rapid precipitation of silica which may be collected in the bottom sampling. The effects will occur independently of the order of sampling.

The removal of the samples will also cause pronounced cooling of the bomb, depending in part on the rate of sampling. If this is fast, then as the latent heat of vaporization of water is in the range 8–6 k. cals/gram mol over this temperature range, and as approximately a gram mol of water is removed at each sampling, then one might expect cooling of the order of 20–30° C. during the sampling. This effect will further tend to throw the system into the liquid-vapor region and the volumes of sample which could be removed without causing inhomogeneity of the fluid phase will be even smaller than indicated in column V of Table 1.

The conclusion which must be reached from the description of the experiments given by the authors is that the anomalous results for the solubility of albite and quartz found are in all probability related to the drastic changes in the state of the aqueous solvent caused by the sampling technique. With this doubt in mind it would be unwise to place too much weight on the deductions made from the experimental findings.

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DIRECTIONAL HARDNESS VARIATION IN TUNGSTEN CARBIDE (WC) MONOCRYSTALS

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Introduction

During a series of experiments designed to increase the hardness and density of tungsten carbide-cobalt alloys, microhardness tests were made on tungsten carbide single crystals.† Measurement of oriented micro-

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† Crystals supplied by Kennametal Inc., Latrobe, Pa.

indentations showed a hardness variation of almost 50 per cent on the *prism face;* no variation was detected on the *basal pinacoid.* Although accounts of directional hardness variation have been given for diamond (references 1–9), corundum (10–13), silicon carbide (10, 14, 15), and other substances (10, 16), no such property has been reported for tungsten carbide.

Procedure

The crystals used in the investigation displayed trigonal symmetry, having fairly well developed basal pinacoid (0001) and first order prism ($10\bar{1}0$) faces. The specimens varied in shape from equidimensional to tabular and had testing surface areas of 0.15 to 1.5 mm^2. The crystals were black and showed a distinct conchoidal fracture. An x-ray powder pattern of the crushed single crystals showed the presence of only one phase—the monocarbide of tungsten (WC). The specimens for hardness testing were selected on the basis of the quality of their natural faces and the sharpness of their interfacial edges. In a few instances the orientation was confirmed by single-crystal x-ray exposures. The selected crystal faces were cemented to a mounting block by a trace of Canada balsam to maintain their orientation during the setting in bakelite.

Surfaces suitable for microindenting were prepared by grinding first on a resin-bonded diamond wheel, next on a glass plate with 600-grit silicon carbide, and finally on a teakwood wheel with 0- to 2-micron diamond paste. It is believed that this procedure resulted in a minimum of polishing (surface-flow) action.

Indentations were made with a Tukon microhardness tester using a Knoop indenter and a 100-gram load. The mounted crystals were oriented on the Microton stage of the instrument by aligning the sharp interfacial edges with the long dimension of the pyramidal diamond indenter. Indentations were made on both the prism and basal pinacoid. For each crystal, the hardness of a particular azimuth was determined by a series of five microindentations. The latter were measured by three observers, giving 15 readings from which the hardness of each crystal-azimuth was averaged. The microindentations were measured with an oil-immersion objective in the optical system of the Tukon apparatus at an effective magnification of approximately 1600 ×. Orientations were verified on the revolving stage of a petrographic microscope fitted with a vertical illuminator.

Results

The data obtained from this study are summarized in Table 1.

Measurements made parallel and perpendicular to an a axis on the *basal pinacoid* of three crystals (a, b, c) indicated no discernible hardness

TABLE 1. KNOOP MICROHARDNESS DATA (K_{100})

Basal Pinacoid (0001)

Specimen	Parallel *a* axis	Perpendicular *a* axis
a	1830	1770
b	1780	1800
c	1845	1945
Average	1820	1840

*Prism Face** ($10\bar{1}0$)

Specimen	0°	22½°	45°	60°	70°	80°	86°	88°	90°	94°	100°	110°
d	975	1035	1195	—	1565	1810	—	—	1890	—	—	—
e	1105	1135	1255	1425	1650	1830	—	—	2090	—	1836	1660
f	1030	1140	1240	—	1565	1785	—	—	1935	—	—	—
g	1130	—	1285	—	—	—	—	—	2015	—	—	—
h	1115	—	1225	—	—	—	—	—	2075	—	—	—
i†	—	—	—	—	—	—	1900	1970	2000	1945	—	—
j†	—	—	—	—	—	—	1900	1985	2000	1905	—	—
Average	1070	1105	1240	—	1595	1810	1900	1980	2000	1925	—	—

* Angles denote azimuth with reference to *c* axis.

† Corrected values—see text.

variation. Indentations made on the *prism face* of three additional crystals (*d*, *e*, *f*) showed a hardness variation of almost 50 per cent. On the basis of these data, no further measurements were made on the basal pinacoid, and attention was directed toward refining and expanding the data obtained from the prism face.

Figure 1 shows graphically the hardness variation observed on the first order prism face. After the general shape of the function had been determined, it seemed advisable to examine directions immediately adjacent to the hard vector (90° from the *c* axis). Accordingly, two additional crystals (*i*, *j*) were indented at the 86°-, 88°-, and 90°-positions. For correlation purposes, the hard vector measurements were compared with the previously determined average for this direction (based on five crystals). The corrections thus derived (averaging +35 Knoop units) were applied to the measurements at 86° and 88° and the corrected values plotted in Fig. 1. Paired measurements made on either side of the hard vector (crystals *e*, *i*, *j*) demonstrated that the hardness function follows the crystal symmetry, and accordingly the curve was drawn symmetrically about the 90°-position. The average microhardness dif-

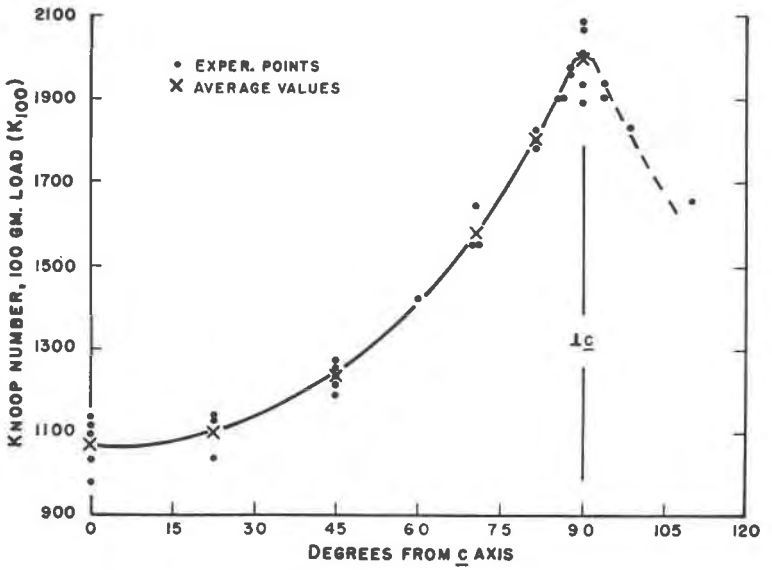

FIG. 1. Variation of Knoop hardness number on the first order prism face of tungsten carbide (WC).

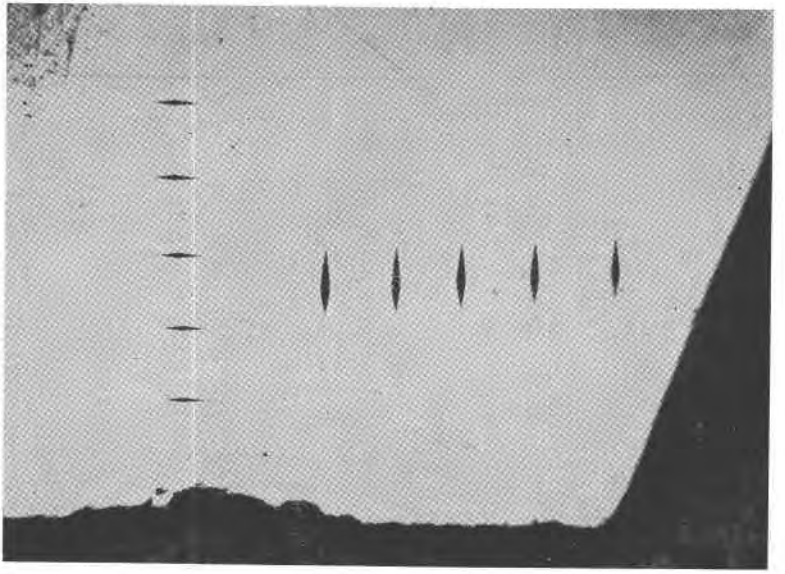

FIG. 2. Knoop microindentations on the first order prism face of tungsten carbide (WC, crystal *d*). The larger indentations are parallel to the *c* axis and approximately 39 microns in length.

ference between the soft direction, parallel to the c axis (1070 K_{100}), and the hard direction, perpendicular to the c axis (2000 K_{100}), is 930 Knoop units, or approximately 47 per cent. This striking hardness variation is shown clearly by the two sets of microindentations pictured in Fig. 2.

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