2.4 Calvert Johnson method, the first correct physical hardness scale, hardness number, F(h) process function, properties, analysis. Law of physical hardness of materials (draft).

1. Function and number of material hardness in MCJ, relationship with empirical functions and hardness number in the standard Brinell method.

2. Analysis of the MKI process in the Calvert Johnson method using the function of physical hardness and parametric functions. Relationship between the parameters of physical hardness PHI and HMCJ. Principles of MCJ.

3. Discussion. Law of physical hardness (draft). Conclusions.

1. Function and number of material hardness in MCJ, relationship with empirical functions and hardness number in the standard Brinell method.

From the analysis of the methods for measuring the hardness of materials, it follows that the first physically justified method was Calvert Johnson, hereinafter briefly MCJ, [2,3]. In MCJ, tests were performed using a special mechanism, a truncated cone indenter was used, the article was published in 1858, sketch Fig. 3 [4]. The authors of this method created the first experimentally substantiated, correct scale of material hardness Table 3.2.5. Hardness was measured by the value of the sum of the force of the weight of weights Fmax acting on the indenter, the dimension is kgf (1kgf = 9.8N). The value of Fmax (hardness) corresponds to the position of the indenter when pressed to a reference depth. Based on the first scale obtained in units of weight, several years later, the authors created a new dimensionless hardness scale. Subsequent scales and methods created by other inventors were intuitively and formally oriented towards the first MCJ weight scale. For example, the Brinell scale approximately repeats the proportions of the hardness values of materials from the first scale. The analytical analysis of subsequent empirical methods [3,4,15] showed that subsequent methods (new indenter shape, etc.) do not have a physically correct definition of the hardness unit, and the physical principles of MCJ measurements are lost. Modern empirical methods do not have a definition of the physical meaning of the measurement process and the hardness number itself [4,15]. The physical meaning of the original method was distorted in the process of utilitarian improvement of the hardness number measurement methods, and the root principle of measurements was lost. Many unsystematized scales arose that did not have a common root physical meaning of hardness, they did not have physical principles for maintaining similarity in measurements, and there were empirical ambiguous rules and requirements for the process of measuring the formal number [3,15]. To confirm this thesis, we will perform a theoretical analysis of the KI MCJ process, consider its properties and parameters, and reveal the physical principles of the material hardness measurement method. For this, we will take the description of the root method outlined by the authors in [16].

Fig. 5 schematically shows the geometry of the indenter, test parameters, process diagrams F(h), PHI(h) of measuring the MCJ hardness. The indentation speed was low and approximately constant. Hardness was measured by the value of the maximum force of the weight of all weights Fi_{max} acting through the lever on the indenter, the measurements were always completed at the same maximum value of the displaced volume of material V_{CJmax} , at the same indentation depth h_{CJmax} , for any material. Various materials were tested for hardness, from lead to steel, as a result the first physically correct scale was obtained, in the dimension - kgf (kilogram force), its range is 75-4800 units of weight, Table 3.2.5.

Table 3.2.5 Calvert and Johnson hardness scale in units of force weight, 1858 g [16].

On the Hardness of Metals and Alloys. 199

Names of Metals.	Weight employed.	Calculated Cast Iron = 1000.
Staffordshire Cold Blast Cast Iron —Grey, No. 3,	4800 lbs.	1000
Steel,	4600 ?	958 ?
Wrought Iron,*	4550	948
Platinum,	1800	375
Copper—pure,	1445	301
Aluminium,	1300	271
Silver—pure,	1000	208
Zinc "	880	183
Gold "	800	167
Cadmium "	520	108
Bismuth "	250	52
Tin "	130	27
Lead "	75	16

* This wrought iron was made from the above mentioned cast iron.

Fig. 5 a shows the shape and dimensions of two indenters on the same scale: the MCJ truncated cone, the D2.5mm sphere. Fig. 5b shows schematic diagrams of F(h, Di) for comparison, different spheres with diameters D1<D2<D3. (black), for a material of the same hardness HB=const. Three F(h) diagrams are shown in green – for the MCJ cone, conventionally shown for different material hardness (HBi=1,2,3). Different parameter of the linear trend kfcji (slope) of each MCJ diagram is shown – F1,2,3(h), kfcji <kfcji <kfcji, for three materials HBi=1 <HBi=2 <HBi=3. Fig. 5c shows generalized diagrams of physical hardness PH MKI for the sphere PHIi(HBi) and for the MCJ indenter - PHiMKJ (green).

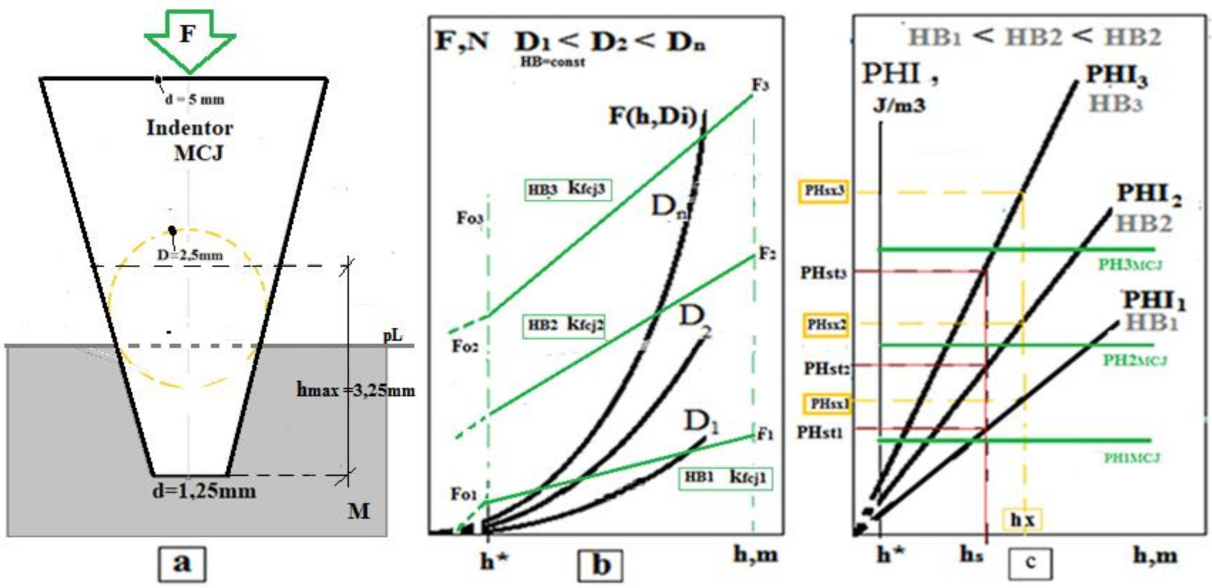

Fig. 5: a) Parameters of the MCJ indenter geometry and other indenters; b) Graphs of the F(h) functions for MKI with the Brinell sphere (black) and the MCJ truncated cone (green); c) Their respective physical hardness diagrams PHIi(h). A change in the depths hs □ hx causes a change in the scale of the hardness scale (MCJ standard, dashed line black - red), hx is a violation of the depth standard, an incorrect or scaled-down segment scale (yellow).

To analyze the properties of MKI, the sphere shows the nature of the change in the scale of the empirical hardness scale as a result of an incorrect change, an increase to hx of the standard of the MKI indentation depth. Hardness values of the true standard empirical hardness are the intersection points of the dotted line "black - red" with the black rays of the PHIi diagram (these values theoretically coincide with the HBi standard). As a result of deviation from the standard of the MKI depth hs→ hx, the scale of the unit of measurement is violated, a new "segment" scale incorrect in terms of the unit of measurement is formed. Physically, the scale is obtained correctly, but formally this means a change in the measure of the quantity-unit of the specific power (hardness) of the MKI process. The line of the false new "standard" for the depth hx is shown in yellow. As a result of deviation from the hs standard to the new depth hx, the scale of the hardness value scale is violated (in modern empirical sources this fact is called the "size effect"). The MCJ cone in the physical hardness diagram has no size effect, it is negligibly small (the PHIMCJ diagram is green), the scale or ratio of absolute values of hardness of different materials does not depend on the depth, it depends only on the specific power (on the specific energy dissipated in the material during the time set by the MCJ standard). The absolute value (number) of hardness on the first MCJ scale - FiMCJ, [kgf] is measured for one depth, in all cases hMCJi = const,. At the same time, the requirements for the duration of indentation were met: tMCJi = const, for all materials. In this case, the proportion of hardness (the ratio of hardness numbers) in the MCJ scale depends only on the material itself, the similarity of the physical testing conditions is always preserved. Below we will consider the physical process in detail.

Fig. 5 C shows an important physical property of the function PHI(h) as a state function, it is invariant, does not depend on the trajectory of the function F(h, Di), Fig. 5 b, the ray of the diagram PHIi(h, D1,2,3) is one for three different diagrams F(h, Di). The force diagrams in turn depend on the diameter of the sphere [4].

To maintain the physical similarity of testing materials of different hardness, the properties of the state function were incorporated into MCJ, for this purpose the following principles and reference parameters are met during indentation:

1. The shape of the indenter is a truncated cone ($\alpha = 30^\circ$), unchanged for any hardness.

2. Constant depth of movement of the MCJ indenter for a material of any hardness. $h_{CJ\max} = 3{,}25 \cdot 10^{-3} \mathrm{m}$

3. For a material of any hardness, the condition was always met that the total time of movement of the indenter to the reference depth $h_{CJ\max}$ value was constant $t_{MCJ} = 30\,\mathrm{min}\,(1800\mathrm{s}) = \mathrm{const}$.

4. The load on the indenter was increased gradually, in steps (cycles ΔFi), Fo → Fmax, the required weight of the weights was selected by the method of successive approximations. In this case, for any materials, there was a constant average rheological velocity of movement in the interval of full movement: $\overline{\upsilon}_{it.CJ} = h_{CJ\max} / \Delta t = \mathrm{const}$. Fig. 6a schematically shows the graph of the successive oscillatory process of growth of the total force F(h) as a result of a gradual (by selecting the weight of the new weight) increase in force to the level of Fmax. This technique is necessary to fulfill the condition t_{MCJi} = const. As a result of the

combination of the conditions t_{MCJi} = const. And in the KI process for a material of different hardness, the constant reference average rheological velocity of movement of the indenter in MCJ:

$$\bar{\upsilon}_{it.CJ} = h_{CJ\max} / t_{MKJ} = 3{,}25 \cdot 10^{-3} m/1800 s = 1{,}8 \cdot 10^{-6} m/sec = const \quad (13.5)$$

5. At the same time, under such conditions, the authors ensured experimentally (by selecting weights) a constant average generalized rate of growth of the test force for materials of different hardness, we will denote it as $F'_h(h) \approx \Delta F / \Delta h = F_{max} / h_{max} = ki_{fhCJ}$, N/m . The value of the generalized rate of growth of force F was individual, the index i denotes a specific material and its corresponding hardness:

$$ki_{fhCJ} = F'_h(h) \approx \Delta Fi / \Delta h = Fi_{max} / h_{max} = const, \text{ N/m}$$

$$ki_{fhCJ} = const_i \qquad (13.1)$$

ki_{fhCJ} - a constant value of the parameter for testing materials of different hardness, a material constant in MCJ. The authors of MCJ did not formally measure the value of this rate. Theoretical analysis showed that the rate ki_{fhCJ} is uniquely analytically related to the value of the weight force Fi_{max} (weight force, in the dimension kgf, the first unit of measurement of the hardness number on the MCJ scale). Further, to confirm these conclusions, we will apply parametric rheological formulas of the process (from time), which confirm these properties in general.

6. The function of changing the shape of the material $X_{SV}(h) = \frac{S_a(h)}{V_a(h)}$, $X_{SVMCJ} = const \approx 2{,}3.1/mm$ (see Part 2.6 In MCJ, the MKI process in which the function of changing the shape depends almost little on the depth h.

Thus, the following correct physical conditions, indentation parameters were used in MCJ:

1. Isochoric process, constant volume $V_{CJ\max}$ = const , Vamax = $V_{CJ\max} \approx 8 \cdot 10^{-9}, m^3$

2. Isochronous testing process, constant t_{MCJ} = const = 30 min (1800s)

3. Rheological average indenter velocity is constant $\bar{\upsilon}_{Rhi.CJ} = const = 1{,}8 \cdot 10^{-6} m/sec$

4. Initially, the material hardness number in MCJ is the eigenvalue of the maximum indentation force Fmaxi [kgf, *9.8 m/s2 , we get the force in N], we will further designate this material hardness on the MCJ scale: HCJi, N.

Later (ten years later), the authors made the transition to a dimensionless scale of hardness units in the range from 16 (lead) to 1000 (durable cast iron).

5. Example. Generalized average rate of force growth KI of durable steel Table 3.2.5, its grade is not exactly known (determined approximately):

$$ki_{fhCJ} \approx Fi_{max} / h_{max} = 46000\,N / 3.25E - 3m = 1{,}42 \cdot 10^7, N/m \quad (13.2)$$

Rheological average rate of force increase, according to (13.1), in this case:

$$\upsilon_{Rfi}(h,t) = F_t'(h) \approx \Delta F / \Delta t = F_{max} / t_{max} \;.\; t_{max} = const, Hi, \; N/s$$

$$MCJ \; t_{max} = 1800 sec$$

$$\upsilon_{Rfi}(h,t) = \Delta F / \Delta t \approx F_{max} / h_{max} = 46000, N/1800, s = 25{,}5, \; N/s \quad (13.3)$$

Steel C45 under the conditions of the cyclic test process KI according to ISO sphere [14]:

$$\upsilon_{Rfcycl} = \Delta F / \Delta t \approx 24 \div 28, N/s,$$

6. The indenter movement speed is low, we have an isothermal process $T, K^{\circ} = const$.

7. The shape change parameter $X_{SVPMCJ} = const \approx 2{,}3mm^{-1}$ (Рис.6C, Ч.2.6). (Fig. 6C, Part 2.6). It changes slightly with increasing depth h, this is a feature of the MCJ indenter shape. In this case, each unit of the displaced (activated) volume of material generates approximately the same and constant specific contact surface ΔS/ΔV = const, characteristic of this indenter shape. Consequently, in MCJ, for any material hardness, the shape change parameter is approximately constant Xsv=Sa/Va = [m2/m3 = 1/m].In Fig. 6C, Part 2.6 Fig. X shows the graph of the function Xsv(h) for MCJ. In the method, the specific mechanical work of the indenter PVA = A/V, J/m3 (specific dissipated energy) spent on the indentation process is always directly proportional to the hardness of the material, the PVA value depends entirely on the internal structural and physical properties of the material, because all external empirical (shape, size, displacement) parameters of testing different materials remain the same, constant. This is the main property and difference of MCJ from subsequent empirical, physically incorrect, methods of measuring hardness.

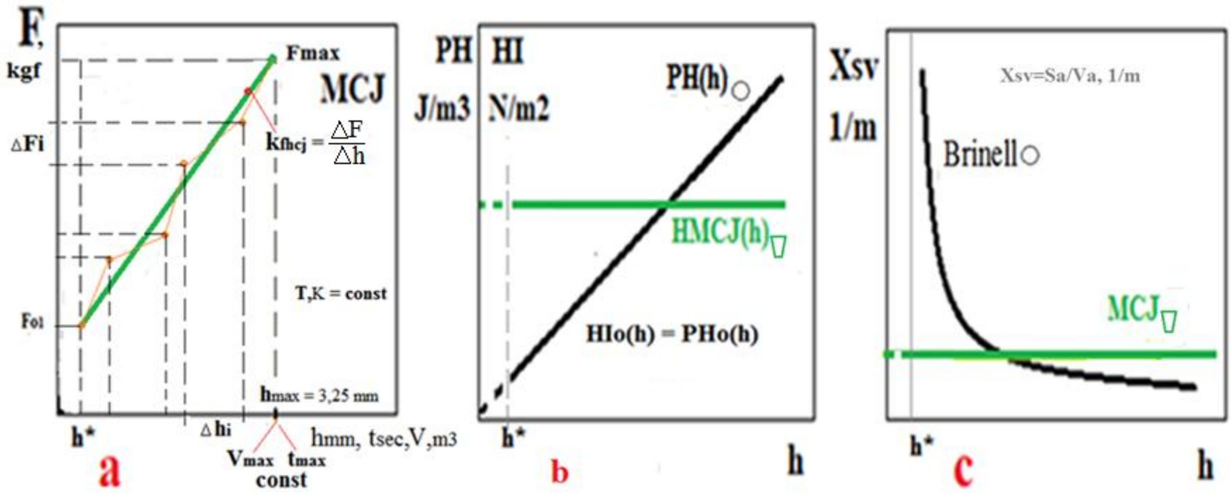

Fig. 6 Typical diagrams of the MKI process in the Calvert Johnson method: a) Force Fmcj(h), yellow force increment cycles, green equivalent diagram – kfcj linear trend; b) Physical hardness MCJ - HMCJ(h), J/m3, green. MKI sphere, empirical HIo(h) and physical hardness PHo(h) black, coincide; c) shape change function Xsv(h), MKI sphere – hyperbola (black), straight line – truncated cone MCJ green.

2. Analysis of the MKI process in the Calvert Johnson method using the physical hardness function and parametric functions. The relationship between physical hardness PHI and hardness HMCJ. MCJ principles.

The results of applying parametric rheological diagrams and functions of the MCJ process are of theoretical and practical interest; they provide simpler, more correct principles for analyzing the data of KI diagrams. We will obtain by this method the ratio of hardness on the MCJ scale in 1 kgf with the universal physical unit of hardness 1 J/m3. Using this method, we will consider the fundamental, root features of the physical process of testing materials in MCJ. The proper number of hardness of the material in the first MCJ scale will be designated HCJi. We will prove analytically that the hardness HCJi, it is in the dimension of kgf (the force of the weight of the weights during testing), with an accuracy of a constant factor Cj (14) is equal to the value of the specific generalized indentation power (physical hardness) - PHCJi of the material:

$$Cj \cdot HCJi = PH_{CJi}, \ J/m^3, \ (14)$$

Where, is the normalization constant or conversion of units of measurement, $h = hmax$ is the MCJ constant.

Let us find the value of two functions from (14) at the point hmax , this is a parameter established by the MCJ method, and find the relationship between the hardnesses for these methods. We define the physical function PHIx(Fcj) in general terms using the formulas of the theory, according to the generalized experimental diagram Fcj(h)) , MCJ Fig. 5b, 6a. Then, we find the value of the physical hardness of the material in the MCJ testing rules. We denote the value of the function PHIx(Fcj), at the point h_{cjmax}, as the hardness - $PHCJi(h_{max})$. Thus, we prove analytically that the hardness HCJi , kgf in MCJ with an accuracy of a constant factor is equal to the specific generalized physical hardness, power - $PHCJi(h_{max})$, J/m3 , and we make sure that it is equal to the specific work of the force of the weight of the weights when moving the indenter to a given depth hmax. Let us consider the derivation of the formula for the connection (ratio) of different physical units of measurement of the material hardness during macroindentation. When measuring the hardness MCJ, (Fig. 5a), the physical conditions for the continuous monotonic process MKI [16] are met, and the average generalized rate of force growth is ki_{fhCJ} equal to:

$$ki_{fhCJ} = F'_h(h) \approx \Delta F / \Delta h = F_{max} / h_{max} = F_{max} / \bar{\upsilon}_{i.CJt} t_{max} = k_{fhCJ} h_{max} / h_{max} = const, \ N/m, \ (15.)$$

Where, from (13.5) $h_{max} = \bar{\upsilon}_{i.CJt} t_{max}$. From this follows the relationship between the hardness number HCJi in units of MCJ (weight force) and the generalized velocity parameter in this method:

$$HCJi = Fi_{max} = ki_{fhCJ} h_{max} = const_i, \ kgf \quad (15.1)$$

Where, the parameter $ki_{fhCJ} = Fi_{max} / h_{max} = const_i$ N/m is the hardness number in MCJ.

From formulas (3), (6), we obtain the main component, the physical hardness function MCJ:

$$\mathbf{PHI}_x(\mathbf{h}) = \frac{\partial A_x}{\partial Vx} = \frac{A'(h)\partial h}{V'(h)\partial h} = \frac{F(h,R)\partial h}{3\alpha_{cj}h^2\partial h} = \frac{k_{fhCJ}h \cdot dh}{3\alpha_{cj}h^2 dh} = \frac{k_{fhCJ}}{3\alpha_{cj}}\frac{1}{h} = const, N/m^2 \quad (15.2)$$

Where, $A_x(h) = A_{MCJ}(h) = \frac{F_{max} \cdot h}{2} = \frac{k_{fhCJ}h^2}{2}$, $A'_{MCJ} = k_{fhCJ}h$, $V'_V(h) = V'_{xcj}(h) = 3\alpha_{cj}h^2$.

For a full cone, the displaced volume $V'_V(h) = 3\alpha_{cj}h^2$. The lost part of the volume of the truncated vertex does not affect the derivative of the volume function, therefore we obtain: $V_{vcj}(h) = \alpha_{cj}h^3$, $V'_h(h) = 3\alpha_{cj}h^2$, α_{cj}- is the dimensionless parameter of the cone shape MCJ.

$$\alpha_{cj} = \frac{1}{3}\pi tg^2(0,5\beta) \quad , \quad \alpha_{cj} \approx 0,076 \quad , \quad \beta \text{ - is the angle at the cone vertex MCJ}$$

$$PHI_x(h) = \frac{k_{fhCJ}}{3\alpha_{cj}}\frac{1}{h}\frac{h}{h} = \frac{Fi_{max}}{h_{max}}\frac{h_{max}}{h_{max}3\alpha_{cj}h_{max}} = \frac{2A_{max}}{3\alpha_{cj}h^3} = \frac{2A_{max}}{3V_{cj\,max}} = 0,67 \cdot PVA = const \quad (15.2.1)$$

Where, PVA=A_{MCJ}/V_{XMCJ}, J/m^3

$$\mathbf{PHcji} = \mathbf{PHI}_{xi}(\mathbf{h}_{max\ mcj}) = \frac{k_{fhCJ}}{3\alpha_{cj}}\frac{1}{h_{max\ mcj}} \quad (15.3)$$

We obtain formula (15.3) for determining the physical hardness number of the conventional material "i" for the rules and parameters KI established in MCJ: the indenter shape is a truncated cone, the process time is $t_{MCJ} = const$, the depth is $h_{CJ\,max} = const$. Formula (15.3) allows us to obtain the physical hardness number by the parameters KI MCJ:

$$\mathbf{PHcji} = \mathbf{PHI}_{xi}(\mathbf{h}_{max\ mcj}) = \frac{k_{fhCJ}}{3\alpha_{cj}}\frac{1}{h_{max\ mcj}} \quad (15.3)$$

Where: $PHcji, J/m^3(N/m^2)$- physical hardness of the material "i" in the MCJ method, provided that it takes into account $h = h_{max\ MCG}$ the indenter shape, the depth is h_{max}., k_{fhCJi} the linear trend parameter of the generalized velocity MKI for MCJ, Fig. 6 a. In (6.2) we see the relationship between the physical hardness and the linear trend parameter k_{fhCJ} in MCJ.

From (5.2), (6.2) by simple transformations we obtain formula (15.4) for the relationship between the force (the hardness number in MCJ) with the process parameters and the physical hardness number for this MCJ method:

$$\mathbf{PHcji} = \frac{Fi_{max}}{h_{max}} = Fi_{max}\frac{1}{3\alpha_{cj}h^2_{max\ mcj}} = Fi_{max}Cj$$

$$PHcji = Fi_{max}Cj \quad , J/m^3(N/m^2) \quad (15.4)$$

Where, $Fi_{max} = HCJi, kgf$ the value of hardness on the MCJ scale, From (6) and (6.4): $Cj = \frac{1}{3\alpha_{cj} h^2_{max}}$ = const parameter KI of the MCJ process.

Now let us compare the values in MCJ hardness units, the weight force (kgf), (6.1) and the hardness values in physical units, for the same Brinell hardness measure HBi. We will finally obtain an analytical ratio of the values of physical hardness $PHCJi$ (J/m3) obtained from the FMCG(h) MCJ diagram and the hardness value in units (kgf) of this method, this is the force acting on the indenter at point h_{max}.

$$Cj = \frac{PHCJi}{HCJi} = \frac{1}{3\alpha_{cj} h_{max}} ki_{fhCJ}(HBi) \frac{1}{ki_{fhCJ}(HBi) h_{max}} = \frac{1}{3\alpha_{cj} h^2_{max}} = const \quad (15.5)$$

Conclusion. Thus, formula (15.5) is analytically obtained, which shows the ratio of the material hardness values obtained by two methods of diagram analysis, the physical method, the KI function PHCJi(hmax) = PHCJi , J/m3 is the physical hardness of the material in the function and the MCJ method. Hardness in the original MCJ scale, $HCJi(h) = Fi$ kgf. The hardness values in these methods differ by a constant.

MCJ principles

1. The measure of material hardness in MCJ is the value of the maximum test load force on the indenter F [kgf], The unit of measurement of material hardness is 1 kgf, in the SI system it is about 9.81,N. Let's designate MCJ as the material hardness (conditionally, the author's designation of the theory):

HCJ = FmaxCJ, [N].

2. The main parameters of the physical and mechanical process of MKI testing for any material hardness, we will divide them into two levels:

The main parameters of the MCJ method.

1- 6 CONST.

1. Indenter travel depth $h_{max} = h_{CJ\,max} = 3{,}25 \cdot 10^{-3} m$ CONST

2. Indenter shape - truncated cone Fig. 5a CONST

3. Displaced (displaced) volume $V_{CJ\,max} \approx 8 \cdot 10^{-9}, m^3$ CONST

4. Indentation process time $t_{MCJ} = 30 \min (1800s) = const$ CONST

5. Rheological velocity of movement, displacement of the indenter:

$\overline{\upsilon}_{it.CJ} = h_{CJ\,max} / t_{MKJ} = 3{,}25 \cdot 10^{-3} m / 1800 s = 1{,}8 \cdot 10^{-6} m / sec = const$ CONST

6. Body temperature T,K = const during testing CONST

3. Individual identification parameters of the material (IPM) during MCJ hardness testing.

1 - 3 IPM MCJ

Maximum force (weight of weights) of indentation of material Fmaxi – 1 IPM MCJ

Rheological rate of growth of force F of indentation of material

$F'_t(h) = \Delta F / \Delta t \approx F_{max} / h_{max}, N/s$ 2 IPM MCJ

Generalized rate ki_{fhCJ} of growth of force F of indentation $ki_{fhCJ} = const_i$

$ki_{fhCJ} = F'_h(h) \approx \Delta Fi / \Delta h = Fi_{max} / h_{max} = ki_{fhCJ} = const$, N/m 3 IPM MCJ

$Cc = \frac{1}{ki_{fhCJ}}, \frac{m}{N}$ - contact stiffness (reciprocal value ki_{fhCJ}) * IPM MCJ

Fig. 7 shows a block diagram of the main functional elements of the algorithm for measuring the hardness of materials in the fundamental Calvert Johnson method – MCJ.

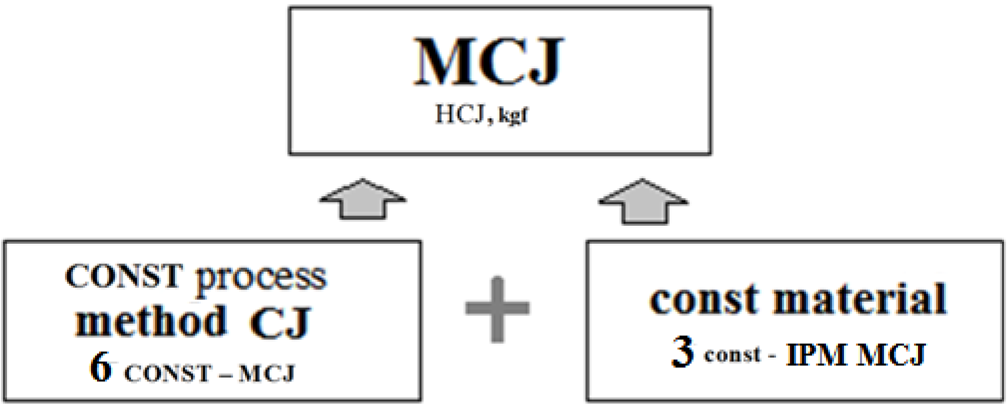

Fig.7 Block diagram of constants and parameters for measuring hardness in the Calvert Johnson method 1859yea. Identification parameters of the material (IPM).

The analysis of the physical properties of the KI process showed that hardness can be measured using a simple universal method (relative to existing standards) if we use a specially shaped indenter in the form of a truncated cone (see the MCJ method Part 2.5). A similar result of constructing the function of the generalized MKI velocity, determining the physical parameter of the material associated with the HBW hardness number will be obtained if we apply a special cyclic MKI process, for example, a sphere (ki_{fhCYCL} steel C45, $D = 2{,}5mm$ Part 2.5).

3. Discussion. The law of physical hardness (draft). Conclusions.

After forty years of using MCJ, its improvements began, which caused a violation and loss of the original physical principles. When creating MCJ, the authors did not set out their theory of the hardness measurement process. The original correct MCJ scale of measuring the number and, accordingly, the method of comparing the hardness of different materials were distorted, without theoretical physical justification. As a result, different empirical single-act methods of measuring the hardness number, different inconsistent scales (in physical theory, these are segmental empirical scales) arose.

Based on my research, I assume that at that time (1859), theoretical physical methods of analysis were just developing, there were no uniform measurement units, so the physical root property and meaning of the KI MCJ process remained unexplored. The first MCJ material hardness scale was not theoretically systematized, the scale division was random, by the value of the weight of the Fmax, kgf weights. About ten different materials formed the reference points of the scale, but there was no measure - the standard of the hardness unit. Later, the MCJ scale was made generalized and dimensionless, but the physical root and meaning of the tests were finally lost. In subsequent methods and scales, physically unsubstantiated proportions were used, conditionally and approximately repeating the ratios of dimensionless hardness numbers of different materials (more than ten) originally obtained in MCJ. The methods were built without theoretical justification of the physical unit and measure of measurement, without systematization of the scale.

Physical law of material hardness (project).

The MCJ method serves as an experimental justification for developing a project of the physical law of material hardness:

If, under the action of the pressure force of an absolutely rigid indenter on the surface of a homogeneous isotropic stable material in a certain structural-energy state, the indenter is pressed in, it moves in the direction of the force action vector into the material under study, if the indenter has performed mechanical work of magnitude A on an irreversible change in the shape and internal state of the material, in particular, as a result of this process, a movement of some activated volume V of this material was performed, in which irreversible internal changes and a change in shape of this volume occurred, a new contact surface was formed between the indenter and the activated material. If certain constant physical and mechanical macro parameters of the process are preserved (T is the body temperature, P is the pressure in the activated volume), then the function of the volume derivative of the thermomechanical potential A: $\frac{dA}{dV} = PHI(A,V)$ is a function of the state of the indentation process and the gradient of the activated volume in this thermomechanical system. $PHI(A,V)$ - is called the volume derivative of the thermomechanical potential A(h) of the activated volume of the material V(h), where the potential A(h) is the mechanical work of the indenter from the displacement h. The volume derivative of the potential A(h) is also called the function of the potential of the total specific power of macroindentation, $PH = dA/dV$ J/m3 [N/m2] is an unambiguous physical and mechanical characteristic, a function of the state of the activated volume of the thermomechanical system under consideration. The main component of the gradient $PHI_x = dA_x/dV_x$ is called the function of the physical hardness of this material, established in a certain physical and mechanical process and a certain thermomechanical system (material - sample - test mechanism) when testing by the macroindentation method. The value, the number of the function $PHI(hst)$, established at a certain value of the shape change parameter Xsv(hst), where hst is the standard of the indentation depth, is the standard number of the physical hardness of this material $PHst = PHI(hst)$ in the established standard, measure or measurement process, the values of the standard of the number of the function of different materials form the standard scale of hardness.

Consequence. 1. If we establish a standard unit of measurement of the physical hardness of the material, a standard of the indenter shape, the MKI speed, a standard of the activated volume of the given material, a standard of temperature, when indenting a homogeneous isotropic stable material, we will obtain the function of the ideal MKI process or the standard of the indentation function $SPHI(A,V)$.

The standard of the specific power function or the standard function of the physical hardness of the material $SPHI(A,V)$ is proposed for a comparative analysis of the property of the structural and physical state of the material and its surface in the process of changing the value of the activated volume or the depth of movement of the indenter. Effect of surface and depth.

Consequence. 2. There is no correct physical theoretical measure of the hardness of the material, but there is an unambiguous function of the process $PH = dA/dV$ and a number of the hardness standard $PHst$ of the given material established in a certain established standard idealized physical and mechanical process of testing the shape change of the given material under macroindentation conditions (a similar version of uniaxial tension testing is possible). That is, a physical measure of the testing process is established.

If some reference testing parameters were not met during the material hardness testing by the macrokinetic indentation method, the hardness value will be incorrect, the scale is not a reference scale, such a hardness scale is called segmental. Having the necessary values of the functions and parameters of such tests, it is possible to perform an analytical translation of the function values, the segmental hardness scale into the values and scale of the existing standard of the MKI process.

Conclusions.

1. In MCJ, the physical hardness of a material $PHCJi$ can be determined by formula (6.3) based on their experimental parameter of the linear trend k_{fhCJi} of the function Fcj(h) or formula (6.4) based on the absolute value of the force.

2. From formula (6.3) it follows that the hardness of a material in the MKJ method is uniquely determined by the value of the maximum force on the indenter Fi_{max} (the force of the weight of the weights). The original MKJ scale, which had a clear physical meaning and dimension, was constructed by comparing the values of force Fi_{max} (absolute values) for different materials.

3. The value of the physical hardness of a material in MCJ is , $PHcji$ J/m3, formula (6.4), with an accuracy of up to a constant factor is equal Cj to the maximum indentation force Fi_{max} , (the hardness number on the first MCJ scale).

4. In MCJ, the generalized specific indentation power of the material was measured experimentally, but in an indirect form, with an accuracy of up to a constant factor $PHCJi$.

5. Hardness measurement in MCJ is a simplified algorithm for the process of measuring the physical property of the material, the ability of the material to dissipate a certain specific power

in a certain reference process during irreversible deformation, under the mechanical action of the indenter. As a result of testing, the specific value of the macro-potential of the material hardness PHCJi = Amax / Vmax is determined indirectly (with an accuracy of up to a constant factor). This value of the material hardness depends on the reference parameters of the process: h_{MCJ} = const, V_{MCJ} = const, S_{MCJ} = const (indenter shape, deformation functions $X_{svCJ}(h) = S(h) / V(h)$ = const), test time = 30 min (1800 s), temperature.

6. For a homogeneous and isotropic material, its potential PHCJi does not depend on the trajectory of the functions $h_{MCJ}(t)$, $V_{MCJ}(t)$ of the process. The value of the maximum test force Fmaxi and the potential PHMCJi are unambiguous interrelated quantitative characteristics of the tested material, they are related by a constant coefficient in the dependence (6.4):

$$\text{PHCJi} = \text{Cj} \cdot \text{Fi}_{max}$$

7. The first version of the MCJ scale. Hardness is measured by the value of the maximum test force Fi max (kgs), with a constant depth hmax and tool shape. In the second version of the MCJ, a dimensionless scale, it already contained the correct method for determining the physical value of hardness. Both options have the correct initial physical algorithm for testing and measuring (see constants Π.), physical similarity of processes is performed. In MCJ, with an accuracy of up to a constant factor, indirectly, the own specific volumetric energy of changing the shape of materials of different hardness is measured. On this basis, the first correct scale of dimensionless relative values of hardness was constructed; at the time of its creation, the accuracy of measurements and consideration of all factors was not high.

8. Main parameters of the MKI MCJ process. Physical parameters of the macrokinetic indentation process, which must be kept constant during testing of materials of different hardness, to maintain the physical conditions of measurement similarity: constant value of the unit of measurement of physical hardness (a measure of the specific generalized power of indentation). Main parameters of the physical method of MCJ indentation:

Six MCJ constants.

1. Depth of indenter movement $h_{max} = h_{CJ\,max} = 3{,}25 \cdot 10^{-3}\,m$
2. Indenter shape - truncated cone Fig. 5a
3. Displaced (displaced) volume $V_{CJ\,max} \approx 8 \cdot 10^{-9}, m^3$
4. Time of the indentation process $t_{MCJ} = 30\,min\,(1800s) = const$
5. Rheological velocity of indenter movement: $\bar{\upsilon}_{it.CJ} = 1{,}8 \cdot 10^{-6}\,m/sec = const$
6. Body temperature T,K = const