The Diamond as a Phonograph Stylus Material

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A thorough knowledge of the characteristics of diamonds is required in the preparation of phonograph styli. The authors show photographs which compare wear of different stylus materials.

UPON EXAMINING the physical properties of groups of raw materials found in nature, we generally find small increments in the values of these properties. Diamond is the outstanding exception to this rule in that it possesses durability and hardness values which exceed those of the closest comparable material—sapphire—by almost a hundred fold.

Diamond was recognized, even in antiquity, as possessing properties which have made it the most valuable material (except for some radio-active elements) on earth. These properties are durability, beauty, and rarity.

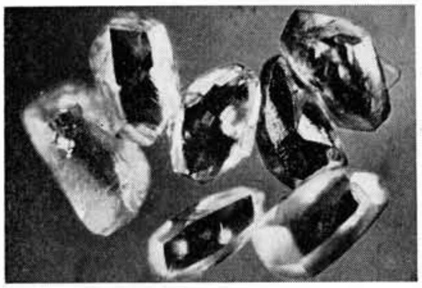

Fig. 1. Small fine industrials. Selected whole diamonds used in manufacture of playback styli. Preferred to cleavages due to greater structural strength. Weight before processing 0.2 gm; after processing, 0.04 gm.

For technical purposes, we are most concerned with the durability and hardness of diamond.

Formation and Occurrence of Diamond

Diamond is pure crystalline carbon occurring sparingly in volcanic rock. Carbon, trapped in molten lava and subjected to tremendous pressure and heat, crystallizes slowly to form diamond. Although it is supposed that all diamonds were formed in this manner, only in South Africa do we actually find large volcanic intrusions or "pipes" containing deposits of diamond. Diamonds found in other parts of the world, the Belgian Congo, Brazil, India, Borneo and Australia, are found in alluvial deposits. The original volcanic sources remain undiscovered. Africa produces about 95 per cent of the world's production, which has amounted to as much as 13,000,000 carats yearly (one carat = 0.2 gms).

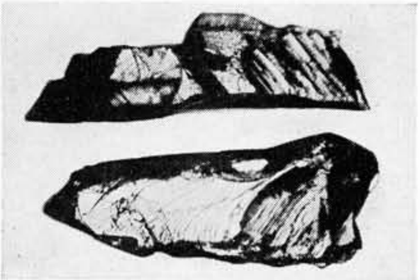

Fig. 2. Diamond cleavages, or chips from larger stones.

The diamond-bearing volcanic pipes in South Africa were discovered accidentally between 1866–1888. These pipes, called blue ground, contain approximately 1 part of diamond in 15,000,000 parts of rock. The soft blue ground is mined, crushed and washed in troughs containing grease pans. Diamond, having a great affinity for oil or grease, sticks to the grease in the pans, and the stones are then collected and sorted.

Classification of Diamond

There are various types of diamonds, and each has its specific application. The most valuable are the large, clear white, nearly flawless stones which are used for gem purposes. However, there are other types used for industrial purposes which possess the same physical and chemical properties but are unsuited for gems. Diamonds may be transparent, cloudy or opaque, clear white, or colored in various hues. The qualities of those diamonds suited for use as styli for audio equipment will be discussed in this paper. Commercial diamonds are classified in several groups, two of which are:

(1) **Fine Industrials:** Diamonds unsuited for use as gem stones due to small size, color or presence of small inclusions. In all other respects these stones are similar to the diamonds used for gem purposes.

(2) **Cleavages or Splints:** Chips cleaved from larger stones, usually during gemstone production. Lack the structural strength of small fine industrials. Sometimes employed for use as phonograph styli due to the comparative ease of fabrication.

Fabrication of Diamond Styli

There are three principal methods of shaping diamond for industrial use, namely bruiting, lapping, and sawing. All other methods are usually variations of the three employing special fixtures.

All methods use diamond in some form to reduce the size or change the shape of another diamond. Diamond is the only material hard enough to cut diamond effectively. Large stones are sometimes cleaved along cleavage planes which can be determined by experts.

Bruiting

The bruiting operation is similar to freehand wood turning in a lathe, using a tool rest. The diamond to be worked is placed in a special holder, called a *dop,* and put in the lathe chuck. A diamond tool placed in a long-handled holder and braced under the arm is worked against

Fig. 3. Each diamond stylus must be inspected carefully on a shadowgraph.

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the spinning diamond in the lathe. This method is quite effective for rapid removal and rough shaping of diamond cones.

Lapping

This is the term used to describe the polishing of diamond surfaces and usually means the generating of a facet on a stone. Lapping is done on a rapidly spinning, porous cast iron wheel which has been impregnated with a mixture of diamond powder and olive oil. The stone is held in the dop and placed in a removable arm called a *tang*. It is then placed against the lap or wheel. Diamond crystallizes in the cubic system and has three equal axes intersecting at 90 deg. Lapping can only be done along planes which have a definite relation to these axes. Under the usual lapping conditions, diamond will not polish or cut readily against the so-called *grain* or out of relation to these planes. Therefore, in the polishing of diamond facets it is necessary to orient the stone properly to obtain the lapping direction. In polishing a cone and radius on a diamond, it is evident that rotating the diamond cone will encounter grain running in several directions and that conventional polishing methods can not be used. It was found necessary to polish at extremely high speeds with very fine diamond powder to develop a high polish on the cone and radius of the stylus. The entire polishing apparatus must be free of vibration and exceptionally accurate.

Sawing

Diamond can be sawed with a thin phosphor bronze saw charged with diamond powder and olive oil. Diamond impregnated metal saws are also used. The diamond to be sawed is nicked with a sharp pointed diamond and moved into the saw. There are optimum sawing directions, depending upon the crystal structure of the stone.

Chemical and Physical Properties

Lavoissier discovered that diamond consisted of carbon when he burned diamond at high temperatures to form carbon dioxide, CO_2. Diamond can be burned in oxygen between 700° and 900° C.

Diamond is very resistant to strong acids and alkalis. Concentrated solutions are frequently used to clean the stones. A mixture of sulphuric acid and potassium bichromate can oxidize diamond slowly at 200° C. Diamonds are cleaned of foreign matter from the mines by storing in hydrofluoric acid. They are cleaned after processing by cooking in a concentrated solution of potassium hydroxide, usually followed by a second cooking in sulphuric and nitric acid. Aqua regia is sometimes used to clean diamonds.

Remarkable as diamond is in its resistance to chemical action, it is even more outstanding in its amazing physical properties. The compact arrangement of the carbon atoms in the diamond has resulted in an extremely durable and hard material.

The following is a list of physical properties of diamond compared with alternative materials:

TABLE I

	Diamond	Alternative Material
Resistance to abrasive wear (Rosiwal)	90,000	Sapphire 1,000
Wear resistance, path of turning tool (Grodzinski)	1,250	Carbide 12.5–20.5
Ratio of time required to saw given area (Grodzinski)	100–300	Sapphire 1.0
Indentation Hardness (Knoop)	6000–6300	Sapphire 1600–2000
Initial bearing friction (Shotter)	0.70	Sapphire 1.13–1.60
Breaking load on a radius (Schuler)	25	Sapphire 5
Compressibility (Williamson)	0.18	Sapphire 0.38
Surface Finish (Kayser)	Better than any other material	
Index of refraction-sodium	2.419	Glass 1.426
Dispersion	2.465	Glass 1.532

Note: Moh's scale (1820) which gives comparative but not quantitative hardness values of gem materials has been omitted. Moh listed gem materials in order of ability to resist scratch marks.

The question is frequently asked, "How hard is diamond?" This is a difficult question to answer, since hardness is a composite property embracing many characteristics. When one thinks of something as being hard, he is at the same time thinking of a number of properties such as resistance to wear, ability to resist indentation of a sharp point and non-compressibility. For example if we say a piece of wood is hard, we mean it cannot be sawed or chopped easily, or that it is difficult to drive a nail into it. If we say a piece of metal is hard, we may mean that it cannot be filed, sawed, or bent readily. Therefore, an answer can only be given in terms of the job being performed by the given materials. Numerical results for comparative hardness and durability of materials will vary from one set of conditions to another. However, a glance at the table of comparative physical properties shows that diamond has a tremendous advantage over its next best alternative material in resistance to abrasive wear, breaking load on a radius, indentation hardness, and compressibility.

Phonograph Stylus Wear Tests

Tests have been conducted to determine the comparative durability of various stylus materials.

When a playback stylus touches a record groove, only a small area of the stylus tip actually makes contact with the groove walls. The pressure per square inch may amount to several tons. The dynamic forces acting on the stylus tip are several and severe. Hard record materials containing abrasive have a greater ability to wear styli, but soft record materials often become imbedded with abrasive particles which also can cause rapid stylus wear. Stylus wear is rapid at first, and then, as the contact area becomes larger and the pressure per square inch decreases, wear continues at a slower rate. This effect is noticed with new clean records; however, as records become worn and the grooves become progressively loaded with abrasive particles, the rate of stylus wear may continue at a comparatively rapid rate.

The softer stylus materials have a great tendency to load the record grooves with abrasive particles, as shown by G. A. Briggs. It is a fallacy that styli made of soft materials cause less record wear. Brigg's photomicrographs show steel flakes imbedded in the groove walls after only one playing of a new shellac disc by a steel needle. Another photomicro-

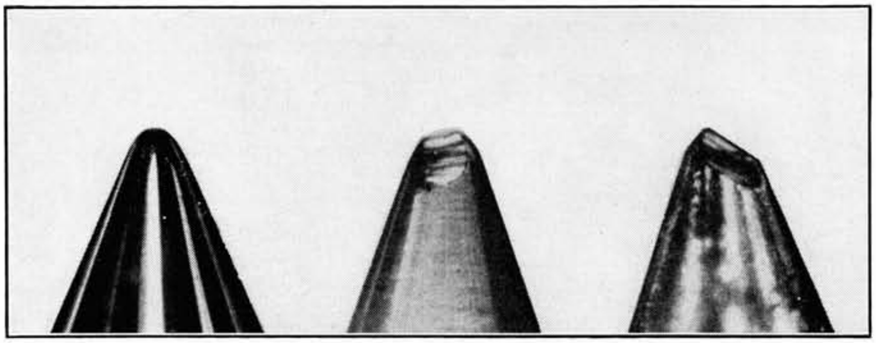

Fig. 4. Showing different 1.0-mil styli after fifteen plays on 12-inch Vinylite records with an 8-gram pickup. Left, diamond; center, sapphire; right, osmium.

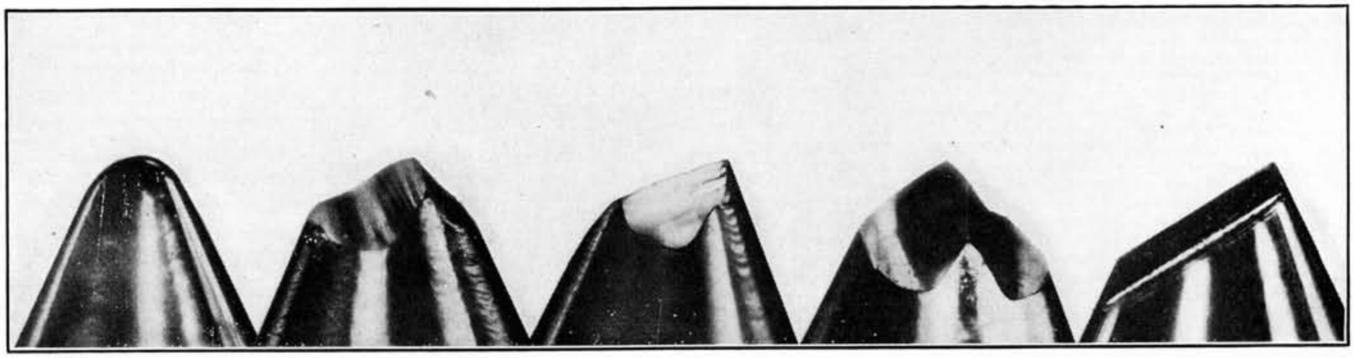

Fig. 5. 2.5-mil styli after 1000 plays on 10-inch Vinylite records with a 1¼-ounce pickup. From left to right: diamond; sapphire, front view; sapphire, side view; osmium, front view; osmium, side view.

graph shows a fibre needle completely abraded after one playing. These conditions lead to excessive record wear and poor response.

Our tests were conducted on Vinylite records, both standard groove 78 r.p.m., and microgroove 33⅓ r.p.m., using three stylus materials, diamond, sapphire, and osmium. The following conditions were observed for all styli under test:

TABLE II

	Standard Groove	**Microgroove**
Record Material	**10″ Vinylite**	**12″ Vinylite**
Record Player	**Garrard Changer**	**Webster 3 speed changer**
Cartridge	**Astatic L 70**	**G. E. RPX-041**
Pick-up weight	**1¼ oz.**	**8 gms.**
Radius of stylus	**2.5 Mils**	**1.0 Mil**

Test methods were made to conform to the severe playing conditions usually encountered with home-type equipment, and both tests were repeated twelve times to eliminate the possibility of error.

The results of the standard groove test showed that after 1000 plays, or approximately 50 hours playing time, wear on both the sapphire and osmium tips was very severe. Considerable wear was noticed as early as 100 plays. There was complete conformity to groove shape after 1000 plays. The diamond stylus did not show any wear after 1000 plays. Shadowgraphic tracings were made after each 100 plays and showed the progression of wear on the sapphire and osmium tips. Photomicrographs were taken of the stylus tips after 1000 plays. Two views were photographed, one parallel to the groove position and the other perpendicular to the groove.

Superimposing the osmium shadowgraph tracing over the sapphire tracing, we found the same amount of wear for sapphire at 1000 plays as for osmium at 400, or a 10–4 ratio. Since the amount of material removed from the diamond was so slight as to escape notice at 500 times magnification, the ratio of resistance to wear could be written: Diamond ∞, Sapphire 10, Osmium 4. However, we know that eventually even the diamond will begin to show wear.

The results of the micro-groove test were rather surprising. We found that after only 15 plays or 5¾ hours playing time, both the sapphire and osmium tips were very badly worn, and the test was stopped at that time. Again the osmium wore out faster than the sapphire. Photomicrographs and tracings were made at the completion of the test. The diamond showed no sign of wear after 15 plays. The microgroove diamond was continued in use for a total of 100 plays or 37 hours. A slight flat was noticed on the diamond at the end of 37 hours.

Apparently, stylus wear is far more rapid on microgroove than on standard groove records. A rough estimate is about three times faster. The rate of wear of the 1.0-mil osmium and sapphire styli caused by microgroove playing is so rapid as to make these materials unsuited for continuous use on microgroove records.

To return now to the hardness values given in the table, we can see that it is necessary to conduct tests under the conditions of use before hardness values can be assigned to any materials.

If we could accurately weigh the stylus tips before and after the tests, it is quite certain we would find a difference between the diamond and sapphire in excess of the 90–1 ratio given by Rosiwal.

According to Ridgway and Eppler, the differences in relative mechanical corrosion hardness become smaller as the hardness of the material used for the corroding or abrading increases. They used a sand-blast technique in determining the resistance of various materials to corrosion. As the hardness of the powder used for the sand-blast was increased in going from quartz to sapphire to silicon carbide, the differences in the hardness values for the test materials become smaller. We observed corresponding results in our stylus wear tests. As we have already shown, the wear ratio between diamond and sapphire when played on Vinylite records is far above the Rosiwal 90–1 ratio, while this difference is not quite as great when these materials are used on shellac records.

Other results of our stylus and record wear tests showed that wherever there was excessive stylus wear it was always accompanied by excessive record wear. The badly worn styli are unable to track properly and have a tendency to chop off the high-frequency crests in the grooves. It was observed that stylus pressure, pick-up arms, and cartridges have a great effect on stylus and record wear. Considerable variation in rate of stylus wear was noticed in making wear tests on different types of equipment. For example, one professional arm caused 1.0 mil styli to wear out about five times faster than did other arms designed for amateur use.

Quality of response deteriorates gradually as stylus wear increases. This deterioration is noticed more readily on good quality audio equipment. On home-type equipment, with its narrower frequency range, stylus wear is usually not noticed audibly until it has become very bad. The gradual wear over a long period of time occurs slowly, and therefore the listener does not readily notice the change. He cannot remember how his equipment sounded six months before when the stylus was new. This has the unfortunate effect of causing excessive record wear by continuing the worn stylus in use.

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