CUTTING OF DIAMONDS FOR INDUSTRIAL PURPOSES

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Introduction

In recent years there has been a remarkable increase in the use of diamonds for industrial purposes. According to Ball[1] about two-thirds of the annual diamond production by weight, and one-fourth by value, is used in industry. These industrial diamonds are not of gem quality. They are a by-product of the mining of gem stones.

The use of diamonds in drill bits for exploration and mining operations began about 1864.[2] Diamond drilling is now so widely employed that forty-five per cent of the annual use of industrial stones is for this purpose.

Rapid and precision manufacture of metal parts has been a constant aim in industry in recent years. Diamond-set tools were accordingly developed. These tools are used in various cutting, grinding, and machining processes of metal parts and also for trueing and re-surfacing abrasive wheels. They are employed in many industries and are exceedingly important in the manufacture of automobiles and airplanes. Today diamond-set tools account for about thirty per cent of the annual consumption of industrial stones.

A third important use of industrial diamonds is in the drawing of fine wire and filaments of uniform diameter. For this purpose diamonds are pierced with holes. The wire or filament is drawn through such pierced diamonds, called diamond dies, with successively smaller openings until the desired size is obtained. About ten per cent of the industrial diamonds is used annually for diamond dies.

There are other miscellaneous uses of diamonds in industry which account for fifteen per cent of the yearly industrial consumption.[3]

Only in the cutting and mounting of industrial diamonds in some of the diamond-set tools is any particular attention given to the fact that the hardness of the diamond varies materially with the crystal face and with the direction on the faces.[4] In other instances the orientation of the stone is quite random or it may be based upon the development of the diamond, preference being given to stones with a tabular habit regardless of what the largest faces may be.

[1] Ball, Sydney H., The diamond industry in 1939: *The Jewelers' Circular-Keystone,* August, **1940,** p. 15.

[2] Grodzinski, P., *Diamant-Werkzeuge,* Berlin, **1936,** p. 154.

[3] Reference 1, p. 16.

[4] Kraus, E. H., and Slawson, C. B., Variation of hardness in the diamond: *Am. Mineral.,* **24,** 661–676 (1939).

It is the purpose of this paper to describe in general terms the preparation of industrial diamonds for diamond-set tools and diamond dies, and to correlate the practice of the industry with our present knowledge of the variation of hardness in the diamond and its crystal structure.

Diamond-Set Tools

Experience has shown that in shaping a diamond for use as the cutting edge of a machine tool, the edge must be so disposed that it will offer the greatest resistance to breakage. Because of the superior hardness of the diamond, abrasive wear is not the important factor in the life of the tool. It is the excellent cleavage of the diamond that most often causes the tool to fail. The cutting edge, hence, should be formed so as to offer the maximum resistance to cleavage and be shaped so as to eliminate possible chipping. Because a sharp point is more readily chipped, it is preferable to give the tool more body and accordingly the cutting edge is commonly a curved "nose."

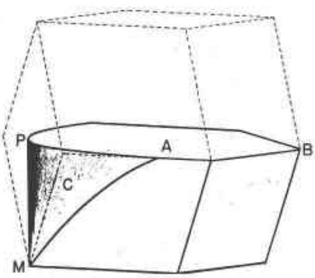

Fig 1

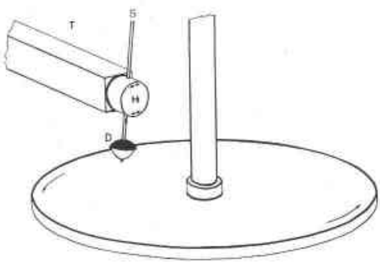

Fig. 2

Figure 1 shows one of the many types of diamond-set tools which possess curved noses. This figure is well adapted to illustrate the various processes that are used in shaping the tool. The top of the tool *A*, is called the "face," and is parallel to one of the planes of the dodecahedron. The part of the tool *C* is called the "flange." The direction *PB* on the face is parallel to the long diagonal of the dodecahedron plane. The direction *PM* on the flange is also parallel to the long diagonal of a second dodecahedron plane. These two planes or crystal faces intersect at 90°. The flange is approximately cylindrical and its axis is parallel to *PM*. The cutting point is at *P*.

In shaping the stone the face *A* (Fig. 1), is cut first. The stone is then placed in a small solder dop *D* (Fig. 2), so that *PB* (Fig. 1), is parallel to the axis of the dop; that is, a dodecahedron face is exposed for cutting the flange. The stem of the dop *S* (Fig. 2), is now placed in the holder *H*, which extends from the end of the "tong" T, and permits the dop to rotate about the axis of the tong. The dop must be so oriented that the direction PM (Fig. 1) is parallel to the axis of the tong. The stone, oriented in this manner in the dop, is placed upon the skeif, so that a portion of the crystal which corresponds to an octahedron face is subjected to cutting. To form the required cylindrical surface the dop must be rocked forward about the axis of the tong. This movement on the skeif must be in one direction only, that is, from an octahedron to a rhombic dodecahedron face, for cutting will take place only in this direction. The tong is then raised from the skeif and the dop rocked back to the original position and the movement repeated. This rocker motion, forward and backward, is repeated rapidly until the surface is finished.

Only one-half of the flange can be cut in this way. This is due to the fact that the hardness of the diamond decreases in passing from an octahedron to a dodecahedron plane and that when the plane of the dodecahedron is reached the sense of the cutting direction is reversed.[5] Hence, it is necessary that the rocker movement start slowly and increase in speed. The cutting ceases abruptly because of the change in the sense of direction when PM (Fig. 1) is reached.

Since only one-half of the flange can be cut in this way, the position of the stone with respect to the skeif must now be reversed in order to cut the other half. This is done by rotating the dop 180° about its axis. The two halves of the curved flange are then lapped into one. Because of the variation in hardness, and hence in the rate of cutting, and also because the two curved surfaces must be carefully lapped into the finished flange, the skill of the workman is the major factor in the efficiency of the operation.

Since the angle between the normals to adjacent faces of the octahedron and the dodecahedron is approximately 35°, a nose with a circular arc up to 70° can be cut by the two operations described. If an arc of more than 70° is desired, additional operations with different cutting directions are required.

As is well known, the cutting of gem diamonds was developed by empirical methods based upon long years of experience. Thus gem cutters discovered very early that the direction of the long diagonal of the dodecahedron face is a hard direction, and accordingly this direction has been called a "rib." The intersection of such ribs is designated as a "hard corner." In the cutting of diamond-set tools the experience and practice of the gem cutting industry have been drawn upon, and, as is evident, the cutting point P (Fig. 1), is a "hard corner."

[5] Reference 4, p. 663 ff.

The life of a tool, as already indicated, depends upon the orientation and the design of the stone. The type illustrated in Fig. 1 has been proven to have the longest life. This is because the cutter has taken advantage of the most favorable inherent properties of the diamond and the manner in which the tool is to be used. The curved surface which is produced by two operations and lapping gives the tool the greatest strength. In the use of the tool the cutting force is applied in a direction parallel to the long diagonal of a dodecahedral plane, which is a rib or resistive direction. In cutting the stone the direction at right angles to a rib, namely, parallel to the short diagonal of a dodecahedral plane, is used because it is a softer direction.

In Fig. 1 the "lip angle," that is the angle between the directions *PB* and *PM* is 90°. In practice it may be necessary to reduce this angle somewhat in order to provide the tool with "end clearance." This is done by giving the face of the tool *A*, the proper inclination to the flange *C*. The nose remains the same and the direction of the cutting force is still parallel to the long diagonal of the dodecahedral plane.

In addition to the tools of the type described, many machining and grinding operations require diamond tools of special design. For example, "chisel-pointed" stones are used to cut the v-shaped depressions of gears. "Pointed" stones are also necessary to cut depressions into the faces of abrasive wheels used to grind gear teeth. All stones for diamond-set tools are shaped entirely by hand, and are carefully checked by projecting an enlarged image of the finished tool upon a large scale drawing which has been made according to the required specifications.

Specially-shaped industrial diamonds are being used increasingly. Their development is greatly retarded, however, because the tool designer does not usually possess an adequate knowledge of the inherent physical properties of the diamond. Thus abrasive hardness is commonly confused with brittle hardness or toughness. Moreover, it is not realized that the diamond cannot be machined like a metal but that the cutting operations on the diamond are dependent upon the selection of favorable directions. This generally causes the tool designer to expect too much of the diamond itself as well as too much from the average diamond cutter.

Diamond Dies

In the preparation of diamond dies it is common practice to select stones with a tabular habit so as to reduce grinding and polishing to a minimum. Such stones are usually distorted rhombic dodecahedrons or octahedrons. The stones are first mounted in metal and then pierced with a small hole of the required dimension in a direction perpendicular to the tabular surface. Generally a slight conical depression is first made with a drill having a sharp diamond point. The actual drilling then takes place. This is essentially a grinding and pecking process. For this purpose a sharp steel point revolves in the conical depression. Fine diamond dust in oil is regularly applied to the revolving point or needle. Depending upon the size of the hole to be drilled the needle revolves from 1500 to 2500 times a minute. The drilling apparatus is so designed that as the needle revolves the mounted stone vibrates gently against the needle point two or three hundred times a minute; that is, as the needle revolves it also pecks. By this pecking process minute cleavage fragments are broken loose which augment the diamond dust in the oil and hence materially hasten the drilling process. It must be pointed out that the actual grinding or drilling is not done by the steel point but by the diamond dust between the needle and the stone.

After the diamond has been pierced in this way, the opening must be accurately shaped and sized and also highly polished. This is accomplished by moving a wire or a revolving needle to and fro in the hole of the diamond, which is constantly rotated. This process is a delicate one and requires carefully adjusted apparatus.

The boring and polishing processes are very slow and may require several days or even weeks of continuous operation. In the preparation of a diamond die as much as twenty to twenty-five per cent of the original weight of the stone may be lost.[6]

As has been indicated, tabular crystals are generally selected for diamond dies for natural and economic reasons. The dominant faces on such crystals are either those of the octahedron or the dodecahedron. If cubical crystals, which are common, were used, or if surfaces on octahedral or dodecahedral crystals were ground parallel to a face of the cube, the boring of the hole and the polishing of the surfaces of the die should be accomplished more readily than when distorted octahedral or dodecahedral crystals are used. This is because the cube face is softer than either of the other faces and also because the direction of the hole would be parallel to a crystallographic axis. According to theory the hardness of the stone in this direction is less than in the others. Moreover, the hardness of the diamond is greatest on faces of the octahedron. On faces of the dodecahedron it is intermediate between those of the cube and of the octahedron.

In the present practice of drilling diamonds for use as wire-drawing dies the ultimate effect of the excellent cleavage does not seem to have been adequately taken into account. The effect of the cleavage will be

[6] Reference 2, p. 181.

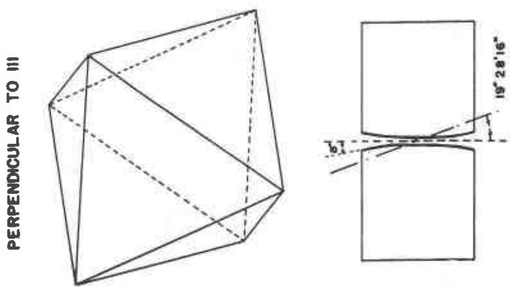

FIG. 3

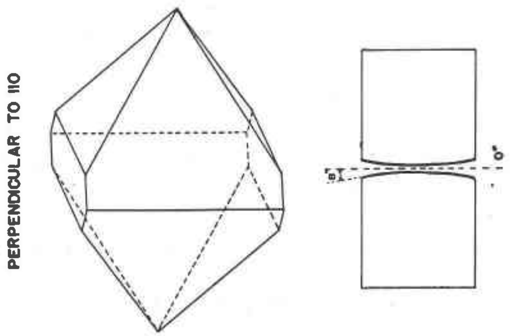

FIG. 4

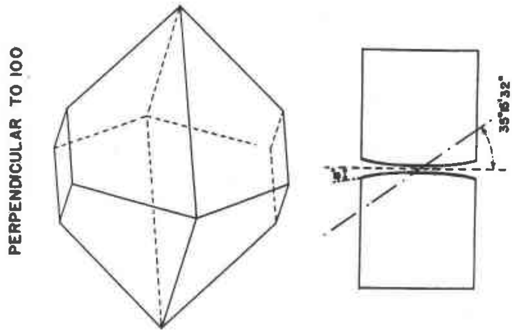

FIG. 5

discussed for three directions of drilling, namely, perpendicular to a plane of

1. the octahedron,
2. the rhombic dodecahedron, and
3. the cube.

1. When drilled perpendicular to an octahedron plane (Fig. 3), three cleavage directions are inclined at about 19° to the axis of the hole, while the fourth is perpendicular to the hole. If, as is frequently the case, the conical wall of the entrance opening makes an angle of about 8° with the axis, it follows that the direction of the drawing force of the wire impinges upon the wall of the opening which makes at three points an angle of 11° with each of the three cleavages. If the angle of the entrance opening is increased, this approximate parallelism becomes greater and at 19° the parallelism is complete.

2. When the diamond is drilled perpendicular to a rhombic dodecahedral plane (Fig. 4), there are two cleavages exactly parallel to the axis of the hole and two which are inclined at angles of 55°. It is well known that cleavage takes place most readily when a force is applied parallel to a cleavage plane, especially if the cleavage is a perfect one as is the case in the diamond.

3. When the hole is drilled perpendicular to a plane of the cube (Fig. 5), the four possible cleavage planes are all equally inclined to the axis, at approximately 35°.

Since cleavage breaks are frequently the cause of the failure of dies, it would appear that the axis of the hole should not, for obvious reasons, be parallel or approximately parallel to cleavage planes, but rather should be inclined to them at as large an angle as possible. From the above discussion it is evident that cleavage failures are more likely to occur when the holes are drilled perpendicular to planes of the dodecahedron or of the octahedron than when perpendicular to the cube.

In order that a wire-drawing die may render the maximum efficiency the constancy of the drawing hole should be maintained for the longest possible period, that is, the hole should remain circular and of fixed diameter. This is very essential since dies are used in a continuous series, that is, in a train, and the wire is drawn through them at speeds of 3000 to 12,000 feet per minute, depending upon the diameter and composition of the wire.

Experience shows that with use the circular holes of the dies tend to change in form. They frequently become elliptical. These changes in form may, it is thought, be correlated with the variation of hardness with direction, and with the crystal structure of the diamond. Investigation of these changes should prove fruitful.

Acknowledgments

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