Reproducibility of hardening depth determination CHD – NHD

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The case depth determination on surfaces hardened components always offers a basis for discussion with regard to the test results found. The accuracy of the test is generally accepted as correct without knowing which factors influence the result. Considering the importance of the case depth determination CHD and NHD for the processes to be monitored, the uncertainty of the test result of the determined case depth is a non-negligible size. The resulting open question "What is the uncertainty of the test result of the case depth determination?", is not answered in the literature.

Based on this question, interlaboratory tests were conducted (with samples). It was to be expected with what determines uncertainties when examining the case depth and about any deviations in different laboratories with each other.

1. Introduction

The determination of the case hardness depth is of elementary importance for the quality determination of the heat treatment result of the application case hardening and nitriding. With hardly any other test of a heat treatment result, there are so many inconsistencies and discussions about the test results, as with the case hardening depth determination.

The influence variables on the test result are often not taken into account when examining the test result. By interlaboratory tests, possible scatterings on real samples should be determined. The correctness of the test results of the participants was not considered. The aim of the interlaboratory test was to show only scatterings as they occur in daily measurements in different laboratories. A detailed analysis of the influence variables on the test result was also carried out.

2. Standardization

To determine the case hardness, the following standards must be observed during the test:

• DIN 50190 T. 3 [1]	Hardening depth of heat-treated parts; Determination of nitriding depth
• DIN EN ISO 2639 [2]	Steels — Determination and verification of the depth of carburized and hardened cases
• DIN EN ISO 4885 [3]	Ferrous Products. Heat Treatments. Vocabulary
• DIN EN ISO 6507 T. 1-3 [4]	Metallic materials –Vickers hardness test
• DIN EN ISO 15787 [5]	Technical product documentation – Heat-treated ferrous parts – Presentation and indications

2.1. DIN 50190 Part 3 - Determination of nitriding hardness depth - NHD [1]

DIN 50190 Part 3, regulates the determination of the nitriding hardness depth and is determined as follows:

- only national, no international / pan-European standardization exists
- standard test load HV 0.5, other test loads permitted by agreement
- HL (limit hardness determined from the core hardness = Is core hardness + 50 HV, (rounded to 10 HV each)
- core hardness determined in approximet 3x NHD
- one hardness series, in case ofarbitration two hardness series
- if the nitriding hardness depth is determined at several points, the arithmetic mean value is required, if the difference between the individual nitriding hardness depths does not exceed 10% of the maximum value.

2.2. DIN EN ISO 2639 - Steels — Determination and verification of the depth of carburized and hardened cases [2]

DIN EN ISO 2639 regulates the determination of the application hardening hardness depth and is determined as follows:

- international standardization
- standard test load HV 1, other test loads permitted by agreement,
- in case of arbitration, the standardized procedure according this standard
- limit hardness 550 HV1, if the core hardness of the finished part is less than 450 HV1 in 3x CHD, if it is higher, the limit hardness can be increased in increments of 25HV, otherwise an agreement is to be made.
- mean value of 2 hardness gradients, permissible deviation ≤0.1mm, from the mean value
- CHD tested after hardening before possible tempering. DIN EN ISO 2639 is clearly that the CHD has to measured before tempering. [2] [3]

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2.3. DIN EN ISO 6507 Part 2 [4]

In this part of the standard, the permissible calibration deviation of the hardness testing machine is determined which is according to the test load:

Test procedure	**Test load**	**Permissible limit deviation**	**Repeatability**
for nitriding hardness depth NHD	HV 0,5	200-300 HV = ± 5% from Hardness value 400-500 HV = ± 6% from Hardness value by 380 HV = ± 19 HV	24 HV 32-40 HV 31 HV
for case hardening depth CHD	HV 1	200-400 HV = ± 4% from Hardness value 400-700 HV = ± 5% from Hardness value 800-1000 HV = ± 6% from Hardness value by 550 HV = ± 27,5HV	44 HV
Test on a CRM Material according to part 3 of the standard, not on the component.			

3. Influences on the test result

There are a number of influencing variables which can influence the test results of the case hardening depth measurement. These are essentially:

- permissible calibration deviation of the hardness tester
- problems with illumination of the hardness testing machine
- deviations from the travel of the cross table, permissible error in the hardness test ± 0.025mm, DIN EN ISO 2639
- incorrect starting point of the hardness,
- blurred edge in the microscope image
- vibrations during the measurement of the hardness
- scattering from the heat treatment in the component or in the heat treatment unit
- dispersions within the component, from the machining and the material influences
- incorrect metallographic sample preparation

often a combination of different errors is present.

3.1. Calibration deviation of the hardness testing machine

If the permissible calibration deviation of the hardness testing machine according to DIN EN ISO 6507 T.2 is entered into the hardness curves, permissible deviations from the hardness testing machine are based on the NHD - CHD mean value curve of:

- NHD 0,23 mm = Scattering 0,07 mm = 30 % of NHD, Figure 1
- CHD 0,79 mm = Scattering 0,19 mm = 24 % of CHD, Figure 2

only from the permissible calibration deviations of the hardness testing machine.

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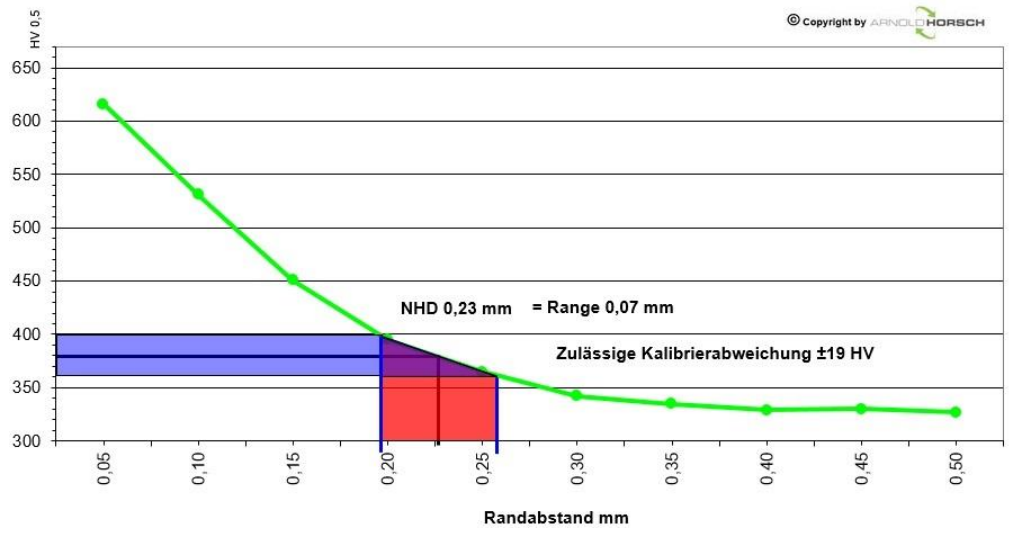

Figure 1

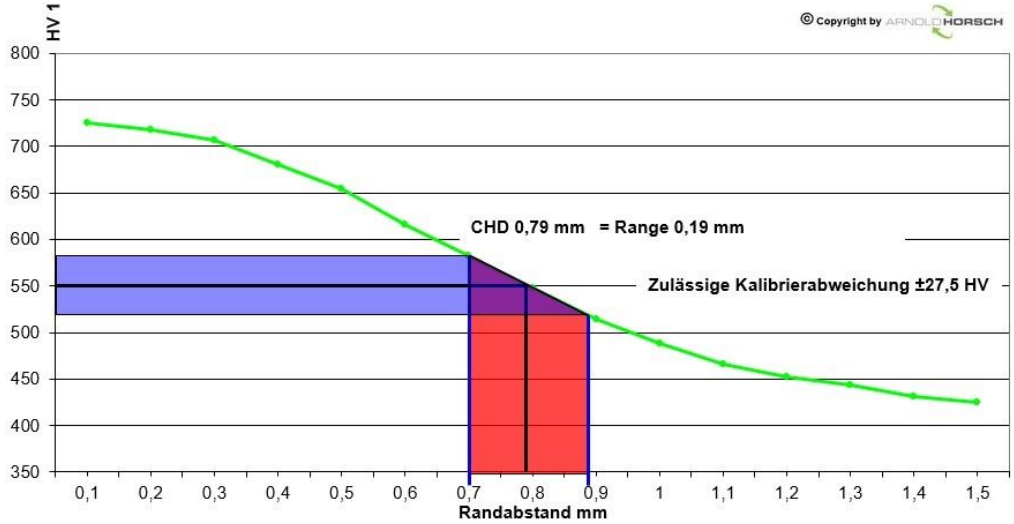

Figure 2

3.2. Illumination of the hardness testing machine

If the illumination on a hardness tester is not adjusted correctly, e.g. after a bulb change, there can be significant deviations in the test result for hardness testing machines operating with image analysis systems.

Figure 3 shows the automatic evaluation on a CRM plate. The same hardness indentations were measured once with optimally centered illumination and once with decentered illumination. The red line shows the hardness values, which deviate by 20HV in some cases, from the optically illuminated hardness values of the blue line.

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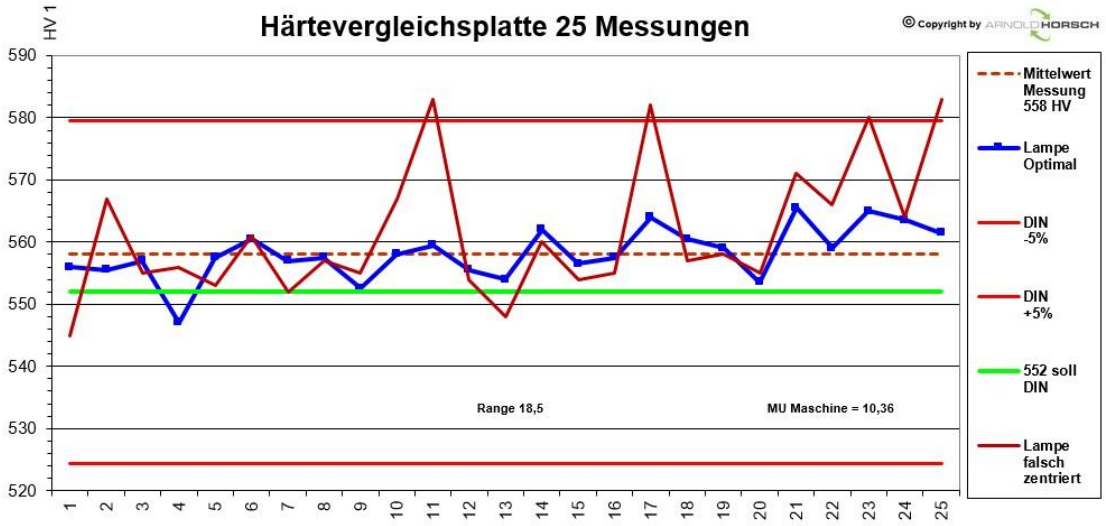

Figure 3

In the case of optimal illumination- as in this example - a hardness tester with very small scattering and deviations from the setpoint can be tested if load, etc. are correct.

3.3. Material influence

It is often underestimated, which influence of the material can affect the test results. A strong segregation, as shown in Figure 4, is a problem. Depending on the location at which the case depth is determined in a machined component, more or less severe scattering results in the result of the case hardening depth measurement because of the differences in concentration in the alloying elements. Note, material is not perfect.

It is precisely in the case of nitriding that such differences in concentration can be clearly reflected in the result, since the alloying elements are primarily responsible for the hardening.

Figure 4 [6]

Example of segregation,
1.7225 +AC, 42CRMo4 +AC, Longitudinal cross section edge-core-edge

4. Interlaboratory test

4.1. Participants

Three labs participated in the interlaboratory test. All laboratories test hardness curves for daily hardness determination in daily practice.

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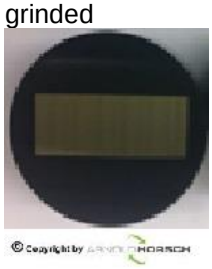
4.2. Samples

Two sample materials were used to prepare the hardness curves.

Sample	Material	Heat treatment	Dimension	Surface hardness
NHD	1.7225+ QT *42CrMo4 + QT*	Gas nitrided	Round Ø 70mm , grinded  Figure 5	615-668 HV 10
CHD	1.7131 + AC *16MnCr5 + AC*	Case hardened to 0,7 - 0,9 mm to 1,3 – 1,5 mm	Bar 40x15x1000 mm grinded  Figure 6	58-60 HRC

4.3. Sample preparation

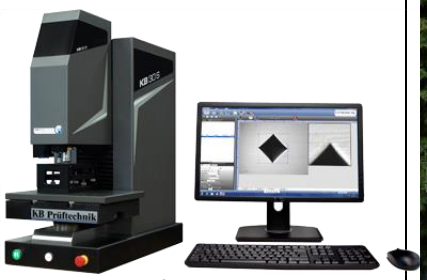
All samples were prepared as follows:

- cutting with a boron nitride cutting wheel on a low-speed diamond saw
- heat mounted at 180 ° C, in epoxy resin with mineral filler
- grinding on SiC paper 180-1200 grain
- polishing with diamond suspension 6µm on hard silk cloth, 3µm on NAP cloth
- fine polishing with a basic oxide polishing suspension (pH ~ 9.8, SiO_2) 0.05µm, on a chem cloth

The sample preparation was done by the author and not by the laboratories, this made sure that there is no influence from the preparation tot he result

4.4. Perform the measurements

Three fully automatic hardness testing machines in three different laboratories carried out a measurement of 5 hardness sequences on each sample - without new preparation. All measurements were therefore carried out with the same sample preparation.
All laboratories have carried out the measurements on machines which are in daily use. The laboratories themselves were responsible for the accuracy of the measurement. The samples were sent twice to repeat the measurements at various times.

Used hardness tester		
 Figure 7	 Figure 8	 Figure 9
DURASCAN 70 Emcotest	KB 30 KB Prüftechnik	FM300+PRECIDUR FUTURE TECH

4.5. Test results

4.5.1. Nitrided sample

On the nitrided sample the core hardness with 330HV was given to the participants. Hardening measurements were carried out at different positions on both parts. The participants were able to determine the test position themselves.

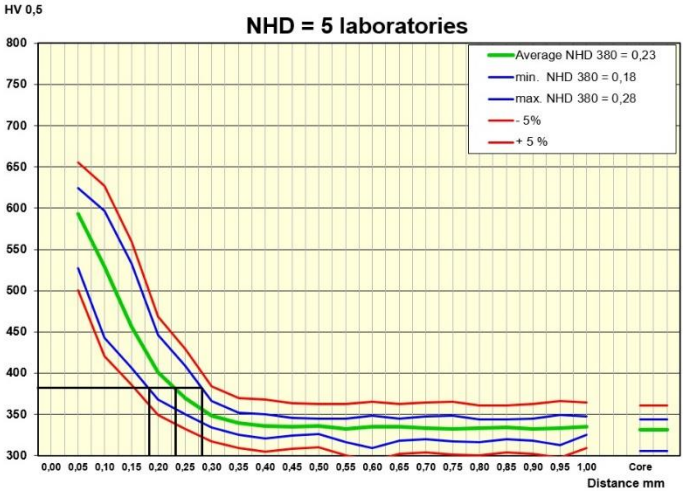


Figure 10

- Green curve Average value of all edge hardening depth determinations
- Blue curve scattering from all measurements
- Red curve permissible calibration deviation of the hardness testing machines
- NHD = 0,23mm, scattering 0,1mm ≈ 40%

4.5.2. Case hardened samples

On the case hardened sample the participants were able to determine the measuring points at which they performed the hardness measurements on the longitudinal side.

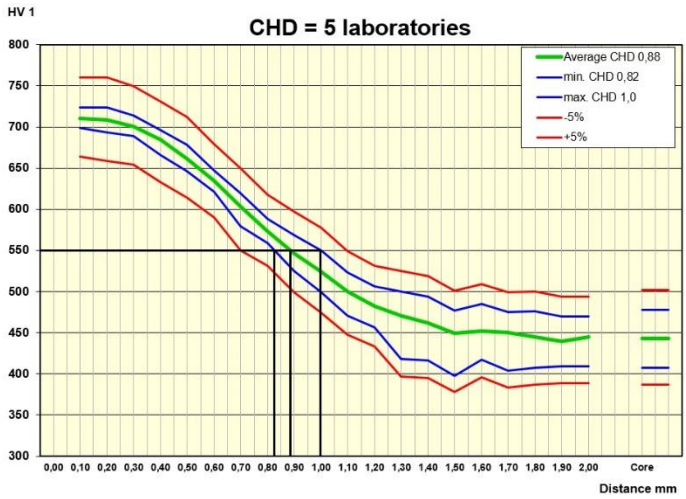


Figure 11

- Green curve Average value of all edge hardening depth determinations
- Blue curve scattering from all measurements
- Red curve permissible calibration deviation of the hardness testing machines
- CHD = 0,88mm, scattering 0,22mm ≈ 25%

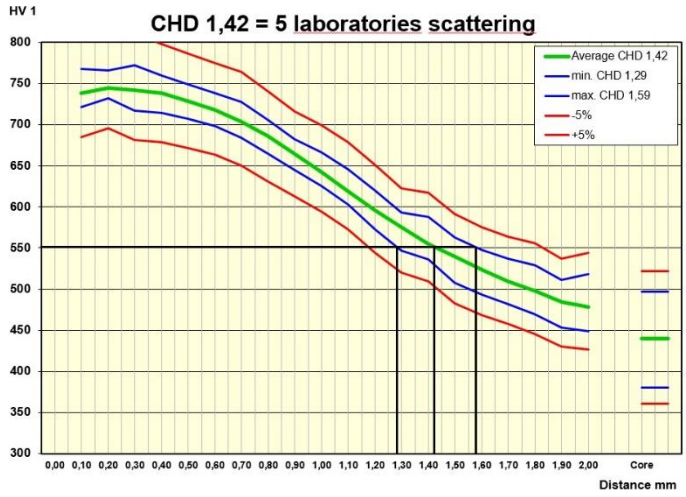


Figure 12

- Green curve Average value of all edge hardening depth determinations
- Blue curve scattering from all measurements
- Red curve permissible calibration deviation of the hardness testing machines
- CHD = 1,42mm, scattering 0,30mm ≈ 21%

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5. Evaluation

5.1. Influences on the test result

As shown in chapter 3, the influence on the test result of the case hardness depth determination from the permissible deviations of the test systems can be significant. The permissible total error on the tested samples is:

- NHD measurement,
  here, the permissible error varies depending on the core hardness. It can be 0.07 mm on the showed sample plus ± 0.025 mm from the permissible deviation of the cross table (not standardized in DIN 50190 T.3). Permissible total error from the test system 0.12 mm, at an
  NHD of 0.23 mm ≈ 50%.
- CHD measurement
  from the limit deviation of the hardness testing machine, in the example shown 0,19 mm plus ± 0,025 mm from the permissible deviation of the cross table. Permissible total error from the test system 0,24 mm, with a
  CHD of 0.88 mm ≈ 30%.

5.2. Measured samples

The samples tested in the interlaboratory test are better than the permissible error of the test machines. However, it is clear that the scatteringof all laboratories together can be considerable.

Procedure	Average	Tested scattring		Figure
NHD	0,23 mm	0,1mm	≈ 40%	10
CHD	0,88 / 1,42mm	0,22 / 0,30 mm	≈ 25 / ≈ 21%	11+12

6. Conclusion

The scattering of the case hardening depth measurement of different laboratories can be considerable. The error can be up to ≈ 40% of the test result. Causes can be the calibration deviation of the hardness testing machine, the influence of the sample material as well as the sample preparation and many other influences.

On the basis of the test results it was shown well that many discussions on the test results are probably not related to the heat treatment but are often discussions about the scattering of the test equipment and sample materials.

In the event of a dispute, a detailed examination of the test system shall be carried out. In case of different results, an arbitration measurement in an other laboratory is not always the solution here, especially if its deviation is not known.

7. Outlook

The next step is to increase the number of laboratories and the number of samples with different case hardening depths for an extended interlaboratory test.

In addition, the influence of sample preparation by the test laboratories is included. The test laboratories will prepare the samples themselves and then evaluate them.

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Literature

[1] DIN 50150 Teil 3
[2] DIN EN ISO 2639
[3] DIN EN ISO 4885
[4] DIN EN ISO 6507 Teil 1-3
[5] DIN EN ISO 15787
[6] http://metallograph.de/

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