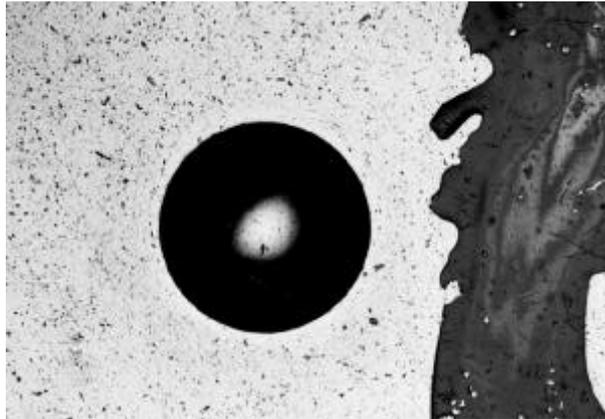

Figure 2. Brinell indentation image showing large and small spurious features (33x)

Figure 3. Result of automatic segmentation of Figure 2.

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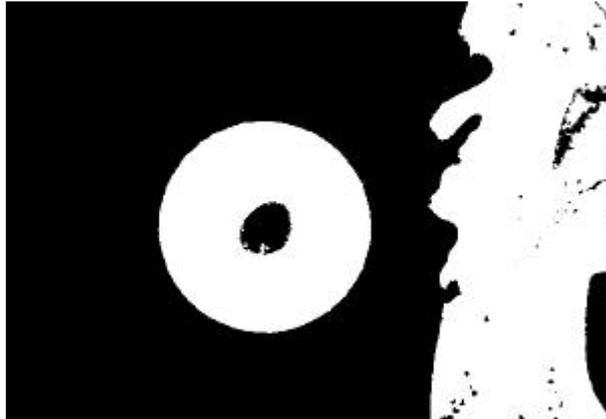Vienna, AUSTRIA, 2000, September 25-28

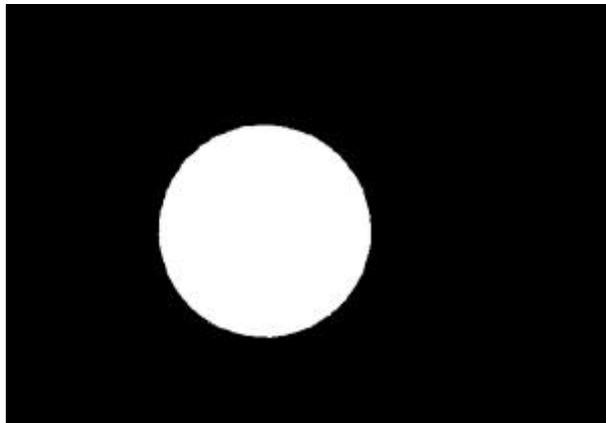**Figure 4.** Result of eliminating the small features.

Figure 5. Circular shape recognition.

The diameter measurement procedure was fully automated and allowed for quick and reproducible analysis of a large sequence of images. It was then applied to the uncertainty analysis sequence, which required a total of 80 images.

Figure 6 shows the dependence of the measured diameter, in microns, on the illumination, in units of the intensity control knob. The graph shows a typical trend in which the indentation diameter increases for lower illumination values. The recommended illumination value for the microscope used is around 10. The sensitivity to illumination was obtained from the inclination of a best straight-line fit and its value was -0.6136 μm/unit. The value obtained for ΔI was 0.1747 units.

The dependence of the diameter with focus is shown in Figure 7. The focus values were measured as the vertical displacement of the sample holder in relation to a given reference level. The optimal focus value corresponds to about 0.1mm in this scale. The calculated standard deviation ΔF was 0.002mm, a very low value showing that it is possible to reproduce an optimal focus setting. There is a tendency of diameter increase with focus value increase. However, it seems to go through a maximum around the optimal value. Thus, it is difficult to choose a value for the sensitivity $\partial d/\partial F$ from a straight line fit. The fit shown in the graph provides just a rough upper bound estimate of 18.1152 μm/mm. The presence of the maximum in the graph may mean that the sensitivity, i.e. the derivative close to the optimal value, is zero in this case.

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DIAMETER X ILLUMINATION
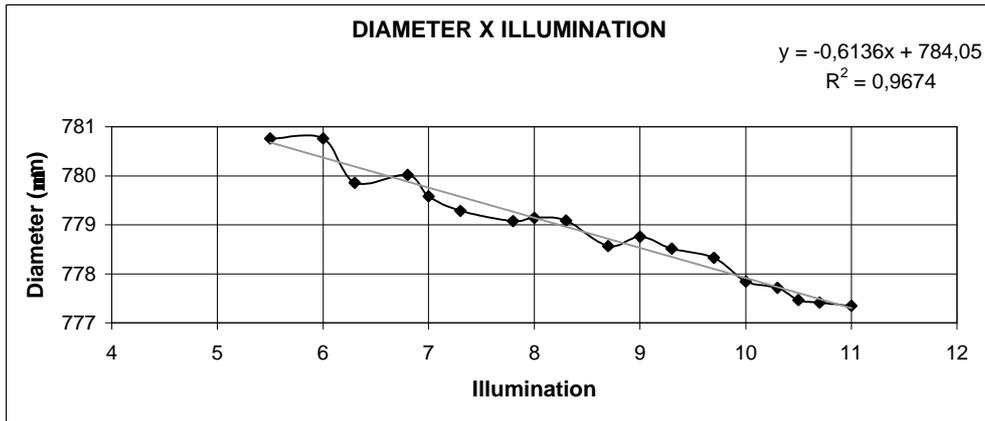
$y = -0{,}6136x + 784{,}05$
$R^2 = 0{,}9674$

Figure 6. Indentation diameter versus illumination (measured as units of the control knob). The squares are experimental points and the gray line is a best fit. The sensitivity was taken as the inclination of the best line fit.
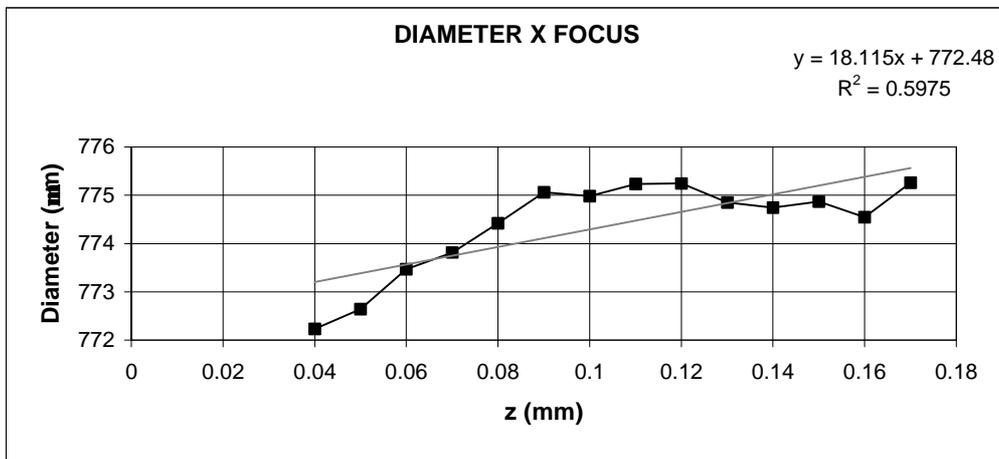
DIAMETER X FOCUS

$y = 18.115x + 772.48$
$R^2 = 0.5975$

Figure 7. Indentation diameter versus focus (measured as the vertical displacement of the sample holder). The squares are experimental points and the gray line is a best fit. The sensitivity was taken as the inclination of the best line fit.

The procedure described above allows the determination of the uncertainty due to the two influence variables that affect the image acquisition step. It must be noted, however, that the image analysis sequence can also introduce uncertainty if any parameters are chosen manually instead of being automatically determined by the software. If this were the case, the compound uncertainty equation (3), would include other terms that should be evaluated as described above.

As used in the sequence shown in **Figure 1**, the image analysis variables only lead to systematic errors that should be obtained by comparing the results with some reference value. Initial results show systematic errors around 1.0% using reference values provided by the Istituto di Metrologia Gustavo Colonnetti from Italy. This analysis is under way and will be reported in the future.

5   CONCLUSIONS

The use of Image Analysis for Brinell measurements in standard blocks proved to be reliable and fast. The strong contrast between the indentation and its surroundings allowed for automatic segmentation, eliminating the operator influence in this critical step. The use of shape recognition added intelligence to the procedure and provided complete automation of the diameter measurement step.

The diameter values obtained were derived from the area of the indentation, differently from the traditional linear measurements. As the hardness measurements are clearly dependent on the surface of the indentation, it is likely that this approach will lead to more physically meaningful results than the measurement of the diameter. The small systematic error obtained in preliminary tests corroborates to

this statement.

The sources of uncertainty in the procedure were restricted to microscope focus and illumination. A procedure was established to obtain the values of the terms in the uncertainty equation. The same procedure can used for other sources of uncertainty. These uncertainties must be included in a complete uncertainty equation that will take into account the indentation imprinting. This procedure will be described elsewhere.

REFERENCES
[1] European Standard, EN10003, 1994
[2] KS400 Software Package Version 3 - Carl Zeiss, 1997.
[3] Otsu, N., IEEE Trans. Syst. Mam. Cybern, 9, pp.62-66,1979.
[4] J.C. Russ, *Computer Assisted Microscopy,* Plenum Press, New York, 1992, 200 p.
[5] Guide to the Expression of Uncertainty in Measurement, INMETRO/BRAZIL, 1998.

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