Martens Hardness - More Than Just Hardness Testing ...

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Abstract:
Exemplary results of the instrumented indentation test within the macro region are presented to provide an insight into the potential of the Martens hardness test method and to deliver new knowledge. Measurements on reference test blocks are carried out using a Zwick hardness testing machine, which is equipped with digital measurement and control technology. Representative results show, for instance, the influences of test force, as is well-known from Vickers hardness, and of test parameters on the result gained. An overview describes the manifold uses of the hardness measurement head of Zwick, in R & D and in industrial applications.

1. Introduction

A variety of classical hardness test methods exist to determine hardness of materials. Fundamentally, they consist of the resistance of a solid material against the penetration of another harder material. In the classical understanding, the hardness of materials often characterises only the permanent plastic deformation of indentation work, and the result gained, describes a “single-point” or differential measurement. A still young standard breaks new ground in hardness testing and offers a potential unknown so far. As we are aware, very little data for Martens or Universal hardness within the macro region is available in literature [4 to 7].

2. Fundamental Principles

The instrumented indentation test [1], for determination of hardness and material parameters, incorporates a method recording and evaluating the loading and unloading cycle. Therefore, a full set of data, including force, depth and time, is recorded with a qualified rate. The test force-indentation depth curve is used to determine the hardness under load, thus, including the elastic part of indentation work, and, further, it derives additional material characteristics. The curve allows the calculation of elastic and plastic indentation work and additionally defined hardness values. Using a force- or indentation depth controlled test cycle, delivers information as to the creep or the relaxation of materials. An indentation and elastic resilience modulus can be calculated using the slope of the tangent at the test force of the unloading curve. All of the possibilities are described in detail in the literature [2, 3].

3. About The Measurement Technology Used

Of course, to industrially introduce a new test method, the availability of a reliable and customer friendly technology is absolutely necessary. Based on the experience and knowledge, gained through the engineering of materials testing machines, new hardness testing machines are designed firstly based on digital measurement and control technology and secondly in modular principle. A Zwick hardness testing machine therefore, consists of a materials testing machine, a hardness testing unit and a testXpert® software unit. One hardness testing unit covers all the hardness test methods based on an indentation depth measurement and, further, if supplied with an additional optical unit, also those with optical evaluation of permanent indentation. Figure 1 illustrates such a hardness testing machine. The schematic construction of the hardness measurement head of Zwick is sketched in figure 2. Two measurement systems, both with high resolution, one for force and one for indentation depth, the indenter and a sensor foot are integrated in a shell. To capture also only slight deviations in material characteristics, a machine with both high differentiation and reproducibility regarding e.g. the test parameters is absolutely necessary. With the measurement head of Zwick, covering test forces up to 2500 N, a Martens hardness test is simply carried out as is demonstrated in figure 3 by steps 1 to 6. The head is lowered until the sensor foot, and later, the indenter contacts the specimen surface (step 3), then loading (step 4) and unloading (step 5) is carried out, and the head is shifted back to the start position (step 6). The usage of a sensor foot, thus referencing the indentation depth on the specimen surface, allows an optimal test cycle procedure, which is absolutely necessary for automation, if required. It also minimises measuring errors in the indentation depth measurement due to the direct measurement principle.

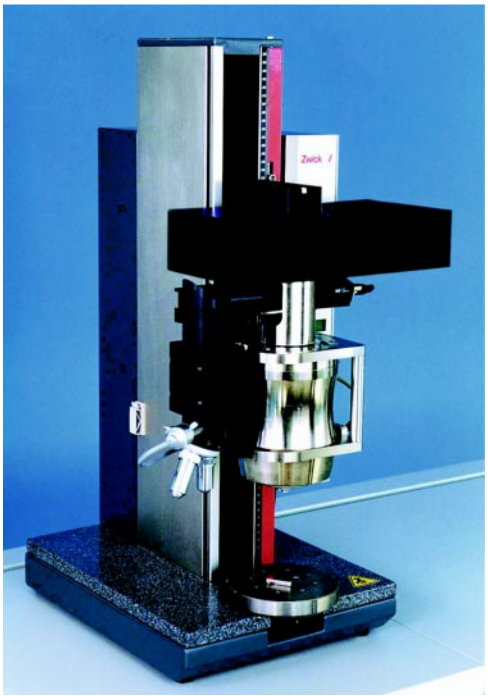


Figure 1: ZHU2.5/Z2.5 Zwick universal hardness testing machine.

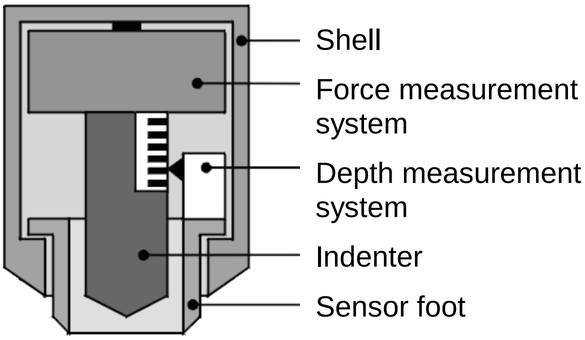


Figure 2: Schematic construction of hardness measurement head of Zwick.

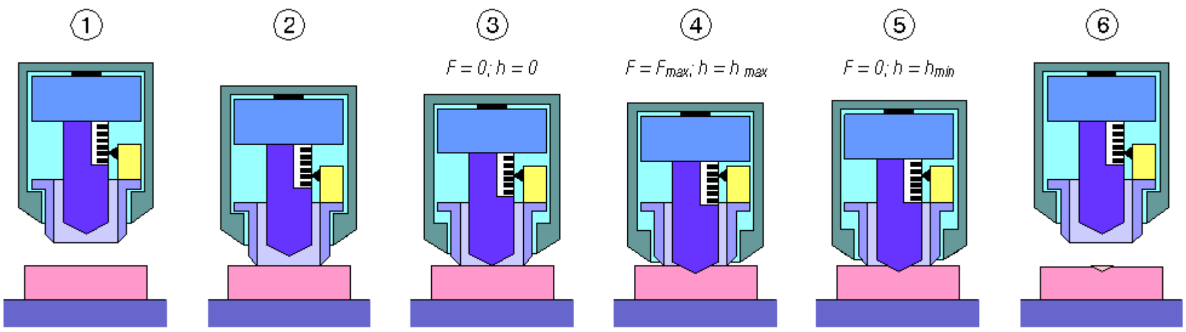


Figure 3: Schematic illustration of test sequence of hardness measurement head of Zwick during the loading and unloading cycle within a Martens hardness test.

4. Application and Use Of Hardness Measurement Head Of Zwick

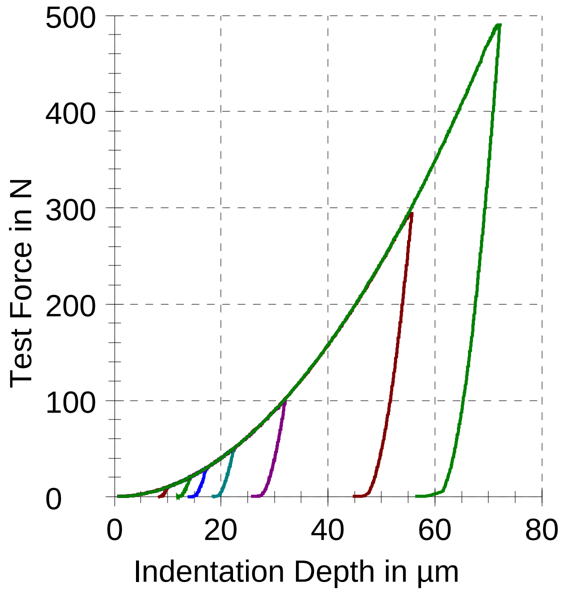
The hardness measurement head of Zwick is used in R & D as well as in industrial applications. The materials tested cover ferrous and non-ferrous metals, plastics, wood and specials. Some of the main focus of applications are the correlation to other hardness scales, estimations of the layer thickness of hardened materials by depth measurement and the various analysis of the loading and unloading curve. Exemplary for the latter is the display of (local) hardness during the indentation. Of course, classical Rockwell tests or ball indentation method are also tested with hardness measurement head.

Mainly the recording of the test force-indentation curve and its evaluation possibility combined with the flexible parametrisation of test procedures, are the points of our customer's main concerns. These may be amplified by the advantages of testXpert®, a universal software designed by Zwick.

5. Representative Results

Figures 4 and 5 show representative results gained using reference test blocks with certified values of 384 HV10 and 702 HV5, and an estimated measurement uncertainties of 1% of the hardness value. Each figure consists of two diagrams. The left one shows the loading and unloading curve and the right one shows the Martens hardness, both as a function of the indentation depth. The data represents the mean value of 10 and 6 measurements, respectively. The test force is primarily changed as parameter. A further variation includes the effect of loading cycle and of full load dwell time.

The data of figure 4 illustrates the test results on the reference test block with a value of 384 HV10, carried out with periods of loading of approximately 10 seconds, and dwell times of 2 seconds and loads from 9,8 N to 490,3 N.



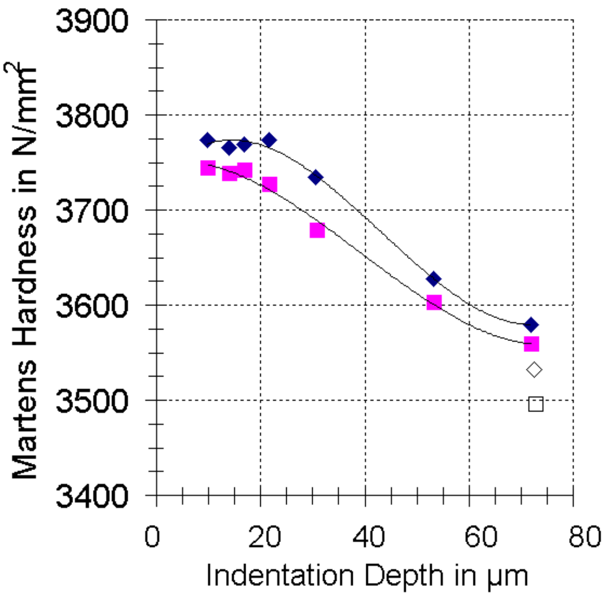


Figure 4: Results of Martens hardness test on a reference test block, with a certified value of 384 HV10, in terms of loading and unloading curves and Martens hardness, both as a function of the indentation depth; Load variation: 9,8 N to 490,3 N; Loading time: 10s; full load dwell time: 2s. The evaluation at the beginning and end of dwell time is indicated by the rhombuses and squares.

The loading and unloading curves on the left indicate an excellent congruent behaviour, which is only possible, if test parameters are highly reproduced. The verification in terms of a root force versus indentation depth results in a straight line. To point up the influence of the time of evaluation, shown in the right diagram, the rhombuses indicate the Martens hardness at the beginning and the squares those at the end of the dwell period. The difference is somewhat in the order of less than 1%. As well-know and expected; the quantitative hardness value is load-dependent. On the reference test block used, higher values are observed at smaller loads and vice versa. The results agree well with each other within loads up to HV5. Increasing the load reduces the Martens hardness up to a certain limit. The absolute difference in hardness from the smallest to the highest load is in the order of approx. 5%. The opened symbols show the combined effect of an increased loading period and a full load dwell time of 12s, which, at the highest load, lowers the hardness value by approximately 1,5%.
Figure 5 illustrates the results of the test on the reference test block with the certified value of 702 HV5. The data contains a loading period of 25s (and 12s) and a dwell time of 12s. The loads are varied from 49,03 N to 2000 N.

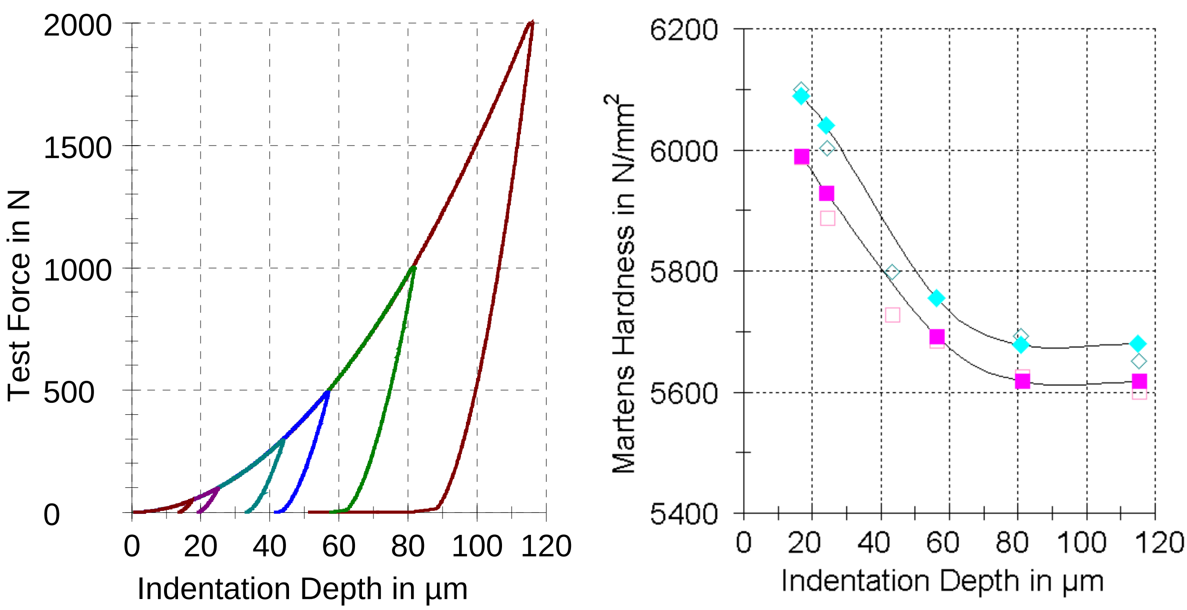


Figure 5: Results of Martens hardness test on a reference test block, with a certified value of 702 HV5, in terms of loading and unloading curves and Martens hardness, both as a function of the indentation depth; Load variation: 49,03 N to 2000 N; Loading time: 25s (12s); full load dwell time: 12s. The evaluation at the beginning and end of dwell time is indicated by the filled rhombuses and squares.

As already seen in the previous figure, the loading and unloading curves on the left of figure 5 again show, for the same reasons as already explained, an excellent congruent behaviour. Also a straight line is achieved by the verification in terms of a root force versus indentation depth diagram. The opened symbols of the right diagram refer to the shorter, the filled ones to the longer test cycle. Again, the evaluation of Martens hardness is considered at the beginning (filled rhombuses) and at the end of the full load dwell time (filled squares), the difference is somewhat in the order of less than 1%.
Further, on the reference test block used within the loads covered by the tests, the load-dependent hardness value varies from the smallest to the highest load by approximately 6%.

Due to the choice of the long dwell time, an influence of the shortened loading period on the result gained is not explicitly observed.

6. Summary and Conclusion

The results clearly demonstrate the influences of test force, of loading period and of full load dwell time on the calculated Martens hardness value. Within the test conditions and reference test blocks used, a load- and dwell time-dependence of Martens hardness is observed; the load-dependence of hardness is well-known from Vickers method. While the first quantifies a deviation of up to 6%, the second results in one of less than 2%.
Thus, reliable measurements require a hardness testing machine with high reproducibility and differentiation, which allows to recognise and to record even small differences in material characteristics, as may exist in manufacture and processing of many products.
In comparison with classical hardness testing methods, instrumented indentation test offers advantages. The method is independent of material, free of testers influence, suitable for automation and capable of delivering additional information in mechanical characteristics.

7. References

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