КРАТКИЕ СООБЩЕНИЯ

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METROLOGICAL ASPECTS OF MATERIAL HARDNESS MEASURING BY THE METHOD OF DYNAMIC INDENTING

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The problem of application of hardness measurements based on the dynamic indentation approach in the Russian Federation is reviewed. Metrological aspects of using the dynamic indentation method to control the hardness of materials are discussed. Principles of the hardness measurement method are described. Metrological support of the dynamic indentation method is considered and recommendations for the method improvement are formulated.

Ключевые слова: *dynamic indentation, metrological support, hardness of materials, scales, standards, test blocks*

Introduction. Based on the results of the analysis of the existing approaches, it was revealed that the method of dynamic analysis of indentation (DI) is a promising direction in the development of non-destructive methods for the noninvasive rapid assessment of mechanical characteristics. This method combines the advantages of standardized techniques of determining the mechanical properties of materials.

At the present time, a wide application of devices has been invented that implements the DI methods, and allows to assess necessary mechanical properties of the controlled material using the developed algorithms. Despite this, there are still several unsolved problems in the field of metrological support of the method.

Specifics of the dynamic indentation method. The method is based on continuous registration of the process of impact local contact interaction of the indenter with the tested material, namely, registration of the current velocity of the indenter.

The essence of the dynamic indentation method lies in the impact penetration of a rigid indenter of a certain geometric shape and dimensions under the action of the normal force $F(t)$ varying according to the known law and parallel registration of the depth of penetration of the indenter into the material $h(t)$. The recorded data are presented in the form of the functional dependence $F(h)$ [1].

The resulting indentation diagram “contact force” vs. “penetration” $F(h)$ consists of the loading (a) and unloading (b) curves (Fig. 1).

Today, dynamic indentation devices are manufactured in several versions. DI devices are distinguished both by the principle of the sensors and by the degree of “mobility” of the tool.

Using results of DI testing with a spherical indenter, matching GOST R 56474-2015[1], the dynamic hardness is determined by the formulas:

[1] GOST R 56474-2015 Space systems. Non-destructive testing of physics and mechanical properties of space technique's materials and coatings by dynamic indentation. General requirements.

$$H = \frac{F_{h\max}}{2\pi R h_f} \quad (1)$$

or

$$H = \frac{F_{h\max}^2}{2\pi R m (V_{\max}^2 - V_{\min}^2)}, \quad (2)$$

where $F_{h\max}$ is the contact force value corresponding to the maximum indentation depth, H; R — indentor radius, m; h_f — residual indentation depth after indentation, m; m — mass of indention system, kg; $V_{\max}$ — velocity of the indenter at the moment corresponding to the onset of contact interaction of the indenter with the test material, m/s; $V_{\min}$ — velocity of the indenter at the moment corresponding to the completion of contact interaction of the indenter with the test material, m/s.

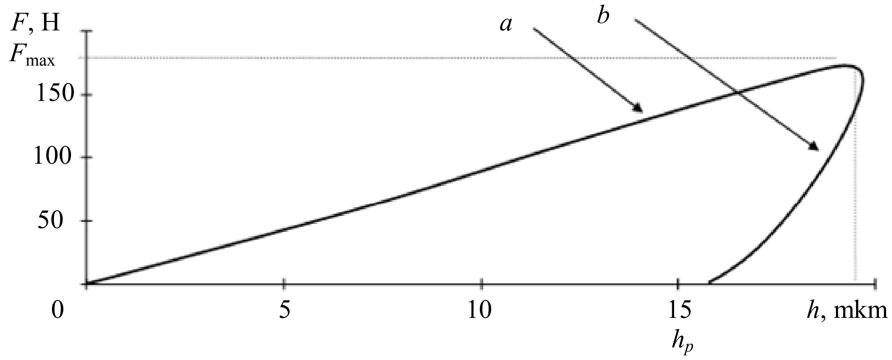

Fig. 1

This approach to determining the hardness of a material can be called a general term — an assessment of the surface dynamic hardness, since the hardness is defined as the ratio of the contact force value corresponding to the maximum penetration depth, to the surface area of the residual plastic impression [2].

Metrological aspects of the DI method. Today in the Russian Federation the following methods of measuring the hardness of metals and alloys are standardized: Brinell [3], Rockwell[1] hardness, and Vickers[2] tests, plastics hardness measuring method[3], Knoop hardness test method, instrumental indentation method[4], the Shore test, the Leeb rebound hardness test[5], dynamic indentation method (GOST R 56474-2015). Metrological support for measuring the hardness of metals and alloys by these methods is regulated by the standards listed above, as well as standards that establish requirements for measuring instruments, standard samples and auxiliary equipment, for the conditions and methods of their verification and calibration[6].

It should be noted that for a quantitative assessment of the hardness of metals and alloys, conditional scales of order are used - the scale of hardness numbers, which have unequal dimensions of hardness units and reflect application of specific approach (technique) of measurement. In this way, hardness numbers measured by different methods and under different conditions are different quantities, and hardness is not a physical quantity characterizing a material, but an ordinal quantity that de-

[1] GOST 9012-59. Metals. Method of Brinell hardness measurement; GOST 9013-59 (ISO 6508-86) Metals. Method of measuring Rockwell.

[2] GOST 2999-75. Metals and alloys. Vickers hardness teat by diamond pyramid.

[3] GOST R ISO 4545-1-2015 Metallic materials. Knoop hardness test. Part 1. Test method.

[4] GOST 9450-76 (ST SEV 1195-78) Measurements microhardness by diamond instruments indentation.

[5] GOST R 8.969-2019 (ISO 16859-1:2015) National system for ensuring the uniformity of measurements. Metals and alloys. Leeb hardness test. Part 1: Test method.

[6] GOST R 8.695-2009 (ISO 6507-2:2005) National system for ensuring the uniformity of measurements. Metals and alloys. Vickers hardness test. Part 2. Verification and calibration of testing machines.

pends not only on the material, but also on the method of its measurement. Therefore special attention should be paid to consideration of issues related to metrological traceability of the hardness measurement result, which is understood as the measurement property, according to which the result can be correlated with a basis for comparison through a documented continuous chain of calibrations, each of which contributes to the measurement uncertainty[7]. According to RMG 29-2013[8] metrological traceability requires an established calibration hierarchy and/or verification scheme, which in the Russian Federation is represented by a four-level structure of a metrological traceability chain for determining and spreading the hardness scale (Fig. 2) and National verification schemes for hardness measuring instruments for Brinell, Rockwell and Super-Rockwell, Vickers, Martens and indentation scales, and Shore D hardness scale.

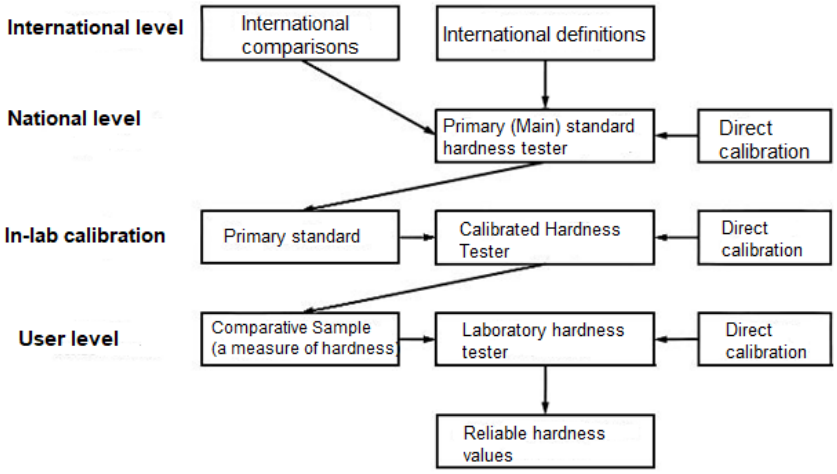

Fig. 2

To reproduce and store hardness units on various scales (Brinell, Rockwell and Super-Rockwell, Vickers, Martens and indentation, Shore D and Leeb) with the highest accuracy achieved in the Russian Federation using exemplary measuring instruments, and transfer the units size to working measuring instruments, five National primary special gauges (standards) are established[9].

Also, it should be mentioned that today the issues of metrological support for measuring the hardness of metals and alloys by this method remain open, Viz.:

— the standard GOST R 56474-2015-does not establish specific requirements for the values of the sensor parameters: kinetic energy of impact W_0; impact speed (speed of movement of the indenter at the moment of time, which corresponds to the beginning of the contact of the indenter with the material); the striker mass, which includes the mass of the indenter (tip); the geometric dimensions of the indenter (tip), for example, the radius of the sphere for a spherical indenter (tip) or the angle of sharpness of a tetrahedral pyramid with a square base. Therefore, with different values of the sensor parameters, it is possible to obtain different values of the dynamic hardness of the same material, since its value may depend on the ratio of elastic and plastic deformation during the impact contact interaction of the indenter with the test material;

— lack of metrological traceability of measurement results, which consists in the absence of a National verification scheme, a National primary standard, reference hardness measures;

— lack of a standardized method for assessing uncertainty of hardness measurements.

[7] GOST R 8.904-2015 (ISO 14577-2:2015) National system for ensuring the uniformity of measurements. Metallic materials. Instrumented indentation test for hardness and materials parameters. Part 2. Verification and calibration of testing machines.

[8] RMG 29-2013 GSI. Basic terms and definitions, sec.9.2.

[9] GOST 8.516-2001 National system for ensuring the uniformity of measurements. National verification schedule for means measuring hardness of metals according on Shore D hardness scale.

This fact significantly affects the widespread introduction and use of the method and means of dynamic indentation for solving practical problems of unremarkable control of the mechanical properties of materials of products, including hardness, during their production and operation, research problems in the field of materials science, tribology, fracture mechanics, etc. To resolve a similar problematic situation, which related to ensuring the uniformity of hardness measurements using Leeb approach in the Russian Federation, in 2020 GOST R 8.969-2019 (ISO 16859-1: 2015) was implemented, the National primary standard of metal hardness was created and approved based on the Shore D scale and the Leeb scale (GET 161-2019), and it is planned to release standards harmonized with the standards ISO 16859-2: 2015[10] and ISO 16859-3: 2015[11].

Conclusions. Based on the research materials above, it is believed necessary to propose for discussion the following recommendations aimed at solution of the problem under consideredation:

— for Rosstandart authorities, to initiate development of the national standard “Metals and Alloys. Measurement of Leeb hardness. Method of measurement, verification and calibration of hardness testers and hardness measures” based on the international standards ISO 16859 [4];

— to schedule the creation of the National primary special standard of Leeb hardness and the National verification scheme based on the generalized traceability frameworks (metrology chain) shown in Fig. 4 for the definition and distribution of Leeb hardness scales;

— to develop measures of hardness according to Leeb scales and carry out the type approval tests.

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[10] ISO 16859-2:2015 Metallic materials — Leeb hardness test — Part 2: Verification and calibration of the testing devices.

[11] ISO 16859-3:2015 Metallic materials — Leeb hard-ness test — Part 3: Calibration of reference test blocks.

МЕТРОЛОГИЧЕСКИЕ АСПЕКТЫ ИЗМЕРЕНИЯ ТВЕРДОСТИ МАТЕРИАЛОВ МЕТОДОМ ДИНАМИЧЕСКОГО ИНДЕНТИРОВАНИЯ

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Рассмотрены проблемы обеспечения единства измерений твердости методом динамического индентирования в Российской Федерации. Метрологические аспекты применения метода динамического индентирования для контроля твердости материалов. Рассмотрены технические принципы метода измерения твердости. Приведены аспекты метрологического обеспечения метода динамического индентирования и рекомендации по совершенствованию метода.

Ключевые слова: динамическое индентирование, метрологическое обеспечение, твердость материалов, шкалы, эталоны, меры твердости

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