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INVESTIGATION OF A GROUP STANDARD OF ROCKWELL DIAMOND INDENTERS

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Abstract – The specific hardness deviations of a Rockwell diamond indenter can be determined by a group standard, consisting of several indenters, using correction functions. In this paper the establishment of an HRC group standard in the PTB and comparative investigations of the group standards in the PTB and the calibration laboratory MPA NRW in Germany are reported. Above all the group standard is advantageous for maintaining the stability of the Rockwell hardness scales.

Keywords : Rockwell diamond indenter, group standard, Rockwell hardness scales.

1. MOTIVATION

Rockwell tests are the most widely applied hardness tests in industry. Again, within the different standardized Rockwell hardness scales, the scales which are realized with diamond indenters (cone shape with a ball cap), like HRC, HRA and HRN, are of utmost importance for industrial practice.
In the Rockwell tests using diamond indenters the geometrical and other specific deviations of the diamond indenter deliver the largest contribution to the measurement uncertainty.
Although nowadays for the determination of the geometry of the Rockwell diamond indenters special interferometers, high resolution profilers and nanomeasuring machines can be applied, which generally have an uncertainty in the range from 10 nm to several 100 nm, the function test of the Rockwell diamond indenters reveals that the uncertainty can scarcely remain under ca. 0.3 HRC.
Therefore additionally to the geometry determination by interferometery and coordinate measurements with a nanomeasuring machine the concept of a group standard is investigated. The idea of an group standard for Rockwell indenters was already theoretically elaborated by R.S. Marriner [1] and F. Petik [2], but so far seldom applied.

2. INVESTIGATION OF A GROUP STANDARD OF ROCKWELL DIAMOND INDENTERS

2.1. Selection criteria for the group standard and investigation plan

2.1.1. Selection criteria for the group standard

The indenters for the group standard were selected according to the following criteria:

- Fulfilment of the geometrical deviations according to ISO 6508-3 (at least acc. to ISO 6508-2)[3][4]
- The mean value of the indenter deviations in different sections of the indenter height should also be near the normative value
- The geometrical deviations of the indenters chosen for the group standard should be distributed symmetrically to the nominal value

In Table 1 the geometrical deviations of four Rockwell diamond indenters chosen for the group standard of the HRC hardness scale are given.

TABLE 1. Geometrical deviations of Rockwell diamond indenters for the HRC group standard

Indenter No.	Mean cone angle	Mean radius (mm)
836	119°59’	0.199
838	120°01’	0.194
839	119°58’	0.195
840	120°02’	0.199

From Table 1 it can be derived that the selection criteria are quite well fulfilled for the group standard.
Fig. 1 shows the indentation depth values on a Rockwell diamond indenter in dependence on the HRA, HRC and HRD hardness scales and different hardnesses.

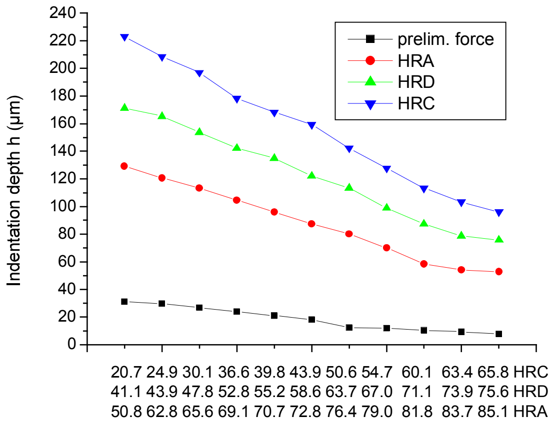

Fig. 1. Relationship between the indentation depth of a Rockwell diamond indenter and the hardness scales HRA, HRC, HRD and different hardness values

The curves of Fig. 1 show the indentation depth under the action of the preliminary test force (F_0) and of the total test force (F). From this diagram the parts of the indenter can be determined which participate in the indentation process. The acting indenter height is the largest for the hardness scale HRC, followed by the scales HRD and HRA. The section of the indenter which participates in the indentation under the action of the preliminary force (F_0 = 98.06 N) is the smallest.

Fig. 2 shows the same relationship for the hardness scales HR15N, HR30N and HR45 N.

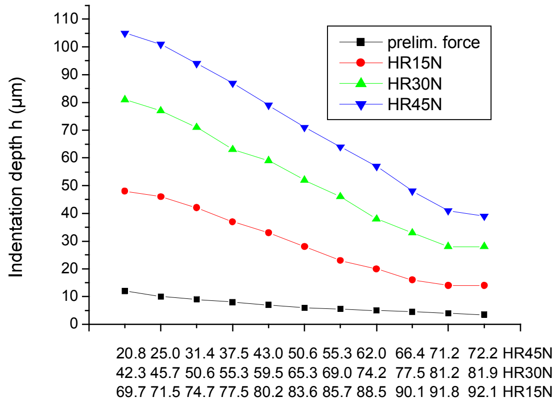

Fig. 2. Relationship between the indentation depth of a Rockwell diamond indenter and the hardness scales HR15N, HR30N, HR45N and different hardness values

Compared with the indentation depths at the hardness scales HRA, HRC and HRD, the indentation depths at the superficial hardness scales HR15N, HR30N, HR45N and the corresponding preliminary force (F_0 = 29.04 N) are less than one half.

In Table 2 the variation of the cone angle for different cone heights of several Rockwell indenters (from MPA NRW) and in Table 3 the corresponding variation of the ball cap radius is given.

TABLE 2. Variation of the cone angle for different cone heights of selected Rockwell indenters

Indenter No.	Cone angle (°) for different heights of the cone			
Cone height (µm)	8 - 113	8 - 85	8 - 56	8 - 27
5888	120.03	120.13	120.17	119.75
5884	120.05	120.15	120.19	119.80
7012	120.05	120.17	120.27	120.03
2012	119,98	120.09	120.22	120.00
2059	120.03	120.16	120.31	120.18
7780	119.97	120.07	120.18	120.04
7783	120.04	120.10	120.19	119.98
5775	119.97	120.07	120.13	119.80

The variation of the cone angle in dependence on the cone height is based on the crown of the cone generatrix.

TABLE 3. Variation of the mean ball cap radius for various heights from the indenter tip and for various groups of indenters

Indenter No. of various indenter groups	Mean ball cap radius in various indenter heights (µm)				
Indenter height (µm)	0 - 21	0 - 6	0 - 3	6 - 21	3 - 21
5888,5884,7783,5775,7785	200.07	199.45	197.70	200.66	200.25
5888,5884,7780,5775,7785	199.64	199.98	200.15	200.41	199.78
5888,5884,7783,5775,7780	199.55	201.19	200.87	199.35	199.22
5888,5884,7783,5775	200.25	200.23	198,71	200.48	200.23
5888,7785,7783,5775	199.95	200.45	197.62	199.65	199.74
5888,7783,5775	200.15	201.83	198.94	199.08	199.54
5888,5884,5775	200.69	199.54	199.21	201.96	201.12

In Table 4 the maximum variations of the mean ball cap are summarized for the indenter groups listed in Table 2.

TABLE 4. Maximum variations of the mean ball cap for selected indenter groups

Indenter No. of various indenter groups	Maximum variation of mean ball cap radius (µm)
5888,5884,7783,5775,7785	2.96
5888,5884,7780,5775,7785	0.77
5888,5884,7783,5775,7780	1.97
5888,5884,7783,5775	1.77
5888,7785,7783,5775	2.83
5888,7783,5775	2.89
5888,5884,5775	2.75

Table 4 clarifies that the 2., 3. and the 4. indenter group have maximum radius variations < 2 µm, which are suited for group standard indenters.

From the investigation of indenters which can be included into a Rockwell indenter group standard the following can be stated:

- The group standard can be used for the definition of all Rockwell scales.
- The sections of the indenter which participate in the indentation process differ in dependence on the hardness scale and the hardness level.
- The form deviations in the range of the ball cap can be well balanced.
- Because the crown always appears in the same section of the cone, it cannot be compensated.

2.1.2. Investigation plan

At first the group standard for the HRC scale, as comprised in Table 1, was investigated with 6 hardness reference blocks having the following nominal hardness levels: 20 HRC, 30 HRC, 40 HRC, 50 HRC, 60 HRC and 65 HRC. With each of the 4 chosen indenters 8 indentations evenly distributed over the hardness reference block were carried out.

In order to investigate the capability of Rockwell indenter group standards for the remaining Rockwell hardness scales performed with diamond indenters sets of hardness blocks according to the hardness scales HRA, HRC, HRD, HR15N, HR30N and HR45N were indented. For the comparison each two Rockwell diamond indenters from PTB and MPA NRW were selected. Moreover, one indenter of MPA (indenter No. 2012) was used as common indenter for indentations both in PTB and MPA NRW.

Table 5 shows the hardness levels of the used hardness reference blocks for the mentioned hardness scales.

TABLE 5. Hardness levels of the used hardness reference blocks for the investigated hardness scales

Hardness scale	Hardness levels (HR)			
HRA	60	70	78	84
HRC	20	40	55	65
HRD	40	55	67	75
HR15N	65	80	88	92
HR30N	41	60	73	82
HR45N	20	43	61	72

On each hardness reference block with each of the 5 selected indenters 9 indentations were made. In this way the inhomogeneity of the hardness reference block can be compensated.

The time regime of the hardness standard machine corresponded with ISO 6508-3.

3. INVESTIGATION RESULTS ON A GROUP STANDARD OF ROCKWELL DIAMOND INDENTERS

3.1. Results of the HRC group standard

Fig. 3 illustrates the homogeneity of the used hardness reference blocks, expressed by their variation coefficient, which was obtained each from 8 measurements.

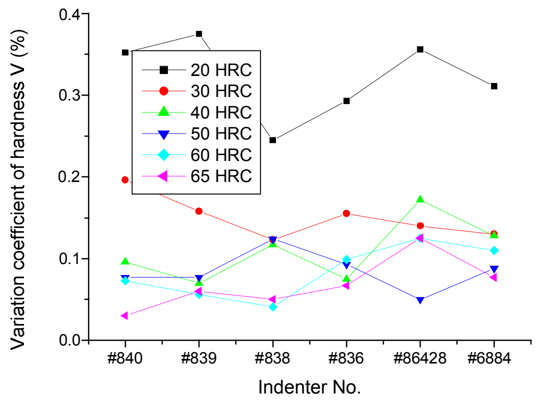

Fig. 3. Homogeneity of the used hardness reference blocks, expressed by the variation coefficient of the hardness measurement results in dependence on the hardness level and the investigated indenters

Fig. 3 clarifies that the variation coefficient increases with decreasing hardness, that is, with increasing indentation depth. Moreover, a certain dependence of the variation coefficient on the indenter can be observed. For instance, the variation coefficient for the indenters #838 and #839 is the smallest for most of the hardness levels. This can be due to differences in the friction coefficient of the indenters.

Table 6 summarizes the mean values of each 8 hardness measurements obtained by the 4 indenters on the 6 hardness reference blocks.

TABLE 6. Measurement results (mean values) obtained for the indenters of the HRC group standard on a set of hardness reference blocks (HRC)

Nominal hardness, HRC	Indenter No. 836	Indenter No. 838	Indenter No. 839	Indenter No. 840
20	20.602	20.441	20.283	20.555
30	31.497	31.255	31.150	31.340
40	41.495	41.367	41.241	41.486
50	50.472	50.354	50.264	50.561
60	61.139	61.009	60.822	61.165
65	64.604	64.418	64.281	64.583

In Fig. 4 the hardness deviations of each indenter from the mean value of hardness received for the 4 indenters are depicted.

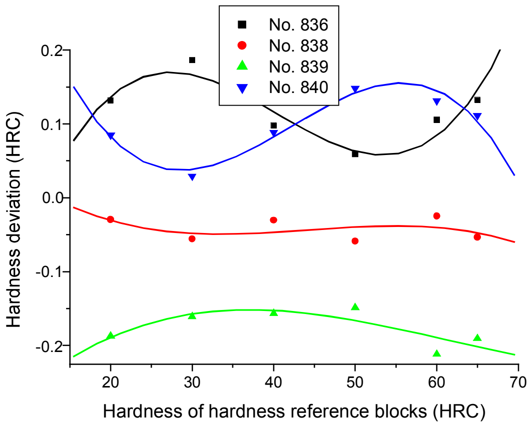

Fig. 4. To be corrected hardness deviations of the indenters belonging to the HRC group standard

Fig. 4 clarifies that the order of magnitude of the specific hardness corrections of each indenter is within the range ±0.2 HRC. The hardness deviations are fitted with polynoms of 3. order.

Fig. 5 shows the remaining hardness deviations for the case that the hardness corrections in the form of 3. order polynoms were carried out.

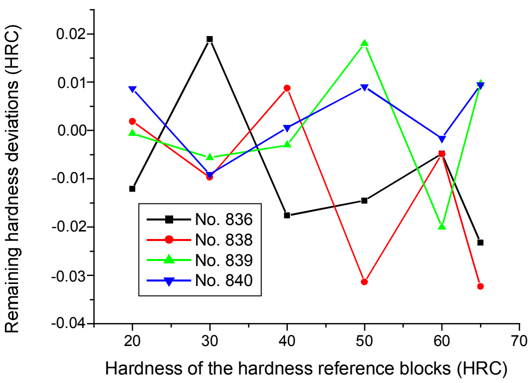

Fig. 5. Hardness deviations remaining after the correction for the specific indenter deviations

From Fig. 5 it can be derived that the remaining hardness deviations after the correction for the specific indenter deviations are in the order of magnitude +0.02/-0.03 HRC.

3.2 Investigation of the capability of the group standard concept for all ISO hardness scales with Rockwell diamond indenters

As mentioned in section 2.1.2, for each of the hardness scales HRA, HRC, HRD and HR15N, HR30N, HR45N hardness reference blocks with each four hardness levels were indented each by two indenters from PTB (indenters No. 838 and 840) and MPA NRW (indenters No. 2012 and 2059). In Fig. 6 the mean hardness values of the hardness standard machines in the PTB and the MPA are compared for the HRC scale.

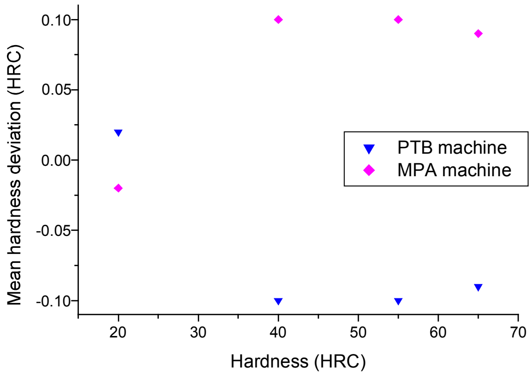

Fig. 6. Comparison of the mean HRC values of the hardness standard machines in PTB and MPA NRW

From Fig. 6 it can be derived that the mean hardness differences between the two standard hardness machines is not larger than 0.2 HRC.

Further, in Fig. 7 the standard deviations of both machines are compared for the scale HRC.

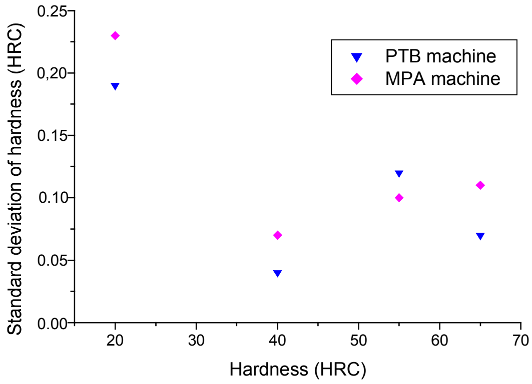

Fig. 7. Comparison of the standard deviations of the standard hardness machines in PTB and MPA NRW

The standard deviations of the standard hardness machines show a tendency to decrease with increasing hardness level with a minimum at about 40 HRC.
The Fig. 8 to Fig. 13 illustrate the specific hardness deviations of the four indenters for the above mentioned hardness scales.

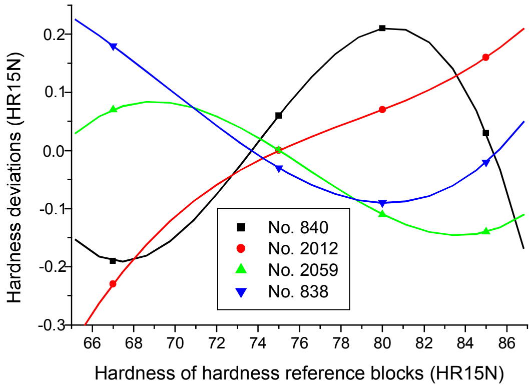

Fig. 8. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HR15N

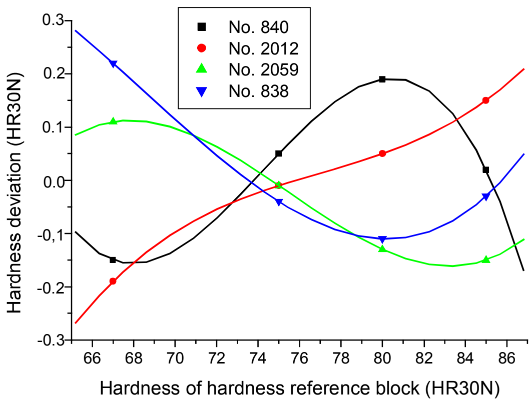

Fig.9. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HR30N

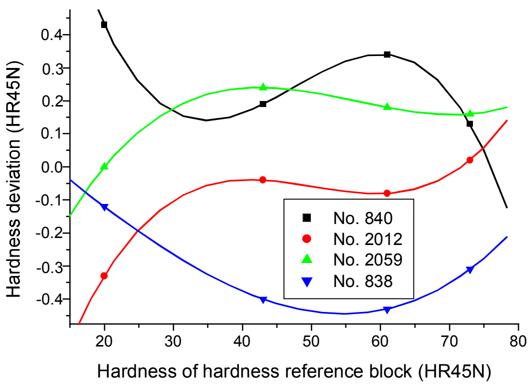

Fig. 10. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HR45N

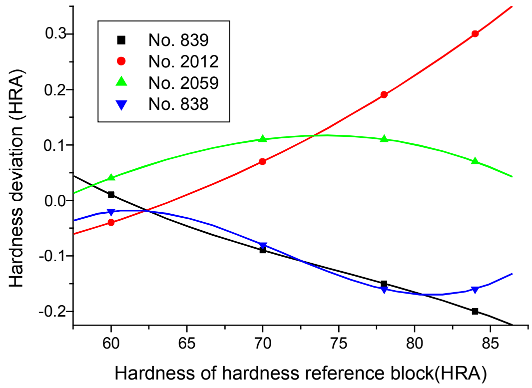

Fig. 11. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HRA

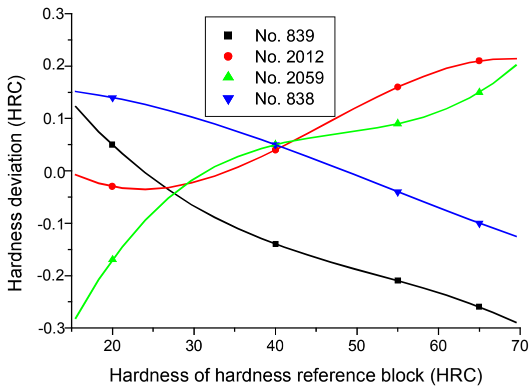

Fig. 12. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HRC

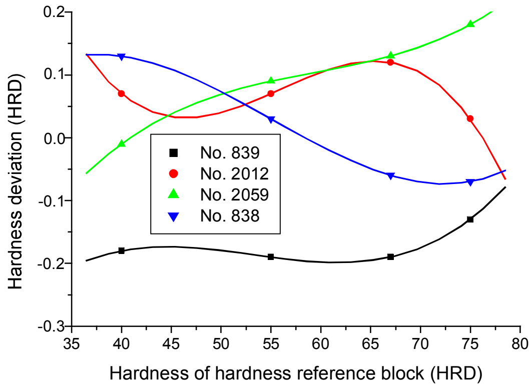

Fig. 13. Specific hardness deviations of each two indenters from PTB and MPA NRW for the hardness scale HRD

The correction functions of the four indenters from PTB and MPA NRW shown in the Fig. 8 to Fig. 13 reveal that the correction is in a range between ±0.2 HR and ±0.25 HR. Only for the hardness scale HR45N an amount of correction of ±0.4 HR was observed. This phenomenon can be explained by the remarkable influence of the crown of the indenter cone, if one considers the typical indentation depth at this hardness scale.

3.3. *Comparison of the group standards of PTB and MPA NRW*

For the comparison of the group standards of both institutes at first a common indenter was used with which the same set of hardness referenced blocks on the hardness standard machines in PTB and MPA NRW was measured. In Table 7 these measurement results are summarized.

TABLE 7. Measurement of the HRC set of hardness reference block with a common indenter (No. 2012) in PTB and MPA NRW (HRC)

Measurement in MPA	Measurement in PTB	Difference Δ(MPA-PTB
17.80	17.84	-0.04
41.29	41.08	0.21
56.85	56.65	0.20
65.69	65.52	0.17

Then Table 8 shows the results of indenter corrections for the indenter No. 2012 (MPA NRW) and No. 838 (PTB).

TABLE 8. Results of the correction of each one indenter from PTB and MPA NRW on the HRC scale (HRC)

PTB indenter No. 838	MPA indenter No. 2012	Difference Δ(MPA-PTB)
17.83	17.80	-0.03
41.25	41.29	0.04
56.69	56.85	0.16
65.48	65.69	0.21

The results in Tables 7 and 8 demonstrate that the differences for the measurement with the common indenter and after the correction of the specific indenter deviations amount to not more than 0.2 HRC.

It should be underlined, that the correction functions depend on the composition of the group standard. This means that after the replacement of an indenter the correction functions must be determined anew, because their values will change by a small amount.

4. SUMMARY AND OUTLOOK

The specific hardness deviations of a Rockwell diamond indenter can be determined by a group standard with corrections functions which have remaining deviations of 0.02 HR for the scales HRA, HRC, HRD and remaining deviations of 0.07 HR for the scales HR15N, HR30N, HR45N. Additionally interpolations deviations of the corrections functions of ca. 0.1 HR have to be considered.

By the use of a group standard of indenters the measurement uncertainty for the reproduction of the Rockwell scales HRA, HRC, HRD can be reduced to 0.2 HR and for the reproduction of the Rockwell scales HR15N, HR30N, HR45N to 0.25 HR. The most important advantage of the group standard of Rockwell diamond indenters lies in the fact that the stability of the Rockwell hardness scales, which depend sensitively on the diamond indenter, can be maintained safely.

Present investigations in the PTB are focussed on the idea, based on geometrical measurements to determine area functions of Rockwell diamond indenters with coordinate measurements on a nanomeasuring machine having an uncertainty of only a few nanometers.

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[4] ISO 6508-3: Metallic materials – Rockwell hardness test – Part 3: Calibration of reference blocks (scales A,B,C,D,E,F,G,H,K,N,T)

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