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THE INFLUENCE OF INDENTER CHARACTERISTICS ON HARDNESS MEASUREMENTS

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Abstract – This paper details work carried out to determine the influence of indenter geometry on measured hardness values for both Vickers and Rockwell hardness methods. For Vickers Hardness, the effect of indenter angle is quantified, and for Rockwell Hardness, the effect of varying both cone angle and tip radius is investigated.

Keywords: hardness, indenters.

1. INTRODUCTION

The indentation hardness of a material is a measure of its resistance to permanent deformation caused by a force applied to its surface through an indenter. A number of different test methods exist (including Vickers and Rockwell), and the magnitude of the force, the geometry of the indenter, and the time profile of the force application and removal are all specified in the relevant Standard.

It has been recognised for a number of years [1] that different indenters, of nominally similar geometry, can lead to large variations in measured hardness values. Work has mainly been carried out within the Rockwell scale, but it has been identified that Vickers indenter morphology will contribute to the uncertainty in the hardness measurement. Therefore, it would be advisable to investigate these effects. It would also be useful to investigate these effects within the Rockwell scale, in order to compare the results with those from other work.

The work described in this paper aims to quantify the effect of different indenter geometries on measured hardness, within Vickers and Rockwell scales.

2. EQUIPMENT

The work was performed in NPL's 1,5 kN hardness standard machine (Fig. 1), which applies forces from 30 N to 1,5 kN. A high accuracy load cell, traceable to NPL force standard machines, measures the applied force. Indenter depth measurement is by a laser interferometer system, traceable to the UK realisation of the metre at NPL [2].

The machine is PC-controlled and uses generalised waveforms, for closed loop control, to run standard indentation profiles.

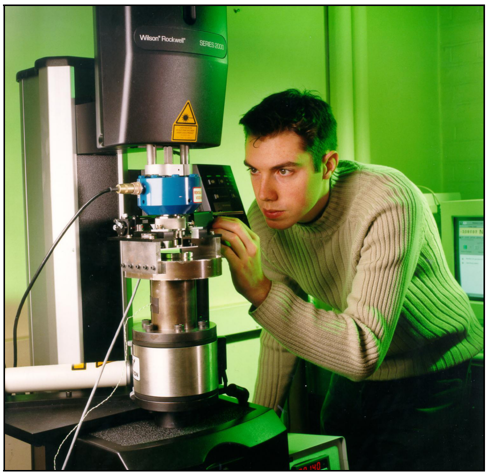

Fig. 1. NPL 1,5 kN hardness machine.

The uncertainty in the hardness measurement with this machine for Rockwell is ±0,2 % (at a 95 % level of confidence), and ±0,3 % (at a 95 % level of confidence) for Vickers.

For the Rockwell measurements, the values were calculated automatically and stored on the PC, whereas the Vickers values were obtained by measurement of the resulting indentations within NPL's indentation measuring equipment [2], which uses a microscope with CCD camera to image the indentation, an interferometer to measure the stage movement, and image analysis software that controls the measurement process. The measurement system minimises human manipulation of 'cross hairs' in identifying the diagonal vertexes of a Vickers indentation in an automated process, reducing the associated uncertainty.

3. PROTOCOL

The Vickers and Rockwell Standards [3, 4] give tolerances for various parameters of the indenter geometry. The parameters considered in this paper are given in Table I.

TABLE I. Investigated indenter parameters

Rockwell C		Vickers	
Cone angle:	120,00° ± 0,35°	Angle:	136,0° ± 0,5°
Tip radius:	0,20 mm ± 0,01 mm		

For the Rockwell C measurements, four indenters were obtained, each of which had either the maximum or minimum cone angle allowed, together with the maximum or minimum tip radius (see Fig. 2a).

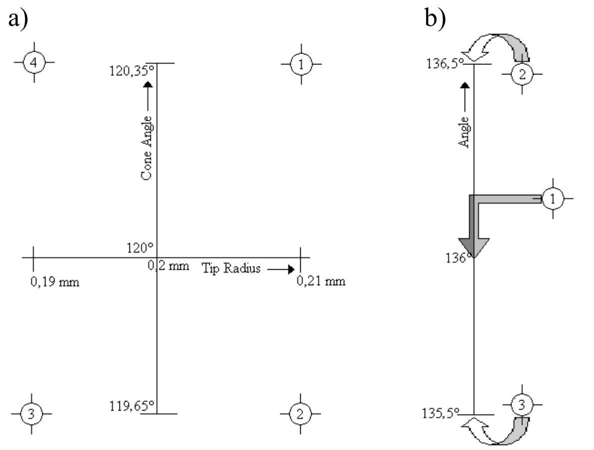

Fig. 2. Indenter characteristics to be used. a) Rockwell b) Vickers

For the Vickers measurements, indenters were obtained with angles of 135,62°, 136,14°, and 136,64°, to cover the range of geometries allowed by the Standard (see Fig. 2b).

The Vickers work was carried out on reference blocks of nominal hardness 300 HV 10 and 800 HV 10, and the Rockwell work on blocks of nominally 30 HRC and 63 HRC.

Five indentations were made by each indenter in each block, at positions spread evenly over the block's surface.

4. RESULTS

4.1 Vickers

Three Vickers indenters were used, their measured angles are detailed in Table II.

TABLE II. Measured Vickers indenter angles.

Serial Number	Indenter Angle (°)
40226	135,616
40227	136,143
40228	136,639

Tables III and IV show the results obtained from the Vickers measurements. The indentations measurements on the 300 HV10 block were made using a combination of x20 and x0.8 magnification lenses with the microscope. The indentations on the 800 HV10 blocks were measured with x20 and x1.25 magnification lenses.

TABLE III. Compiled results of HV10 Tests (300 HV10)

	300 HV10		
	40226	40227	40228
1	320,023	319,647	312,947
2	319,020	318,276	316,717
3	318,782	316,429	315,066
4	318,175	320,347	317,811
5	319,625	319,011	312,699
Average	**319,125**	**318,742**	**315,048**

TABLE IV. Compiled results of HV10 Tests (800 HV10)

	800 HV10		
	40226	40227	40228
1	825,982	824,038	817,251
2	824,825	822,520	821,645
3	819,716	820,097	820,261
4	822,119	819,734	817,396
5	826,717	823,416	814,941
Average	**823,872**	**821,961**	**818,299**

To understand more about the reasons that the indenters give different measured hardnesses we need to compare their different characteristics with the hardness measurements obtained. Fig. 3 and Fig. 4 plot the mean measured hardness values against indenter angle for the two blocks.

There appears to be a definite trend for the measured block hardness to decrease with the increase in the Vickers indenter angle, this trend being more distinct between 136,0° and 136,5°. The effect on the measured hardness is slightly greater (in hardness units) on the 800 HV10 block although this equates to approximately 0,68 % compared to the approximate 1,26 % change for the HV10 300. However, slight increase in spread of the results could account for the increased gradient.

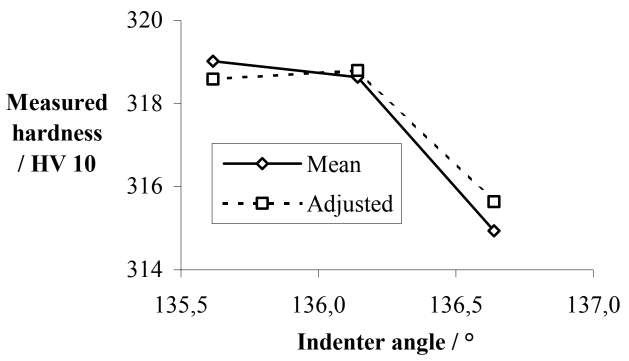

Fig. 3. Effect of indenter angle on Vickers Hardness (300 HV 10)

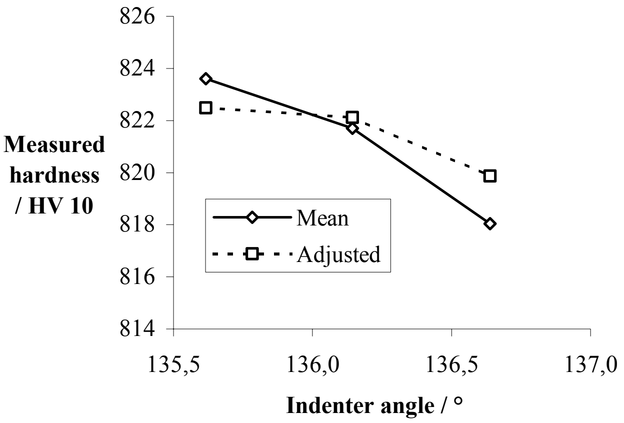

Fig. 4. Effect of indenter angle on Vickers Hardness (800 HV 10)

Equation (1) gives the formula used to calculate Vickers Hardness, where F is the applied force, α is the indenter angle, and d is the mean indentation diagonal.

$$HV = 0{,}102 \times 2F \sin\left(\frac{\alpha}{2}\right) \Big/ d^2 \qquad (1)$$

Using the measured indenter angle in (1), rather than assuming it to be 136°, allows adjusted hardness values to be calculated which take into account the deviation from the nominal value. This has been done in Fig. 3 and Fig. 4.

These new sets of readings can be seen to reduce the error caused by the indenter angle difference, levelling out the readings at the smallest angle, but only reducing the error slightly at the larger angle. The adjustment of the readings also seems to have a greater effect on the harder block reducing the error down to within 2 HV10.

4.2 Rockwell

As mentioned, four Rockwell indenters were used. Their details are given in Table V.

TABLE V. Measured Rockwell indenter parameters

Serial Number	Cone Angle (°)	Tip Radius (mm)
40222	120,244	0,1915
40223	120,286	0,2090
40224	119,566	0,1890
40225	119,569	0,2100

Tables VI and VII, show the results obtained from the Rockwell measurements using the 1,5 kN hardness machine, with each of the four indenters on both hardness blocks.

TABLE VI. Compiled results of HRC Tests (30 HRC)

30 HRC	Hardness Value [HRC]			
Indenter:	**40222**	**40223**	**40224**	**40225**
1	32,19	33,14	30,22	30,96
2	32,26	33,17	30,98	31,11
3	32,43	32,84	30,87	31,06
4	31,97	33,24	31,29	31,34
5	32,65	33,25	31,18	31,33
Mean	**32,30**	**33,13**	**30,91**	**31,16**

TABLE VII. Compiled results of HRC Tests (63 HRC)

63 HRC	Hardness Value [HRC]			
Indenter:	**40222**	**40223**	**40224**	**40225**
1	64,15	65,07	62,72	63,63
2	64,14	65,26	63,20	63,85
3	63,84	65,01	63,02	63,60
4	64,21	65,24	63,26	63,95
5	64,15	65,22	63,34	63,85
Mean	**64,10**	**65,16**	**63,11**	**63,78**

When assessing the error caused by the differences in the indenter characteristics we need to take into account both tip radius and indenter angle. Looking at the effects of these characteristics collectively is a suitable way of achieving this.

The effects of varying both cone angle and tip radius are shown together in Fig. 5 and Fig. 6, for the two hardness levels investigated.

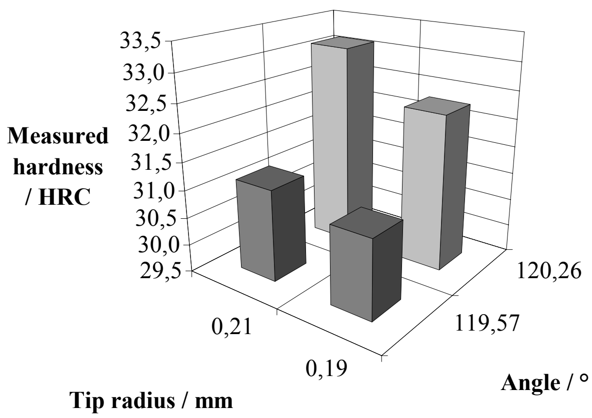

Fig. 5. Effect of angle and radius on Rockwell Hardness (30 HRC)

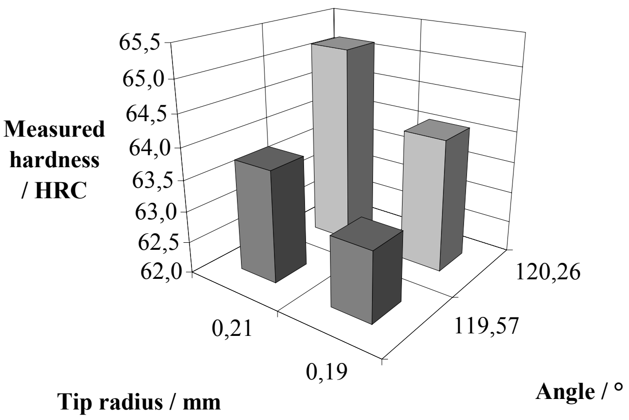

Fig. 6. Effect of angle and radius on Rockwell Hardness (63 HRC)

From Fig. 5 and Fig. 6 it can be seen that a larger tip radius increases the measured hardness, as does a larger cone angle. Although they both contribute to the measured hardness it can be seen that increasing the cone angle, within the range allowed by the standard, causes a greater effect on the hardness value than the tip radius.

5. ANALYSIS

5.1 Vickers

The unadjusted results shown in Fig. 3 and Fig. 4 support the general theory that an increase in indenter angle leads to a decrease in measured hardness. An indenter with a larger angle will produce, for the same force, a shallower but wider indentation. A wider indentation results in a lower hardness value.

When the results are corrected to allow for the actual angle of the indenter used, the results obtained at the smallest angle agree well with those at the nominal value. However, the results at the largest angle still give too low a hardness value, particularly on the 300 HV 10 block. The reason for this is unclear and merits further investigation.

Although the uncertainty for these results does mask some of the effects, there still appears to be a general trend as described. Further work with a larger number of indenters could be done to understand the observed effect more, clarifying if the effects here are just due to different indenters or an actual trend caused by the differences in indenter angle, and then maybe suggesting a correction factor.

It is worth stressing that variations in indenter angle, while within the limits allowed by the Standard, can lead to significant variations in measured hardness.

5.2 Rockwell

The results obtained at the two hardness levels, shown in Fig. 5 and Fig. 6, demonstrate similar characteristics, namely that there is an increase in measured hardness with increases in both tip radius and cone angle.

These effects are both expected – a larger tip radius suggests a blunter indenter which will not penetrate as far, leading to a greater hardness value, whereas an increase in cone angle will also lead to less penetration depth, due to a larger indenter area at a given distance from the tip.

Previous work [5] has suggested sensitivity coefficients for tip radius of 20 HRC/mm (at 30 HRC) and 50 HRC/mm (at 63 HRC) and for cone angle of 1,1 HRC/° (at 30 HRC) and 0,4 HRC/° (at 63 HRC).

The results presented here suggest sensitivity coefficients for tip radius of 30 HRC/mm (at 30 HRC) and 45 HRC/mm (at 63 HRC) and for cone angle of 2,4 HRC/° (at 30 HRC) and 1,7 HRC/° (at 63 HRC).

The tip radius results therefore agree well with previous work, but the results for cone angle suggest that the previous figures underestimate the effect by a factor in the region of two to four.

It should again be stressed that major variations in hardness can be obtained using different indenters, all of which meet the requirements of the Standard.

6. CONCLUSIONS

Some of the effects of indenter geometry on measured Vickers and Rockwell hardness have been quantified. The results demonstrate that different indenters meeting the requirements of the Standards can lead to significantly different hardness measurements.

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