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TESTING HARDNESS OF METAL ITEMS WITH MET-UD COMBINED PORTABLE HARDNESS TESTER

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Abstract — A new approach to portable hardness testers has been developed and introduced. It makes it possible to inspect hardness by one and the same hardness tester applying both, the ultrasonic contact impedance method and rebound method. Hardness tester wide possibilities which allow to inspect hardness of metal and alloy products with all standardized scales (Rockwell, Brinell, Vickers and Shore) have been demonstrated. The possibility to improve the precision of portable hardness testers of this type by calibrating them for each of the above listed scales with hardness reference blocks only without any conversion tables has been shown.
Experiments and real measurements conducted on cold rolls showed that change in hardness of a hardened layer in depth and surface stresses influence can be disclosed in the process of hardness measurement by portable combined hardness tester by two different methods.

Keywords: combined portable hardness tester, ultrasonic contact impedance method, rebound method

1. INTRODUCTION

Portable measuring instruments play their important role in rationalization of metal products hardness inspection. Hardness testers of this type possess a number of indisputable advantages, such as productivity and universal character, they are also suitable for express hardness measurements, they are portable and do not produce any indentation on the tested surface. They make it possible to test hardness of metal products with various weight and shape of any configuration in hard reach places in various spatial position. In many industrially developed countries, there has been developed and used a big variety of portable hardness testers, both, of quasi-static principle of tested surface loading and impact principle. The present paper demonstrates the possibility to apply a combined hardness tester of MET-UD type, combining these two principles.

2. DESIGN AND SPECIFICS OF COMBINED HARDNESS TESTER

MET UD combined hardness tester is a small-sized instrument which consists of one universal character electronic module and two plug-in transducers for ultrasonic and dynamic operation.

When hardness is measured by quasi-static method ultrasonic contact impedance (UCI) [1] method is used. Ultrasonic hardness tester contains a steel rod with Vickers diamond pyramid at the tip, which is an acoustic vibrator of the in-built automatic ultrasonic frequency generator. When pyramid is forced on to a tested article, the system frequency is changed, which depends on the hardness of the material. The penetration force is equal to 9.8 H and is created by a calibrated spring. Resonator relative frequency change is transformed by electronic module into the selected scale hardness number and is then shown on the display.

When hardness is measured by the impact method, standardized in USA (ASTM A 956-00 "Standard Test Method for Leeb Hardness testing of Steel Products") rebound method [2] is used. Dynamic transducer contains a hammer with a hard-alloy ball at the tip, which impacts a specimen surface with a certain velocity under the spring force. The signal from the transducer is sent to the electronic modulus inlet where it is transformed into the selected scale hardness number and is then shown on the display.

Combined hardness tester combines all positive features of both methods and, depending on mass, configuration, structure, degree of mechanical and heat treatment of the measured product, either ultrasonic or dynamic transducer shall be connected to the electronic module and after that the hardness tester shall implement the relevant to the transducer method of measurement [3,4].

One of the MET-UD combined hardness tester specific features which allows to improve measurements precision is individual calibration of hardness scales, i.e. every hardness scale, Rockwell (HRC), Brinell (HB), Vickers (HV) and Shore (HSD), is calibrated with primary hardness reference blocks only without using any conversion tables.
The results of the research show that it is practically impossible to establish a unified conversion dependence which will be suitable for all metallic materials even if measurements are carried out with very high precision. It is explained by the fact the indentation depth, obtained on a tested material

surface, is in a complex dependence on stress and deformation state of the tested material. Consequently, usage of any data for hardness numbers conversion from one scale into another can provide for different reliability degree depending on hardness measurement methods and conditions under which the test to establish the ratio between hardness numbers under a certain correlation between stress and deformation for the material in question was conducted. That is why all current Russian standards do not contain any recommendations concerning hardness numbers conversion from one scale into another. On the contrary, it is indicated in them that “one should avoid such conversions except separate cases when owing to comparative tests, there is a reliable basis for conversion”. Comparative study of different conversion tables [5] shows that in every case there is some systematic influence of some unknown factors on the hardness numbers under comparison. It points out to the existence of some systematic errors when tables are prepared by different authors. Hence, the majority of the known conversion tables do not have any advantages in comparison with the other, and it is impossible to unite them into one integrated conversion table. That is why any conclusions and recommendation concerning the possibility of hardness numbers conversion from one scale into another are permissible only for approximate metal properties estimation, but not for exact recalculations.

In connection with the above said, in MET-UD hardness tester, there is an independent scale calibration both, for dynamic and ultrasonic transducers. The main hardness scales are calibrated for tool and structural steel. For other metals and alloys, there are also other additional scales which are calibrated with test specimens made of investigated materials. Independent calibration makes it possible to exclude an error of the hardness scales table conversion from one into another, and a scale transfer [6] from national primary standard machines through the reference hardness blocks to portable hardness tester directly will allow to reduce a transfer error to a minimum, reducing the traceability stages from national standard to industrial measuring instruments (Fig. 1).

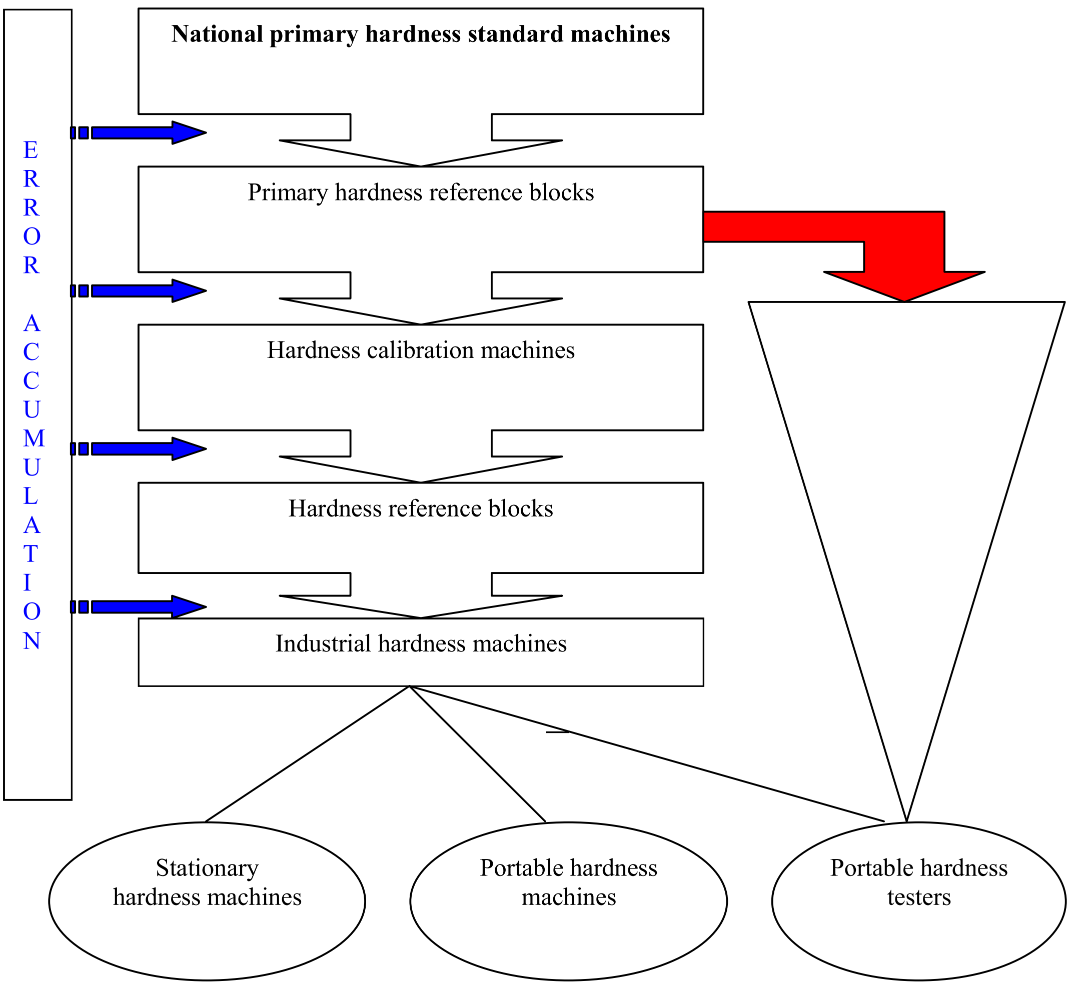

Fig.1.

3. EXPERIMENTAL RESULTS AND ANALYSIS

Two different methods combined in one hardness tester allow fast and exact hardness measurement, and make it possible to estimate both, the hardness change in depth and surface stress influence. To confirm these possibilities, some experiments were conducted, in the process of which surface metal hardening was simulated by specimens made of two flat parallel metallic plates (the upper and the lower) with an insignificant difference between hardness values on the surface. These plates were put tight one to the other and fixed on a massive rigid horizontal structure. Schematically, the experiment is shown Fig.2.

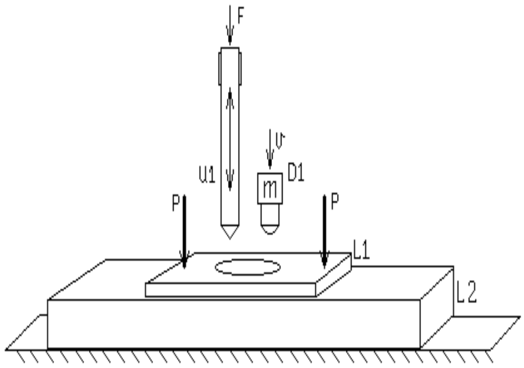

Fig.2

Symbols: U1 is quasi-static loading transducer (ultrasonic), D1 is dynamic transducer (dynamic), L1 is the thickness of the upper plate (surface), L2 is the thickness of the massive lower plate (base), P is effort pressing the upper plate to the lower one.

Before the experiment, the hardness of all plates was determined on a Vickers hardness calibration machine. 8 sets of upper plates were prepared. There were 3 plates of similar thickness in every set. The thickness varied from 2 to 8 mm with one mm step. The hardness of plates in one set was 250±50 HV30, 450±50 HV30, 800±50 HV30. The hardness of 4 lower plates of 20 mm thickness was 287 HV30, 420 HV30, 635 HV30, 821 HV30. In the course of the experiment, the dependence of normalized difference in the readings of hardness of ultrasonic and dynamic transducers on the hardened layer characteristics (difference in hardness number of the upper and the lower plate, divided by the upper plate thickness) was disclosed. All simulation experiments were conducted at similar surface treatment conditions and similar effort of pressing the upper plate to the lower one. The results of the experiment are shown the Fig.3.

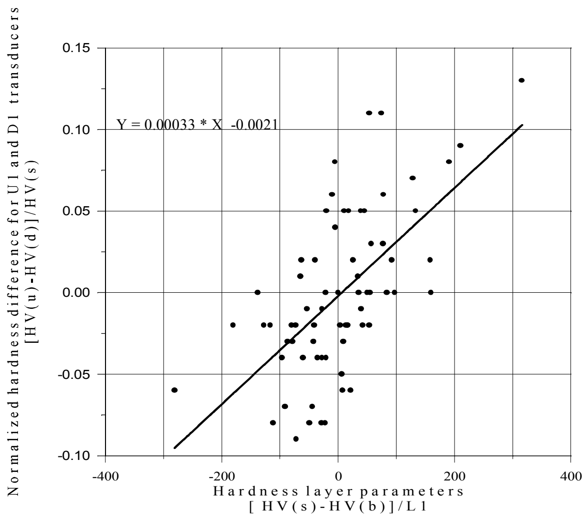

Fig.3.

Here HV(u) is the upper plate hardness on Vickers scale measured by the combined hardness tester by ultrasonic contact impedance method; HV(d) is the upper plate hardness on Vickers scale measured by the combined hardness tester by rebound method; HV(s) is the upper plate hardness on Vickers scale measured by hardness calibration machine; HV(b) is the lower plate hardness on Vickers scale measured by hardness calibration machine.

The dependence of the normalized difference in the readings of hardness of ultrasonic and dynamic transducers on the hardened layer characteristics for MET-UD combined hardness tester is:

$$[HV(u)-HV(d)]/HV(s)=0.00033\times[HV(s)-HV(b)]/L1 \quad (1)$$

For metal products with rough surface not exceeding 2,5 Ra, the difference between hardness values measured by ultrasonic transducer is different from the true hardness by less than 2%. That is why it is possible to use HV(u) as an estimation of HV(s). Thus, within the framework of the described above model, one can obtain a product hardness estimation at L1 depth.

With the help of MET-UD hardness tester, measurements on real products such as cold rolls produced at Uralmasshzavod Machinery Works. Hardness along the hardened layer depth and surface stress of the rolls are the main characteristics of the finished product [7]. In compliance with the normative documents for cold rolls, hardness testing was conducted on standardized in Russia Shore D scale [8]. In practice, to investigate the hardening depth, layer-by-layer rolls grinding was exercised together with the layers hardness testing on Shore D scale with the step of 1 mm. In case of hardened roll layer-by-layer grinding [9], the hardness value changes from 95±3 HSD on the surface to 62,5±2,5 HSD at the depth of 50 mm. It follows from the above mentioned experiments, that the difference in the ultrasonic and dynamic transducer readings, which is a consequence of hardness change along the cold roll depth, is small – 0 < H(u)-H(d) < 5 HV.

Besides hardening change along the depth, there are surface stresses on the cold rolls, as well. To estimate them, comparative measurements by MET-UD combined hardness tester and by hardness calibration machine of Shore D type were carried out for the working rolls. Ultrasonic and dynamic transducers of MET-UD hardness tester were calibrated with Shore D primary hardness reference blocks. The measurements results are given in Table 1.

TABLE 1.

Item	H, HSD	HSD(u) , HSD	HSD(d), HSD
Rolling billet	28	30.4	29.5
Roll № 1 (neck)	33	33.4	33.8
Roll № 1 (barrel)	92	86.8	90.2
Roll № 1 (barrel)	92	86.6	89.6
Roll № 2 (neck)	34	34.9	35.2
Roll № 2 (barrel)	97	93.1	96.2
Roll № 2 (barrel)	98	94.6	96.6
Roll № 3 (neck)	34	34.6	34.1
Roll № 3 (barrel)	93	85.6	90.9
Roll № 3 (barrel)	92	86.0	90.1

Here H is the roll hardness on Shore D scale, measured by a hardness calibration machine of Shore D type; HSD(u) is the roll hardness on Shore D scale, measured by a combined hardness tester by ultrasonic contact impedance method; HSD(d) is the roll hardness on Shore D scale, measured by a combined hardness tester by rebound method.

From Table 1, one can see the decrease in the ultrasonic and dynamic transducer readings in comparison with Shore D hardness calibration machine readings. It can be explained by the fact that in case of reference hardness blocks which were used for the combined hardness tester calibration, there are neither surface stresses, no hardness value change along the depth. The difference in the readings is 3…4 HSD for the roll surface hardness of 92 … 98 HSD, i.e. H(u)-H(d) < 0 и H(d)-H(u) > 30 HV

Thus, conclusion can be made that the surface stresses on the roll barrel exceed considerably the contribution into the difference in the readings of MET-UD combined hardness tester transducers, than the roll hardness change along the depth. Alongside with it, measurement by ultrasonic contact impedance method does not consider surface stresses influence, and the rebound method considers it. Thus, the true hardness of a metallic material without considering surface stresses can be seen from ultrasonic transducer readings. If surface stresses are considered, the true hardness of a metallic material is seen from the dynamic transducer. On the basis of the difference between ultrasonic and dynamic transducers readings of MET-UD hardness tester, the following conclusion can be made: if the readings of ultrasonic and dynamic transducers calibrated with one and the same hardness reference blocks has a positive difference (ultrasonic transducer readings exceed the readings of the dynamic), then we deal with the change in the product hardening along its depth (with the depth increase, hardness decreases). And if the difference in ultrasonic and dynamic transducers is negative, then we deal with considerable surface stresses of the metal product.

4. CONCLUSION

On the basis of the experiments results and the real measurements performed on the working cold rolls, one can make the conclusion that a hardened layer hardness change along the depth and the influence of its surface stress can be disclosed under comparative measurements by two different methods, by ultrasonic contact impedance and by the rebound method. For express hardness measurements and obtaining a true estimation of both, products surface hardening and material properties changes along the depth, it is appropriate to use MET-UD combined hardness tester in which both methods are present and which is calibrated on every hardness scale with the relevant primary hardness reference blocks.

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