DIRECTIONAL GRINDING HARDNESS IN DIAMOND: A FURTHER STUDY*

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ABSTRACT

Additional results of measurements of directional relative grinding hardness of single crystal diamonds are given for selected planes. The dependence of relative grinding hardness of a given direction upon the position of the plane being ground is illustrated. The relation of grinding hardness to class symmetry is discussed.

In a previous paper[1] the results of the measurement of the relative grinding hardness in oriented planes on single crystal diamonds have been considered. The present paper deals with results of further work in five additional planes.

The experimental technique of the measurement of relative grinding hardness in single crystals has been briefly described in the above-mentioned paper. Essentially a grinding constant, K, the volume of material removed per unit time per unit thrust on a conventional diamond cutter's wheel, was determined simultaneously on two separate crystals for a reference direction and the direction under investigation. The relative grinding hardness is the ratio of the grinding constant of the specified direction with respect to that of the reference direction. In all cases the reference direction used was [100] in (001). In the present tests thrusts of two kilograms were maintained on the stones. The areas of the ground facets were between one-half and two square millimeters.

In zone [010] measurements on planes 5° and 38° from the cube plane are given. The zero azimuth for grinding directions in these planes is a direction toward the cube. For the plane 5° from the cube (Fig. 1), the maxima and minima are located as in the cube. It will be noted that the minimum at zero degrees represents a very hard direction, but that the minima at 90° and 180° represent relatively soft directions. It can be seen from the great changes in the magnitude of the zero degree minimum on this plane as compared with the cube that a very small orientation error on the cube may produce a large change in the relative grinding hardness so that unless a cube plane be oriented with high accuracy (a few minutes of arc) the characteristic four-fold symmetry of the hardness vectors on the cube will not be observed.

If it is assumed that the relative grinding hardness variation with re-

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[1] Denning, Reynolds M., Directional grinding hardness in diamond: *Am. Mineral.*, **38**, 108–117 (1953).

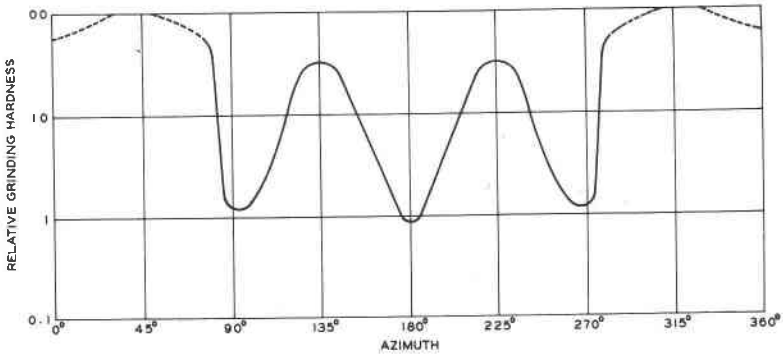

FIG. 1. Zone [010] 5° from cube.

spect to this misorientation is linear, then the rate of change of relative grinding hardness with respect to angular deviation is 20% per minute of arc. This high rate of change explains the extreme sensitivity of the symmetry of grinding rates with respect to small misorientations. With the exception of the great increase in relative grinding hardness in one sector, the curve rather closely resembles the curve for the cube face. The minimum at 180° seems to be a little lower than the corresponding point when the cube is being ground. Unfortunately, the difference lies at about the limit of accuracy of measurement so that this relation may not be significant.

A plane 38° from the cube (7° from the dodecahedron) in zone [010] exhibits the relative grinding hardness variation illustrated in Fig. 2. This plane shows hardness variation of the same order of magnitude as the dodecahedron. (The zero azimuth of the published dodecahedron curve[2]

[2] *Ibid.*, Figure 4.

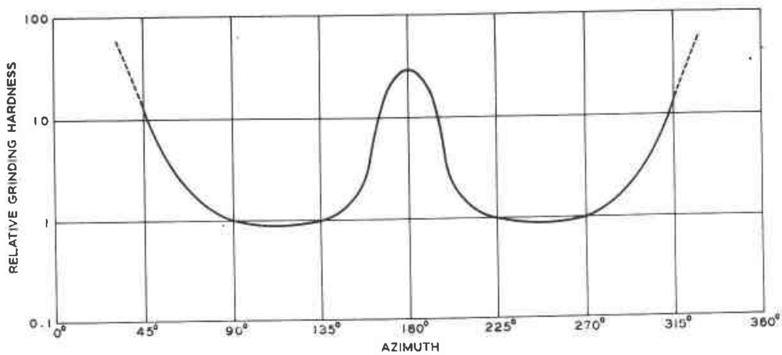

FIG. 2. Zone [010] 38° from cube.

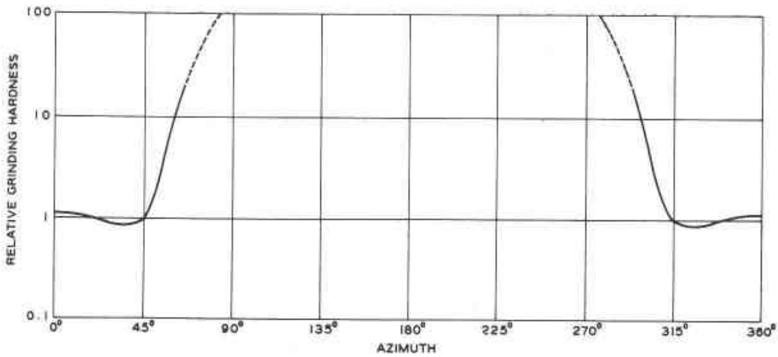

FIG. 3. Zone [$\bar{1}$01] 5° from dodecahedron.

is shifted 90° with respect to other planes in the zone [010].) In the plane 38° from the cube, the hardness minimum is rather broad, covering two 45° sectors. From the shape of this curve it can be seen that small orientation errors of (101) are not serious in the determination of the hardness curve of the dodecahedron, provided that the plane being measured accurately lies in zone [010]. That such is not the case if the plane measured does not accurately contain the [010] direction is illustrated by considering the next plane.

If a plane in zone [$\bar{1}$01], 5° from the dodecahedron, be ground in a series of azimuths and the results plotted, a curve such as that of Fig. 3 is obtained. The zero of azimuth toward the dodecahedron is common to all of the curves for the zone [$\bar{1}$01] (including the dodecadehron, Fig. 4, in the previous paper). A very broad maximum of over 180° is apparent. Experimental difficulties prohibited any reliable measurements in this sector. Probably the minimum of 0.9 at 30° is real, although the deviation from unit hardness here is of the same order of magnitude as the uncertainty of the measurements. From this curve it can be seen that a plane

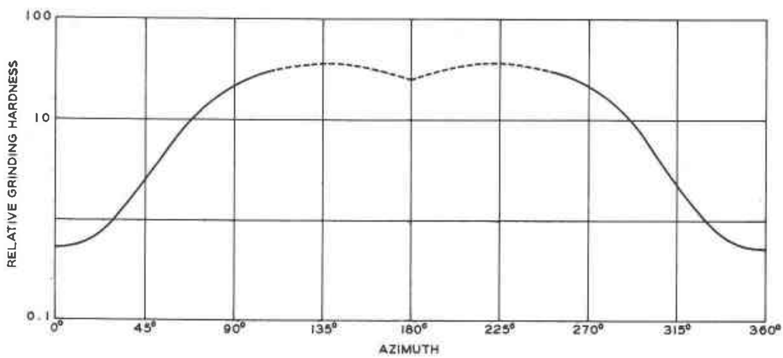

FIG. 4. Zone [$\bar{1}$01] $7\frac{1}{2}$° from octahedron.

accurately oriented in zone $[\bar{1}01]$ but otherwise differing from the dodecahedron by a small angle will produce a large error of hardness measurements with respect to those obtained on a true dodecadehron. This error chiefly occurs in azimuths from 90° to 270°.

Figure 4 represents the relative grinding hardness on a plane in zone $[\bar{1}01]$, $7\frac{1}{2}$° from the octahedron ($27\frac{3}{4}$° from dodecahedron). The direction toward the dodecahedron is most readily cut. The direction toward the octahedron is very hard. The maximum hardness seems to lie at an azimuth of 135°, although satisfactory measurements were not obtained in the sector from 100° to 260°. From this curve it can be seen that a

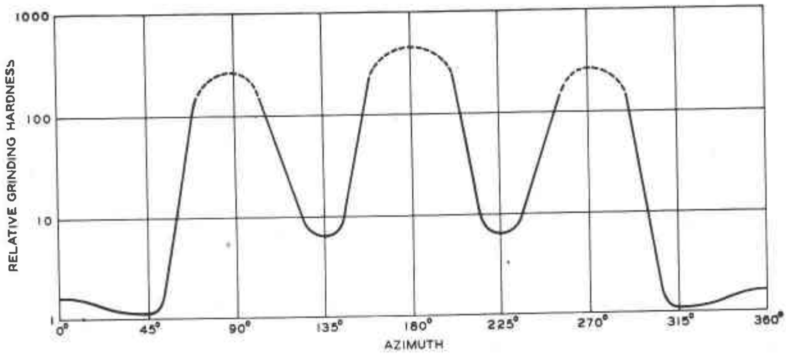

FIG. 5. Zone $[1\bar{1}0]$ 15° from cube.

plane accurately oriented, located in zone $[\bar{1}01]$ but otherwise not accurately located on the octahedron, would show a hardness minimum toward the nearest dodecahedron.

In the remaining important zone, $[1\bar{1}0]$, a plane 15° from the cube was studied. The resulting curve is plotted in Fig. 5 with the zero azimuth taken as a direction toward (111). The maximum at 0° is quite low. This is analogous to the high 45° maximum of the cube shown in Fig. 3 of the previous paper. The greatest ease of cutting in the 15° plane occurs at an azimuth of 45°. This corresponds most closely with the optimum cutting direction of the cube face. It should be noted that in Fig. 6 of the previous paper, illustrating the relative grinding hardness of a plane in zone $[1\bar{1}0]$, 39° from the cube, the zero azimuth is taken as toward the cube. Thus there is an inadvertent 180° shift of zero between these curves.

An attempt was made to obtain a curve on a plane 48° from the cube ($8\frac{3}{4}$° from the octahedron), but the results were not consistent enough to warrant plotting a curve. This plane possesses a very high grinding hardness in a direction toward the octahedron and a lower hardness toward the cube.

So far the variation of hardness along a series of azimuths for each

TABLE 1. DEPENDENCE OF GRINDING HARDNESS IN CERTAIN DIRECTIONS UPON THE ORIENTATION OF THE GRINDING PLANE

Preliminary Data

Grinding Direction		Plane Being Ground		Relative Grinding Hardness
ϕ	ρ	ϕ	ρ	
0	90	—	0	1.0 (assumed)
		90	5	1.2
		90	23	1.3
		90	38	1.0 (?)
		90	45	1.4
90	95	90	5	0.9
		0	90	1.3
270	85	90	5	x0.
		0	90	1.3
90	113	90	23	0.9
		0	90	40.
270	67	90	23	x00.
		0	90	40.
90	128	90	38	30.
		0	90	x00.
270	52	90	38	x00.
		0	90	x00.

plane has been considered. It can be seen from the data presented that for a given linear direction of grinding, the relative grinding hardness is dependent upon the orientation of the plane being ground.

As pointed out by previous investigators,[3] the principal axial directions, those of a four-fold symmetry, are directions of easy grinding, while the diagonal directions, those of two-fold symmetry, are very hard directions. This is true regardless of what plane containing these directions is used for the grinding. When a crystal is ground in the [010] direction, the rela-

[3] Bergheimer, H., Die Schleifhärte des Diamanten und seine Struktur: *Neues Jahrb. Min., Geol. und Pal.*, **74**, 318–332 (1938).

Kraus, E. H., and Slawson, C. B., Variations of the hardness of the diamond: *Am. Mineral.*, **24**, 661–678 (1939).

Slawson, C. B., and Cohn [sic], J. A., Maximum hardness vectors in the diamond: *Ind. Diamond Rev.*, **10**, 168–172 (1950).

Wilks, Eileen M., An interferometric investigation of the abrasion hardness properties of diamond: *Philosophical Magazine*, Ser. 7, 43, 1140, November, 1952.

tive grinding hardness value obtained is dependent upon the position of the "$(h0l)$" surface on which the hardness measurements are made. The dependence of the position of the ground surface along a linear direction is much more striking in more generally located linear directions. Table 1 illustrates, by way of preliminary data, this interdependence.

The linear grinding direction is expressed in ϕ and ρ values. Also the sense of the grinding is defined by these coordinates. It is assumed that the upper portion of the crystal is being ground. The plane in which the grinding direction lies is indicated by the conventional ϕ and ρ of two-circle goniometry. Thus a grinding direction of $\phi=90$, $\rho=95$, indicates that the grinding is toward the front of the crystal, while $\phi=270$, $\rho=85$, indicates that the grinding is toward the rear of the crystal. Only one direction of a kind is specified, inasmuch as the duplication of these according to the hexoctahedral symmetry would unnecessarily lengthen the table.

In grinding direction $\phi=0$, $\rho=90$, i.e. [010], it will be noted that there is a small gradual increase in hardness as the plane is changed from (001) to (101). The low value for the plane of $\rho=38°$ seems rather out of place. More detailed work is planned for this easy grinding direction. For a grinding direction $\phi=90$, $\rho=95$, the plane (010) shows a somewhat greater hardness over the $(h0l)$ plane. However, here an interpolation between 0° and 10° is involved, and the effect may not be significant. For grinding direction $\phi=270$, $\rho=85$, the relative grinding hardness is much greater on the "$(h0l)$" than on (010). Similar relations hold for the last four grinding directions in the table.

Thus it can be seen that the position of a plane being ground may profoundly affect the grinding hardness of a given grinding direction, especially in the more general directions, i.e., those that do not bear special relations to the symmetry directions of the crystal. Consequently, bond strength components in the grinding direction can not by themselves explain all of the observed variations of directional relative grinding hardness.

It will be noted that grinding hardness curves on diamond are indicative of the crystal symmetry. Surfaces accurately located normal to planes of symmetry show in the curves a line of reflection symmetry parallel to the trace of the symmetry plane. If a rotation symmetry axis is normal to the surface being ground, then a point of rotational symmetry is observed in the hardness curve. In the case of diamond, hardness measurements indicate hexoctahedral symmetry.

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