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Andrzej SZYMAŃSKI *, *Janusz M. SZYMAŃSKI* **

CALCULATION OF MOHS HARDNESS SCALE OF MINERALS FROM IMPACT ABRASION HARDNESS

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Abstract. Basing on the abrasion hardness tests of Mohs scale minerals, the authors worked out a formula that permits plotting a corrected curve of dependence of the depth of abrasion with a sand grain on hardness. From the rectilinear dependence the formula was derived which makes it possible to recalculate abrasion hardness to the generally accepted Mohs hardness scale for the materials with continuous structure. The results evidence that impact abrasion hardness can be used to determine Mohs scale hardness of minerals.

Hardness is one of the basic diagnostic features in mineralogy, as well as the main factor determining the possibility of exploitation and processing of minerals with industrial applications. Several methods of testing hardness have been developed, which are more or less commonly used depending on tradition and laboratory equipment. Since the adopted instrumental methods of hardness testing are manifold (diamond indenters according to Vickers, Knoop, Grodziński, Berkowicz, Hanneman, or hardness testers according to Brinell, Rockwell, Shore), it is a troublesome task to relate the results obtained to the generally accepted Mohs scale of hardness, introduced in 1812, because of unequal distances between its degress. Several attempts have been made to adapt Mohs scale and relate it with the results yielded by instrumental tests (Povariennykh 1963, A. Szymański, J. M. Szymański 1976). Owing to those efforts, Mohs scale can still be used for diagnostic purposes.

Hardness testing by scratching soft mineral with a harder one, which served to establish Mohs scale, has one undisputable merit, viz. multidirectional action of forces destroying the tested sample. Due to this, it is possible to relate Mohs scale and the adequate methods of hardness testing to the method of testing impact abrasion hardness, in which the effect of collective scratching is determined. Dynamic measurements are more useful for the practical estimation of mineral hardness as being closer to

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* Research Centre of Semiconductors, Warsaw (Warszawa, ul. Konstruktorska 6).
** Institute of Glass and Ceramics, Warsaw (Warszawa).

the conditions under which the tested material usually fails during exploitation.

The sand blower, called Mackensen's apparatus, works on the principle of abrading the surface tested (mineral face or section) with a stream of quartz sand of the grain-size 800—500 μm, blown under the pressure of 1.5 atm. from the chamber with a capacity of 28 cm³. A measure of abrasion hardness is the depth h_m of the hole blown out in the tested material (Phot. 1), measured with a needle applied to the surface before and after the blowing action.

The blower is calibrated by abrading pyrex glass down to a depth of 2.13 ±0.05 mm, or a fluorite crystal on the face *(111)* down to a depth of 3.95 ±0.05 mm, or else a magnetite crystal on the face *(111)* to a depth

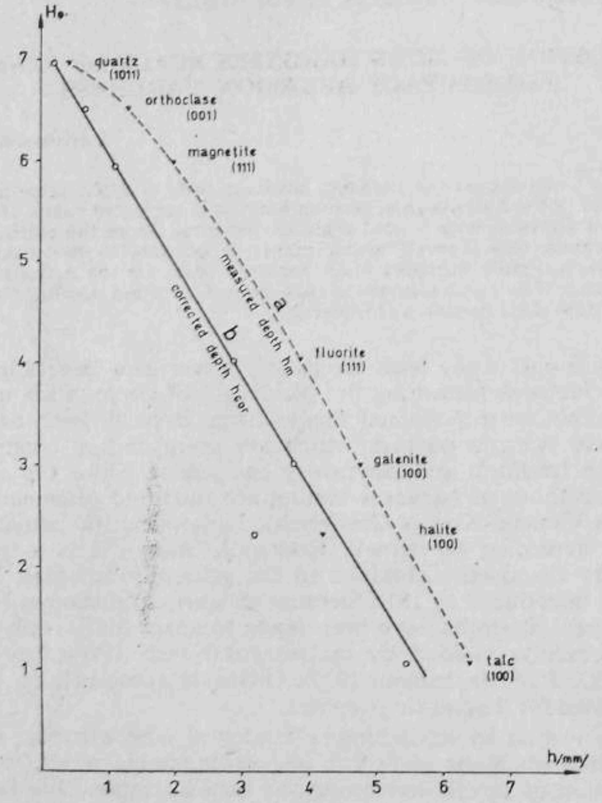

Fig. 1. Relationship between Mohs scale hardness classes according to Khrushchev and impact abrasion hardness tested with quartz grains

H_0 — hardness classes according to Khrushchev in Mohs hardness scale corrected by Povariennych, h — hardness estimated from depth of hole blown by grain stream from 28 cm³ capacity chamber under pressure 1.5 kG/cm²

of 2.00 ±0.05 mm. In view of substantial differences in its composition depending on the manufacturer, glass must be treated as a secondary standard and each batch calibrated in comparison with fluorite or magnetite.

Milligan (1936) was the first to test hardness of minerals by the method of impact abrasion. Later A. Szymański (1972, 1973) made an attempt to interpret abrasion hardness in relation to Mohs scale. As a result of his investigations, he obtained a curve illustrating the relationship between the depth h_m of the hole blown out by the sand stream and the Mohs scale hardness classes H_0 (Fig. 1, curve *a*), proportional to hardness measured with Vickers microhardness tester:

$$H_0 = 0.7 \sqrt[3]{H_v} \qquad [1]$$

where:

H_0 — hardness classes,
H_v — Vickers hardness number in kG/mm².

A change in the shape of curve a for minerals with hardness numbers greater than 5 made it difficult to find a mathematical expression for the relationship between impact abrasion hardness and hardness classes.

Analyses of several cross-sections of samples after abrasion hardness testing (Phot. 1*c*) and an assumption that the mass of abraded material rather than the hole depth is a measure of abrasion hardness permitted the authors to derive formulae describing hardness determined by the method of impact abrasion.

The size distribution curve of grains striking the surface of the tested material is a normal curve; hence, the depth of the hole blown out is different at different points, being approximately constant at the same distance from the hole centre. The bottom of the hole assumes the shape of a spherical cap (Fig. 2). The radius of the sphere was determined experimentally. When a Mackensen sand blower is used for tests, the radius is 3 mm, being equal to the radius of the circle on the surface of the tested material within which abrasion occurs. As appears from the study of the mechanism of hole formation, certain expansion of the abraded area outside the circle is due to the secondary abrasion by the grains and abraded material conveyed with the air blown out through the blower outlet pipe.

Assuming that the mass of the abraded material is proportional to its volume and that the measurement conditions are constant, the relationship between the hole volume and its measured depth h_m was examined.

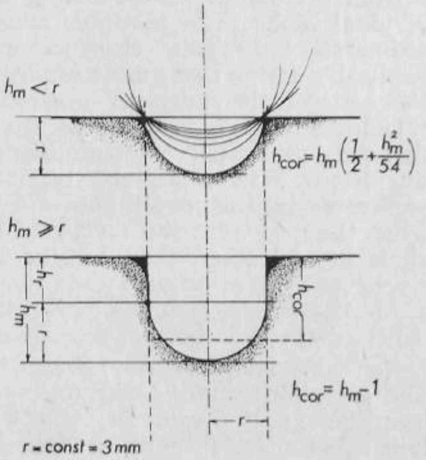

Fig. 2. Geometrical rule of calculation of corrected depth from depth of blown-out hole

Three cases were considered: $h_m < r$; $h_m = r$; $h_m > r$. On account of the constant radius $r = 3$ mm of the blownout holes, the corrected depth h_{cor} was introduced, i.e. the height of a cylinder with the base radius $r = 3$ mm, whose volume is equal to that of the hole (Fig. 2).

If $h_m < 3$ mm, then the measured depth h_m is the loop of the spherical cap, and h_{cor} may be calculated from the formula:

$$h_{cor} = \left(1/2 + \frac{{h_m}^2}{54}\right) \qquad [2]$$

If $h_m = 3$ mm, then:

$$h_{cor} = \frac{2}{3} h_m = 2 \text{ mm} \qquad [3]$$

If $h_m > 3$ mm, then the hole volume may be set up of a cylinder with the base radius of 3 mm and the height $h_r = h_m - 3$ and a hemisphere with a radius of 3 mm. Accordingly,

$$h_{cor} = h_m - 1 \qquad [4]$$

Taking the value of h_{cor} instead of h_m as a measure of impact abrasion hardness, the results of A. Szymański's investigations (1972) were recalculated and plotted on the diagram (Fig. 1, curve *b*).

From the resultant rectilinear dependence the formula [5] was derived which permits recalculating of abrasion hardness to the units of the generally accepted hardness scale for minerals and other materials with continuous structure.

$$H_0 = 7 - 1.05\, h_{cor} \qquad [5]$$

The physical sense of assuming the value of h_{cor} instead of h_m is self-evident because the effect of abrasion in the whole area and by all the sand grains is thus taken into account. The pertinence of this choice is further corroborated by a change of the corrected depth h_{cor} for the individual Mohs scale hardness classes. The curve intersects the axis of ordinates at the point close to hardness of quartz, which is absolutely explicable seeing that quartz sand was used as abrasive. Certain discrepancies between the results of impact abrasion and the values of h_{cor} and H_0 calculated on their basis (Table 1, columns 6 and 7) are due to empirical, therefore somewhat oversimplified, assumptions introduced to the considerations. First of all, the distribution of grain impact on the abraded surface varies with depth. Moreover, the character of abrasion is different when the grains hit the surface at an angle of 90° in the initial stage of abrasion and when they hit the hole bottom of the shape similar to a spherical cap at an angle less than 90°. Neglecting the different energy of blown-out grains in the outlet, the empirical character of the assumption that the hole bottom resembles in shape a spherical cap is obvious.

In Table 1 and Figure 1 worth noting is the value obtained from impact abrasion tests of halite ($h_m = 4.25$ mm) which deviates considerably from the expected value ($h_m = 5.50$ mm). The choice of halite as the standard substituting in gypsum Mohs scale (Povariennykh 1963) is not very fortunate considering its fairly high plasticity under load (A. Szymański 1973). This feature of halite also becomes manifest when testing its hardness by Vickers method.

The suggested method of recalculating the results of impact abrasion to hardness classes H_0 widens the scope of applicability of the latter method. Moreover, it permits scaling of Mackensen blowers on any material whose hardness has been previously determined by one of the microscopic methods. In the case when other abrasives than sand, e.g. corundum or diamond grains, are used in the Mackensen blower, it is possible to test abrasion hardness in the whole range of Mohs scale and to derive formulae similar to the formula [5]. Those formulae would take into account both hardness of the abrasive and the grain habit, which has a bearing on the value of the direction factor of the curve.

Table 1

Impact abrasion hardness of Mohs scale minerals

Mohs hardness scale	Mineral	Symbol of face	Hardness			
			calculated from formula $H_0 = 0{,}7 \sqrt[3]{H_v}$	measured depth h_m (mm)	corrected depth h_{cor} (mm)	calculated from formula $H_0 = 7 + - 1.05\, h_{cor}$
1	2	3	4	5	6	7
1	Talc	*(001)*	—	6.35	5.35	1.38
2	Halite	*(100)*	2.27	4.25	3.25	3.69
3	Galenite	*(100)*	2.97	4.78	3.78	3.03
4	Fluorite	*(111)*	3.99	3.95	2.95	3.90
5	Scheelite	*(111)*	4.98	—	—	no sample
6	Magnetite	*(111)*	5.93	2.00	1.08	5.80
7	Quartz	$(10\bar{1}\bar{1})$	6.96	0.47	0.23	6.77

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Andrzej SZYMAŃSKI, Janusz M. SZYMAŃSKI

ZASADA OBLICZANIA TWARDOŚCI MINERAŁÓW Z PODATNOŚCI NA ŚCIERANIE DYNAMICZNE

Streszczenie

W oparciu o pomiary odporności na ścieranie minerałów skali Mohsa autorzy opracowali wzór pozwalający na wykreślenie skorygowanej krzywej zależności głębokości ścierania ziarnem piaskowym od twardości. Prostoliniowa zależność pozwoliła na sformułowanie wzoru umożliwiającego przeliczanie dla materiałów o strukturze ciągłej ścieralności na twardość według ogólnie przyjętej skali Mohsa. Wyniki wskazują na możliwość stosowania ścieralności dynamicznej do określania twardości minerałów.

OBJAŚNIENIA FIGUR

Fig. 1. Zależność twardości minerałów skali Mohsa, wyrażonej w klasach twardości Chruszczewa i ścieralności dynamicznej ziarnem piaskowym

H_0 — klasy twardości według Chruszczewa wyrażone w skali twardości Mohsa skorygowanej przez Powariennycha, h — twardość wyznaczona na podstawie głębokości otworu wydmuchanego strumieniem piasku z komory o pojemności 23 cm³ pod ciśnieniem 1,5 kG/cm²

Fig. 2. Zasada geometryczna wyprowadzenia h_{cor} w oparciu o głębokość otworu h_m mierzoną iglicą aparatu

OBJAŚNIENIA FOTOGRAFII

Fot. 1. Efekt ścierania halitu na ścianie (*100*) (fot. *a*, *b*) i w przekroju (fot. *c*)

Анджей ШИМАНЬСКИ, Януш М. ШИМАНЬСКИ

ПРИНЦИП РАСЧЕТА ТВЕРДОСТИ МИНЕРАЛОВ НА ОСНОВЕ ПОДАТЛИВОСТИ НА ДИНАМИЧЕСКОЕ ИСТИРАНИЕ

Резюме

На основе измерения сопротивляемости на истирание минералов по шкале Мооса авторы разработали формулу, позволяющую определить кривую зависимости глубины царапания зерном песка от твердости. Прямолинейная зависимость позволила вывести формулу предоставляющую для материалов непрерывной структуры возможность пересчета истирания на твердость согласно обычно принятой шкале Мооса. Результаты указывают на возможность применения динамического истирания для определения твердости минералов.

ОБЪЯСНЕНИЯ К ФИГУРАМ

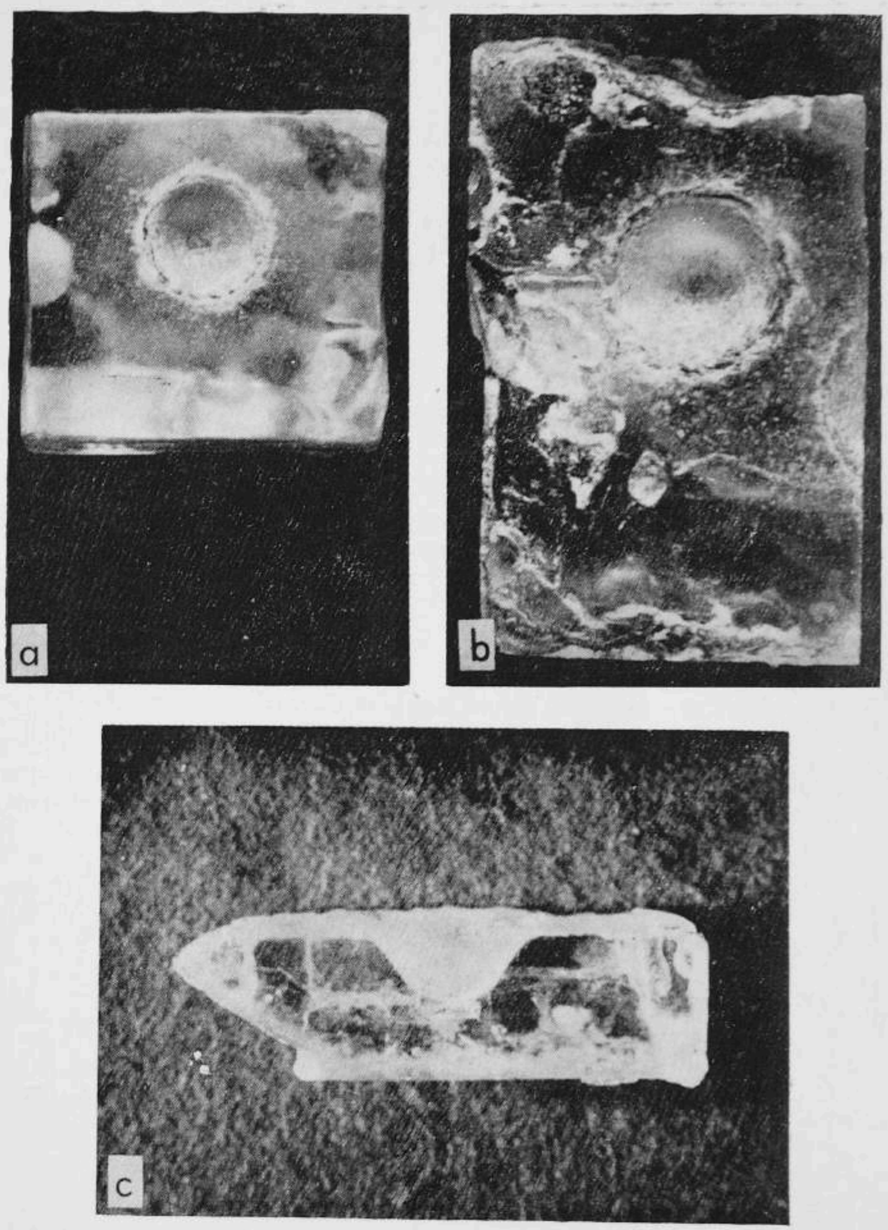
Фиг. 1. Зависимость твердости минералов по шкале Мооса, выраженной в классах твердости по Хрущеву, и динамической истиральностью зерном песка

H_0 — классы твердости по Хрущеву выраженные в шкале Мооса исправленной А. С. Поваренных, h — твердость определенная на основе глубины пробоины выдутой струей песка из камеры емкостью 28 см³ под давлением 1,5 kG/см²

Фиг. 2. Геометрический принцип выведения $h_{\text{направл.}}$ исходя из глубины пробонны $h_{\text{измер.}}$ измеренной иглой аппарата

ОБЪЯСНЕНИЯ К ФОТОГРАФИИ

Фот. 1. Эффект царапания галита на грани (*101*) (фот. *a*, *b*) и *c* разрезе (фот. б)



Phot. 1. Halite crystal after blowing action on face (*100*) (Phots. *a*, *b*) and in section (Phot. *c*)

Andrzej SZYMAŃSKI, Janusz M. SZYMAŃSKI — Calculation of Mohs hardness scale of minerals from impact abrasion hardness