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AUTOMATION OF THE ROCKWELL STANDARD MEASURING MACHINE OF THE PTB

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Abstract: This paper describes an improved method to perform Rockwell hardness measurements according to the standard ISO 6508:2015 Part 3 in a more efficient way. Therein we use data evaluated in the preload phase to complete a running measurement cycle without any additional indentations. This makes Rockwell hardness measurements much more efficiently.

Keywords: Rockwell, automation, standardization

1. INTRODUCTION

A Rockwell hardness testing machine at PTB has been improved to implement a new measurement method. The proposed method allows an automated measurement and thus, accelerates the whole measuring process. The method estimates the hardness of a material from a measurement during the preload phase of the standardized measurement routine and enables to perform traceable hardness tests without additional input of the user or from previous indentation tests.

2. STATE OF THE ART

The Rockwell hardness is defined by the indentation depth of a deformation in a material caused by a test force. An increasing test force causes an increasing indentation depth. A hard material has a lower indentation depth than a soft material at the same loading force.
In order to realize the traceability of hardness measurements hardness test blocks are used. These blocks are calibrated by traceable hardness measurement devices at metrology institutes, and are used by customers to validate their instruments for the application.
In the standard-compliant calibration of a hardness test block with a Rockwell hardness test method, the sequence of the applied force values F (Fig. 1) are described in ISO 6508:2015 Part 3. In phase A the preload force F_0 is applied. In phase B, the complete preload force F_0 remains for a minimum duration time T_{pm}. The additional test force $\Delta F = (F_1 - F_0)$ is applied in phase C during the additional load application time T_{aa}. This phase is divided into two sections. The standard requires a phase of deceleration for the loading of force at (80…100) % of F_1. The duration of the total force T_{df} is shown in phase D. The additional test force ΔF is removed in the phases E and F and remains at F_0 during the final reading time T_{rf}. In phase G, all test forces are removed and the testing cycle ends.

Fig. 2 shows the same cycle, but here the depth is plotted as function of time for the different phases A to G. Phase A shows the first indentation depth, which begins at the surface of the sample h_{Sur} and ends in depth h_0. This indentation depth h_0 is measured in phase B and defines the reference depth after the duration time T_{pm}. Phase C shows the indentation depth during the actual indentation. Valid values for the velocity in phase C_2 are set by the ISO standard 6508-3.
In phase D, the maximum indentation depth h_2 is reached after the duration time T_{df}. In phase E, the indentation depth decreases to value h_1, because the material relaxes elastically. After the duration time T_{rf}, the remaining indentation depth h_1 is measured in phase F. The Rockwell hardness of the material is defined by the difference of the depth h_1 and the reference depth h_0. In phase G, the indentation depth is reduced to zero.
The operation parameters for any Rockwell hardness testing machine are the indentation velocities and the loading times. These parameters have to be adjusted for every type of material and its hardness to fulfill the requirements of the ISO standard. Especially the phase C is important for the whole measurement, because the result of a Rockwell hardness test depends on the selected parameters in this phase. Up to now these parameters have to be determined by a pre-measurement. Therefore, an additional indentation

is needed. This additional pre-measurement is very time consuming.

The requirements described in ISO 6508-3 must be met as accurate as possible, to get a low uncertainty and a better comparison among the tested materials.

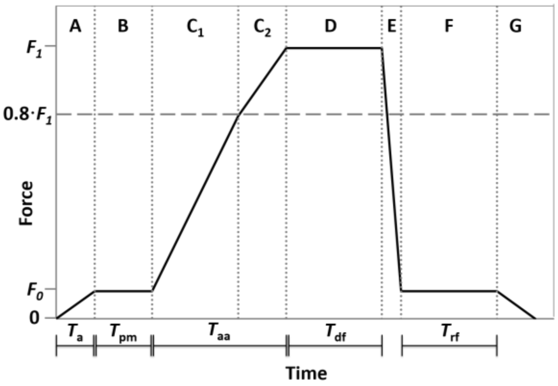

Fig. 1. Schematic time-force-diagram of the standardized Rockwell hardness test.

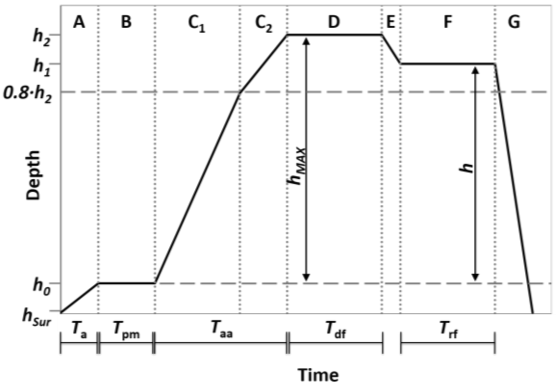

Fig. 2. Schematic time-depth diagram of a standardized Rockwell hardness test.

Fig. 1 and Fig. 2 are mainly different in phases E and F. In these phases in Fig. 1 the force is reduced to the preload test force F_0. In Fig. 2 the indenter remains at the indentation depth h_1, because the material of the sample relaxes by the elastic part of the deformation. The actual measured value to determine the Rockwell hardness value HR is calculated by the indentation depth difference $h = h_1 - h_0$.

$$HR = \mathrm{N} - \frac{h}{\mathrm{s}} \tag{1}$$

where

$h = h_1 - h_0$ - indentation depth difference

s - scaling factor

N – upper scale limit

By generating the indentation (phases C and D) the curves in Fig. 1 und Fig. 2 are very similar. In these phases, a range of valid values for the velocity $v_{fis} = (15\ldots40)\ \mu\mathrm{m}\cdot\mathrm{s}^{-1}$ and the loading time $T_{aa} = (1...8)$ s in the time-indentation diagram is appointed through the standard ISO 6508:2015 Part 3. The challenge is, to reach the maximum indentation depth h_2 in compliance with the regime defined by the standard by loading the additional test force $\Delta F = F_1 - F_0$.

The PTB is interested in measurements, where this regime does not vary with different materials. This point can only be solved by knowing the resulting maximum indentation difference $h_{MAX} = h_2 - h_0$ before executing the Rockwell hardness test. Fig. 3 shows the dependency between the maximum indentation depth h_{MAX} and the hardness of the sample for a single Rockwell hardness test machine. The maximum indentation depths h_{MAX} for the soft and hard materials are different at the same total force. Thus, a soft material requires a higher indentation velocity then a harder material because of the deeper indentation and the requirements through the standard.

3. ASSUMPTIONS

In Fig. 3 the indentation curves (phases C and D) for two samples out of the same material but with different hardness are shown. They are loaded by the same additional test force. The upper curve (dashed line) shows the indentation depth of a soft material .

The solid line below shows the indentation depth of a hard material . For both curves the force is loaded in the same additional load application time $T_{aa\ Const}$. The indentation depth h_{MAX} is different for both materials. During this time the indentation depth and the force are assumed to be linear. With the assumption of a constant indentation velocity $v_{fis\ const}$ in the section (80…100) % of h_{MAX} for all materials different time intervals Δt_2 result for different hardness values. With the further assumption of a constant loading time $T_{aa\ Const}$ for all materials the time interval $\Delta t_1 = T_{aa\ Const} - \Delta t_2$ is defined for (0…80) % of h_{MAX}. These two values define the required parameter velocity v_{ia} to realize a measurement cycle compliant with the standard.

In the following an algorithm for the material depending indentation velocity v_{ia} will be developed following the rules of ISO 6508-3 and by using two assumptions.

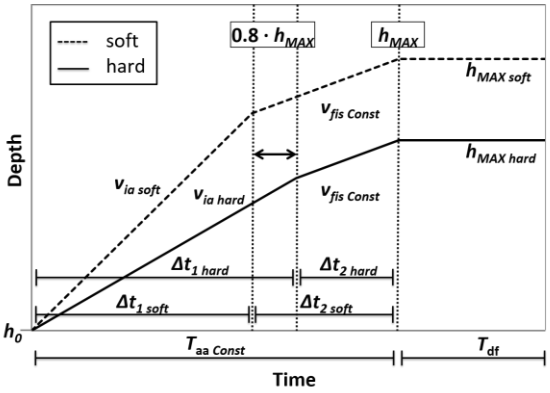

Fig. 3. Indentation depth as function of time during the phases C and D for a soft and a hard material.

Due to the different hardness values of the materials different indentation velocities v_{ia} are required by the same additional test force ΔF. To avoid complexity and to get a better comparability of the measurements, the following two assumptions were made:

- the additional test force $\Delta F = F_1 - F_0$ and the corresponding indentation depth are proportional during the additional load application time T_{aa}.
- the indentation velocity v_{fis} is constant for all materials in phase C_2

The observed deviations of the linearity between test force and indentation depth amounts to 1 % (alloyed steel). Because of the linearity assumption the transition in phase C_2 in the indentation-time-diagram is defined as $0.8 \cdot h_{MAX}$. Based on the definition above, the requirements of the additional load application time in ISO 6508-3 and together with the assumed constant velocity v_{fis} it is possible to evaluate an algorithm for the velocity v_{ia} in addition to the indentation depth difference h_{MAX}.

$$v_{ia} = \frac{(\beta \cdot h_{MAX})}{(T_{aa\ Const} - \Delta t_2)} \tag{2}$$

with

$$\beta = 1 - \frac{0.2 \cdot F_1}{F_1 - F_0} \tag{3}$$

4. EXECUTION

The proposed method can be applied during the preload sequence of a Rockwell test. A simple hardness test in the preload phase estimates the final hardness of the sample. This method allows to accelerate the whole Rockwell hardness test and makes it more independent from the user. The preload test force F_0 is loaded on the sample and causes a small indentation depth h_0. This indentation depth and Eq. 2 allow to predict an estimated hardness value HR_{EST} of the sample. Knowing the hardness HR_{EST} all necessary parameters for an ISO compliant Rockwell hardness test can be calculated.

The idea is to create a library of characteristically curves for every material, which is tested by Rockwell. The curves give information about the indentations depths in phases B and D for a material and its value of hardness.

To measure these curves, our system has been extended by a surface detection. This enables the measurement of the indentation depth h_0 in the preload phase. This system is explained in the following. Before the initial phase starts, the deceleration of the indenter caused by contacting the sample, is used for the detection of the sample's surface. Therefore, the velocity of the indenter is controlled by a laser interferometer and a timer. The surface is detected, if the velocity falls below a threshold value (here: 5 mm·s^{-1}).

From this point on the process is controlled by the measured force after contact with the sample's surface. The position of the detected surface is used as a reference depth h_{Sur} for the measurement of the indentation depth h_0 in the preload phase. The depth h_0 is measured after the duration time T_{pm}.

In the following, we have measured the indentation depths h_0 and h_{MAX} for a complete Rockwell scale by using various hardness testing blocks consisting of the same material but with different hardnesses. Fig. 4 shows the indentation depths (h_0 - h_{sur}) for alloyed steel according to the Rockwell scale A. With the inverse of the function for indentation depth h_0 getting from the preliminary measurement and the hardness values of a standard measurement, every indentation depth h_0 can be directly assigned to a hardness value HR_{EST}.

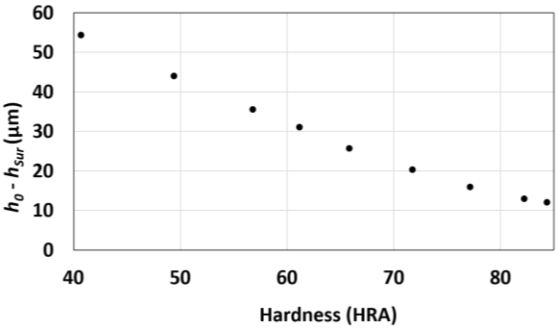

Fig. 4. Estimated hardness values of different hardness test blocks determined from the preload phase (alloyed steel, spherical-conical diamond indenter).

Fig. 5 shows the measured maximum indentation depth h_{MAX} in dependence of hardness for alloyed steel and for measurements according to Rockwell scale A. With the knowledge of this dependence every estimated hardness HR_{EST} can be assigned a maximum indentation h_{MAX}, which defines the velocity v_{ia}.

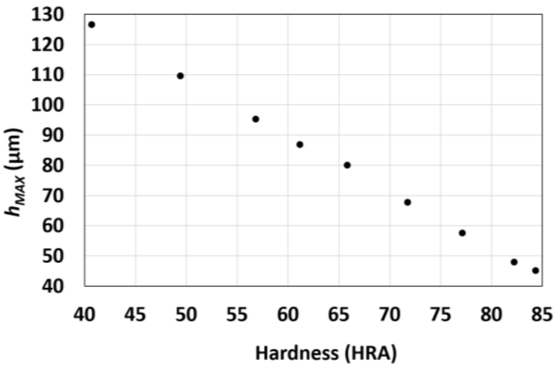

Fig. 5. Typical linear curve for the maximum indentation depth h_{MAX} versus hardness derived from Rockwell A measurements (alloyed steel, spherical-conical diamond indenter).

These measurements of indentation depths have to repeated for any material, which is tested by Rockwell, because the form of every curve depends on the modulus of elasticity. The absolute values of the ordinate values in Fig. 4 and Fig. 5 strongly depend on the deformation of the Rockwell testing machine itself. Therefore, these curves have to be determined for each machine.

Besides the indentation depths, a further parameter is derived from the estimated hardness. A correction factor for the velocity v_{fis} is determined [1]. This correction factor guaranties the required constant velocity, which is needed in Eq. 2.

5. RESULTS

The standard deviation of the preliminary, estimated hardness HR_{EST} in the initial phase is much higher (1.6 %) than during a standard measurement (0.8 %). All preliminary measurements show a systematic deviation of +1.5 scale units (s. Fig. 6). The deviations are attributed to the influence of the sample-roughness and to the deformations of the measurement machine caused by the test forces.

Despite the systematic deviations the method guarantees a Rockwell hardness test according to the ISO standard procedure without an additional indentation and without any previous knowledge. Only the material of the hardness test block and the chosen Rockwell scale are necessary as an input to the process.

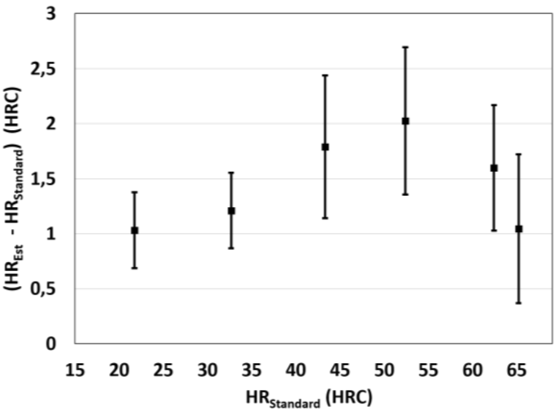

Fig. 6. Measured deviation of the preliminary hardness HR_{EST} determined in the preload phase from the known hardness.

6. SUMMARY

PTB's Rockwell hardness test machine is improved and automated to implement a new method that uses a preliminary hardness measurement in the preload phase of a Rockwell hardness test. The estimated hardness predicts the indentation depths for the further phases of the measurement cycle. Although a small systematic deviation of the preliminary hardness is observed, the method guarantees a near 100 % compliance to the ISO 6508:2015 Part 3.

7. REFERENCES

[1] D. Grziwotz, "Automation of a standard measuring device for Rockwell hardness tests", TU Braunschweig, Masterthesis, 2016.