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MAGNETIC PROPERTIES OF GEM-QUALITY SYNTHETIC DIAMONDS

By George Rossman and Joseph L. Kirschvink

Measurements of the magnetic properties of four gem-quality synthetic diamonds indicate that higher levels of permanent magnetism can be induced in the synthetics than could be induced in a number of gem-quality natural stones. As received, the colored and included synthetics showed much higher levels of magnetism than the natural stones, but one near-colorless synthetic had less magnetism than many of the natural stones. Most of the magnetism of the natural stones is due to surface contamination, which can only be removed by rigorous acid cleaning. After cleaning, the natural diamonds were not only less magnetic than all of the synthetic stones, but they were also more resistant to demagnetization. Significant levels of metallic impurities were detected in most of the synthetics. These results on a limited number of samples suggest that natural diamonds can be distinguished from synthetics on the basis of their magnetic properties, but that in the case of near-colorless, inclusion-free stones, such tests may require sophisticated instrumentation.

The existence of synthetic gem-quality diamonds and speculation about their possible introduction into the commercial market has raised the need for a test to distinguish between visually flawless natural and synthetic diamonds. When we first considered this problem, we speculated that submicroscopic residues of the metallic catalysts used during synthesis could be included in the stones. Such residues are commonly found in non-gem-quality synthetic diamonds (Wedlake, 1979). These residues should be weakly magnetic but detectable with sensitive instruments. When we were informed that some of the synthetic diamonds studied at GIA were attracted to a hand magnet (Koivula and Fryer, 1984), we tested a variety of synthetic and natural diamonds both for their existing magnetism and for their response to induced magnetism. The results showed some relationships that might be useful in the development of reliable tests to distinguish natural from synthetic diamonds.

MATERIALS

Three groups of synthetic diamonds were examined: (1) the three faceted (near-colorless, bright yellow, and grayish blue) stones and largest unfaceted near-colorless crystal described by Koivula and Fryer (1984), (2) an 83.9-mg lot of about 200 deep yellow industrial-quality crystals also made by General Electric, and (3) a 108-mg lot of about

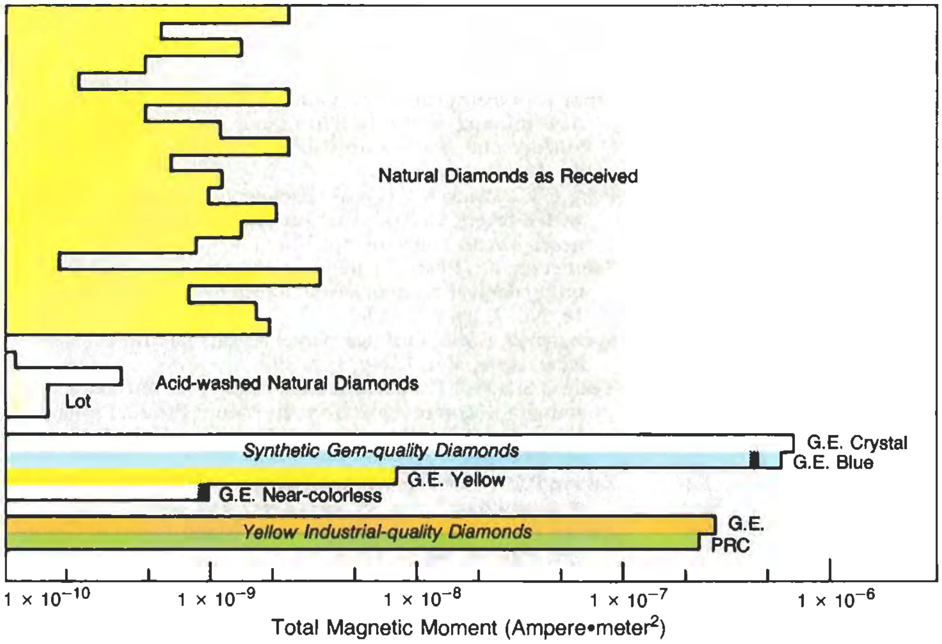

Figure 1. Intensity of magnetization of the natural and synthetic diamonds studied. Values are indicated both for the stones as received and after acid cleaning. The values for the acid-washed natural diamonds represent the minimum and maximum values observed, and the combined value for a lot of 18 stones. The values for the two synthetic gem-quality stones that were acid-washed are indicated by the shaded regions. The yellow industrial stones did not change magnetization appreciably upon acid treatment.

300 deep yellow-green industrial-quality crystals synthesized at the Academica Sinica Institute of Geochemisty, Guiyang, People's Republic of China (PRC), which were chosen to represent a different technology of synthesis.

For comparison, the following natural stones were examined: a lot of 60 colorless to pale yellow faceted stones (ranging from 0.2 to 0.4 ct), six 0.3–0.4 ct stones irradiated to various colors, nine brown to gray industrial grade crystals (about 1 ct each), and an approximately 300-mg lot of colorless melee.

TEST FOR PERMANENT MAGNETISM

Our initial tests consisted of measuring the permanent magnetism contained within the stones as received. Microscopic particles of catalysts such as iron contained within the diamonds will acquire magnetism and will behave like miniature magnets. To detect this magnetism we used an ultrasensitive instrument that utilizes a superconducting detector operating at −269°C (called a Superconducting Quantum Interference Device, or a SQUID Magnetometer, for short) following techniques described by Kirschvink (1983). This instrument can detect the magnetism produced by as little as a few picograms (10^{-12} gram) of most ferromagnetic materials, particularly after they have been briefly exposed to a strong magnetic field.

All of the diamonds initially tested were magnetic, although most of the synthetic stones were stronger than the natural ones (figure 1). Aware, however, that the cutting and polishing processes used to prepare these stones can leave submicroscopic metallic inclusions on their surfaces, we cleaned all of the natural stones and most of the synthetic ones in hot, concentrated hydrochloric acid while in an ultrasonic water bath. The results of this treatment on the natural stones were quite dramatic: It reduced their magnetization by nearly one order of magnitude (again, see figure 1). In contrast, the acid wash produced only minor changes in the two gem-quality synthetic stones washed and in the batch of small, uncut yellow G.E. synthetic diamonds. We did not acid treat synthetic stones with visible inclusions at the surface to avoid destroying the inclusions.

As indicated in figure 1, the level of magnetism of the faceted near-colorless synthetic stone is too

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low to allow the stone to be distinguished from natural stones by readily available methods such as attraction to a hand magnet. Furthermore, several natural diamonds were more intensely magnetic than this synthetic stone before acid treatment. The technique of testing the attraction of the stone to a magnet while suspended in a liquid of a comparable density (Koivula and Fryer, 1984) greatly improves the sensitivity of the hand-magnet test, but such results must be interpreted with caution because the attraction of a stone to the magnet can be due to the presence of either ferromagnetic or paramagnetic impurities. Ferromagnetic materials, such as iron and its alloys, are permanently magnetic; paramagnetic components, such as some forms of nitrogen and some mineral inclusions, will cause the stone to be attracted to the magnet but do not carry any permanent magnetism themselves. The instrument we used responds only to the ferromagnetic components of the diamonds.

COERCIVITY SPECTRUM

Because there is no assurance that future batches of colorless synthetic diamonds will have levels of magnetism as high as the weakest synthetic encountered in this study, we also measured some of the other magnetic properties of the synthetic stones, including the coercivity spectrum. This is a measure of the magnetic field strength required to either magnetize or demagnetize the magnetic components of the stone. In general, this property depends in a complex fashion on the chemical and structural composition, particle size, and spatial arrangement of the magnetic inclusions within the material. All of the gem-quality synthetic stones we examined had median coercivities in the 10 to 50 millitesla (100 to 500 Gauss) range, numbers that are comparable to the magnetic field strength used to record information on magnetic recording tapes. Although there are a number of materials (including a variety of magnetic alloys), that have coercivities in this range, many other materials (including other alloys and materials such as hematite and some hardened steels), with coercivities greater than 1 tesla, can be excluded as the origin of the magnetism.

For the stones that we examined, the coercivity data indicate that the synthetic diamonds all lose their internal magnetism more readily than the natural diamonds. Whether or not this property could form the basis of a definitive test can be determined only after the magnetic properties of a larger number of natural and synthetic diamonds are tabulated. Such a test would be especially useful because it would not depend on absolute amounts of magnetic impurities in the stone.

CHEMICAL ANALYSIS

In an attempt to verify the presence of magnetic elements, several of the synthetic diamonds were subjected to X-ray fluorescence analysis. While traces of metallic elements could be detected in all cases (see table 1), the amounts detected decreased as the intensity of the color of the stones decreased (with the exception of the colorless crystal containing the large metallic inclusion). The proportions of the impurity elements also varied among the stones. Nickel was prominent in the more highly colored stones, but at low concentrations; it was not detected in the pale blue and colorless ones. Although yellow and blue in diamonds is usually associated with nitrogen and boron, respectively, these elements were not determined in

Table 1. X-Ray fluorescence analysis of various synthetic diamonds.[a]

Synthetic diamonds	Cr	Mn	Fe	Co	Ni	Proportions
G.E. colorless faceted	0	0	29	0	0	Fe
G.E. grayish blue faceted	0	0	371	0	0	Fe
G.E. bright yellow faceted	0	0	85	0	63	$FeNi_{0.74}$
G.E. colorless crystal	0	0	2295	0	19	$FeNi_{0.01}$
G.E. deep yellow industrial	308	206	2044	0	683	$FeNi_{0.33}Cr_{0.15}Mn_{0.10}$
Chinese yellow-green industrial	0	8988	151	594	8887	$MnNi_{0.99}Co_{0.07}Fe_{0.02}$

[a]*The proportions are given on the basis of the wt.% of the elements present, but they have not been calibrated in absolute concentrations. The numbers indicated for each element are counts per unit time multiplied times a sensitivity factor for that element.*

this study. The role of the metals in causing or modifying the color, particularly in the case of the yellow stones, has also not been addressed. It is questionable whether the low concentrations of metals found in the colorless synthetic stone would be useful as a test in view of the known occurrence of low levels of iron and other metals in natural diamonds (Fesq et al., 1973).

CONCLUSIONS

This study has shown that the General Electric gem-quality synthetic diamonds contain impurities which allow the stones to carry permanent magnetism. X-ray fluoresence analyses indicate that these impurities are traces of the metallic catalysts used in their synthesis. Some natural diamonds may also contain small amounts of magnetic impurities and have a much greater amount of magnetic contamination on their surfaces. The colored synthetic diamonds, both gem quality and industrial quality, could be magnetized to a greater degree than any natural stone examined, but one near-colorless synthetic was weaker than several natural diamonds before acid washing. The synthetic diamonds were distinguished from rigorously cleaned natural diamonds by their higher level of ferromagnetic impurities and by the ease with which they lost their magnetism. For the near-colorless stones, the levels of magnetism are low and sensitive instruments were required to measure them.

These results indicate that there are fundamental differences between the magnetic properties of natural and synthetic diamonds that can form the basis for a distinguishing test. The types of tests used in this study, while highly sensitive, use instruments that are only practical for the research laboratory. Before the results of this study can be furthered to develop a routine test, the data base needs to be expanded to include a greater number of both synthetic and natural diamonds to ensure that the range of variation in magnetic properties has been covered.

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