FEATURE ARTICLES

Detecting HPHT Synthetic Diamond Using a Handheld Magnet

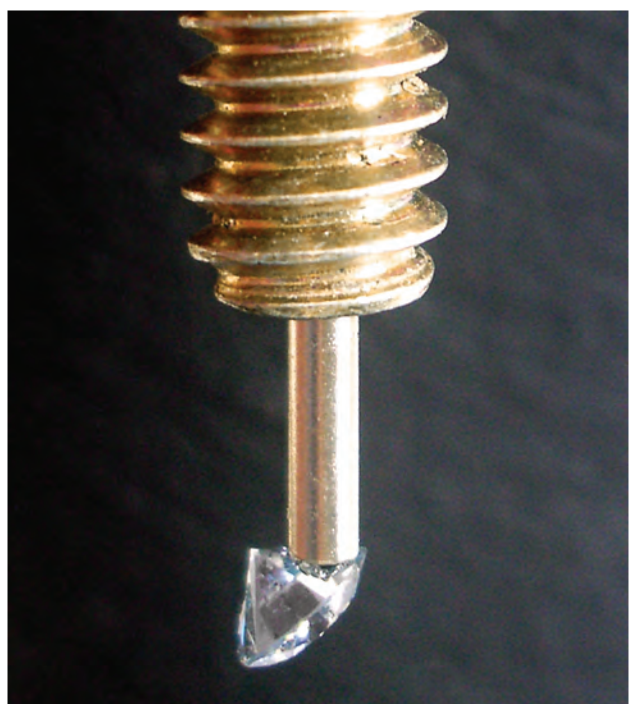
Kirk Feral

This study investigated the effectiveness of a handheld magnet in detecting synthetic diamonds. A total of 104 synthetic diamonds from nine different manufacturing sources were tested. Of the HPHT-grown synthetic samples tested, 58% registered a detectable magnetic response. Strong N52-grade neodymium magnets were able to detect 35% more HPHT synthetics than traditional ferrite and alnico magnets. CVD-grown synthetic diamonds showed no magnetic attraction. A set of 168 natural diamonds, including HPHT-treated natural diamonds, was tested as a control group. None of the natural transparent diamond samples showed attraction to a neodymium magnet, but two heavily included translucent specimens with unusually large opaque inclusions were strongly magnetic. A new magnetic testing method is presented for detecting small magnetic inclusions in loose HPHT-grown products, and for identifying small synthetic diamonds mounted in jewelry.

Instruments used by gem testing labs to identify synthetic diamonds, such as the DiamondView and DiamondSure, are specialized and costly. Electronic diamond testers that measure a gem's thermal conductivity to detect imitations are readily available to consumers, but these instruments cannot distinguish natural from lab-grown diamonds. Spectrometers, microscopes, polariscopes, and UV lamps are standard gemological tools that can be effective in detecting signs of synthetic origin, but only if one knows how to use them and interpret the results. For those without training or access to such equipment, a handheld magnet can serve as a practical and inexpensive tool (Matlins and Bonano, 2008). This study attempts to evaluate the effectiveness of magnetic testing for separating natural from synthetic diamonds.

For decades, gemologists have known that synthetic diamonds grown under high-temperature, high-pressure (HPHT) conditions often contain iron-rich flux particles that are sufficiently large and abundant to cause visible attraction to a magnet (Webster, 1970, p. 332; Koivula, 1984, figure 1). Since natural

Figure 1. Magnetic attraction is an almost certain indication of HPHT synthetic diamond. In this photo, a blue 0.22 ct HPHT synthetic diamond is being picked up by a 1⁄16 in. diameter neodymium magnet at the site of a flux inclusion located below the surface of the pavilion facets. Photo by K. Feral.



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diamonds normally show no magnetic attraction, any positive response is generally considered an indicator of synthetic origin.

This distinction is critical for determining value, as a synthetic diamond sells for considerably less than a natural stone of similar quality. Melee-size goods (under 0.20 ct) are of particular concern, as these generally go untested and their origins may be unknown to the appraiser, gem dealer, or buyer. A study by Kitawaki et al. (2008) identified nearly 10% of the loose yellow melee-size diamonds tested as HPHT-grown synthetics. In that same study, tests on fine jewelry containing yellow melee diamonds showed that half of the pieces each contained an average of 10% HPHT-grown samples.

Laser inscriptions used by most manufacturers to brand their products are seldom applied to melee-size goods. In the current study, loose melee comprised half of the HPHT synthetic diamonds tested, and half of these small samples could be detected with a magnet. Techniques developed during this study provide a means to test individual diamonds mounted in jewelry for synthetic origin, including melee-size goods.

BACKGROUND

Test samples were obtained from all major manufacturers of gem-quality synthetic diamonds, as well as two manufacturers of industrial-grade synthetics (DeBeers and Sumitomo). Table 1 shows how HPHT-grown samples responded to a handheld magnet. Direct responses are further classified as either "Pickup" or "Drag" responses. Fewer than half of the samples showed this type of obvious response. Weaker responses, made visible by floating the individual sample on a small raft in water, are noted as Strong, Weak, or Diamagnetic (repelled).

Relative to the total mining output of gem-quality diamonds each year, synthetic diamond production is still quite small, but their presence in the jewelry trade is growing. Until recently, most gem-quality synthetics were grown using the HPHT process, which has a production time of several days and involves ferromagnetic flux metals such as iron, nickel, and (to a lesser extent) cobalt. Yellow is the most common bodycolor encountered in HPHT-grown synthetic diamonds.

Newer to the trade are synthetic diamonds grown by chemical vapor deposition (CVD) without flux metals or high pressure. This process generally takes longer than HPHT growth, and most CVD synthetics are currently limited to sizes less than 1 ct. At the present time, CVD products are generally colorless, although pink and a number of other colors can be induced after CVD growth by processes such as HPHT treatment, low-temperature annealing, and irradiation (Kitawaki et al., 2010). Methods of synthesis continue to evolve, and some industry observers estimate that the annual production of gem-quality CVD-grown synthetic diamonds now significantly exceeds that of HPHT-grown material (A. Grizenko and S. Pope, pers. comm., 2012).

Figure 2. Five magnets of different sizes and strengths were compared in testing HPHT-grown synthetic diamonds for magnetic response. Left to right: a ½ in. diameter ferrite disc wand, a 1 in. wide alnico horseshoe magnet, a ⅕ in. diameter Hanneman wand, a ½ in. diameter N52 neodymium wand, and a 1⁄16 in. diameter N52 neodymium pinpoint wand. Photo by K. Feral.

Published reports that mention magnetic testing of synthetic diamonds often do not specify the type, size, or strength of the magnets used, or the rate of detection achieved. Traditional magnets such as ferrite refrigerator magnets (containing iron oxides) and alnico (aluminum-nickel-cobalt) horseshoe magnets have been employed by gemological researchers, as well as Dr. William Hanneman's neodymium magnetic wand. The Hanneman wand, introduced as a synthetic diamond tester in 1995, contains a 5 mm diameter neodymium-iron-boron magnet of unspecified grade.

The effect of magnet strength on the rate of detection has not been investigated until now, nor has there been an attempt to standardize testing procedures to the strongest permanent magnet available today, the N52-grade neodymium magnet. This study compares alnico, ferrite, and neodymium magnets as testing tools (figure 2), and looks at the rele-

TABLE 1. Magnetic responses for 85 HPHT synthetic diamonds.

Sample	Weight (ct)	Color	Cut	Response	Sample	Weight (ct)	Color	Cut	Response
DeB 21301	0.06	Colorless	Round brilliant	Diamagnetic	Chat PR13	0.85	Pink	Round brilliant	Pickup
GTL 30580	2.42	Yellow	Rough	Pickup	Chat PR14	0.55	Pink	Round brilliant	Weak
GTL 30579	3.66	Yellow	Rough	Pickup	Chat PR15	0.07	Pink	Round brilliant	Diamagnetic
GTL 30578	3.81	Yellow	Rough	Pickup	Chat PR16	0.06	Pink	Round brilliant	Diamagnetic
Sum 28756	0.37	Yellow	Partially faceted	Diamagnetic	Chat PR17	0.06	Pink	Round brilliant	Diamagnetic
Sum 28753	0.17	Yellow	Square	Diamagnetic	Chat PR18	0.06	Pink	Round brilliant	Diamagnetic
Sum 28521	0.18	Red	Square	Diamagnetic	Chat PR19	0.05	Pink	Round brilliant	Diamagnetic
Sum 28518	0.36	Yellow	Tabular	Pickup	Chat PR20	0.06	Pink	Round brilliant	Diamagnetic
Sum 28516	0.35	Red	Tabular	Diamagnetic	Chat PR21	0.06	Pink	Round brilliant	Diamagnetic
Sum 28513	0.19	Yellow	Round brilliant	Weak	GDC LG7401	0.33	Yellow	Radiant	Diamagnetic
Sum 28507	0.12	Yellow	Tabular	Diamagnetic	GDC LG7402	0.34	Yellow	Radiant	Diamagnetic
Sum 17729	0.80	Yellow	Partially faceted	Diamagnetic	GDC LG8314	0.32	Yellow	Emerald	Diamagnetic
TCG 21892	0.12	Red	Hexagon	Diamagnetic	GDC LG8118	0.34	Yellow	Princess	Diamagnetic
TCG 21891	0.13	Yellow	Hexagon	Weak	GDC LG8203	0.34	Yellow	Princess	Weak
TCG 21006	0.61	Yellow	Partially faceted	Pickup	AOTC YB84	1.10	Yellow	Round brilliant	Drag
UIM 21500	0.17	Yellow	Round brilliant	Pickup	AOTC BB414	0.77	Blue	Round brilliant	Pickup
UIM 21305	0.08	Colorless	Round brilliant	Pickup	AOTC YB136	0.62	Yellow	Round brilliant	Diamagnetic
UIM 21304	0.23	Colorless	Partially faceted	Diamagnetic	AOTC B407	0.56	Blue	Round brilliant	Pickup
UIM 21303	0.06	Blue	Round brilliant	Pickup	AOTC B192	0.51	Blue	Round brilliant	Diamagnetic
UIM 21300	0.17	Colorless	Square	Diamagnetic	AOTC BB242	0.30	Blue	Round brilliant	Diamagnetic
UIM 20490	0.50	Brown	Partially faceted	Pickup	AOTC BB79	0.28	Blue	Round brilliant	Diamagnetic
UIM 20489	0.55	Brown	Partially faceted	Pickup	NAD YR001	0.47	Yellow	Rough	Pickup
UIM 20488	0.68	Brown	Partially faceted	Strong	NAD YR002	0.54	Yellow	Rough	Pickup
UIM 20426	0.16	Yellow	Tabular triangle	Weak	NAD YR003	0.61	Yellow	Rough	Weak
UIM 20425	0.17	Brown	Tabular triangle	Diamagnetic	NAD YR004	0.46	Yellow	Rough	Pickup
UIM 20423	0.46	Yellow	Tabular	Weak	NAD YR005	0.42	Yellow	Rough	Pickup
UIM 20201	0.17	Yellow	Tabular triangle	Diamagnetic	NAD YR006	0.30	Yellow	Rough	Pickup
UIM 20195	0.45	Yellow	Tabular	Diamagnetic	NAD YR007	0.24	Yellow	Rough	Pickup
UIM 20194	0.46	Yellow	Tabular	Diamagnetic	NAD YR008	0.29	Yellow	Rough	Pickup
UIM 20193	0.16	Yellow	Tabular triangle	Diamagnetic	NAD YR009	0.29	Yellow	Rough	Pickup
UIM 19368	0.09	Yellow	Cube	Diamagnetic	NAD YR0010	0.08	Yellow	Rough	Diamagnetic
UIM 17799	0.15	Yellow	Square	Diamagnetic	NAD YR0011	0.06	Yellow	Rough	Diamagnetic
UIM 17621	0.06	Colorless	Round brilliant	Diamagnetic	NAD YR0012	0.14	Yellow	Rough	Pickup
UIM 17620	0.19	Blue	Partially faceted	Pickup	NAD YR0013	0.07	Yellow	Rough	Pickup
UIM 17619	0.05	Colorless	Round brilliant	Pickup	NAD YR0014	0.04	Yellow	Rough	Pickup
UIM 21499	0.16	Yellow	Round brilliant	Weak	NAD BR001	0.16	Blue	Rough	Drag
UIM 24030	0.22	Blue	Round brilliant	Pickup	NAD BR002	0.09	Blue	Rough	Pickup
UIM 28754	0.19	Yellow	Baguette	Diamagnetic	NAD BR003	0.03	Blue	Rough	Pickup
UIM 23580	1.07	Yellow	Square	Strong	NAD BR004	0.04	Blue	Rough	Pickup
UIM 21501	0.14	Yellow	Round brilliant	Strong	NAD BR005	0.25	Blue	Rough	Pickup
UIM 28957	0.58	Yellow	Partially faceted	Pickup	NAD BR006	0.35	Blue	Rough	Pickup
UIM 0212	>0.50	Yellow	Faceted	Pickup	NAD BR007	0.02	Blue	Rough	Drag
Chat PR12	0.65	Pink	Round brilliant	Pickup					

Abbreviations: DeB=De Beers, TCG=Tairus Created Gems, GTL=Golden Triangle Ltd., Sum=Sumitomo Electric, Chat=Chatham Created Gems, GDC=Gemesis Diamond Company, AOTC=AOTC Group B.V., NAD=New Age Diamonds, UIM=Unidentified Manufacturer

BOX A: TERMINOLOGY OF MAGNETISM

1. **Magnetic:** In the context of this paper, referring to any material that displays visible attraction to a handheld magnet.
2. **Diamagnetic:** Having a temporary low magnetization that is opposed to the inducing field of a magnet and is consequently repelled by it. Using a strong neodymium magnet, we can clearly demonstrate this phenomenon by placing a diamagnetic material such as natural diamond on a raft floating in water. The raft moves away from the magnet.
3. **Paramagnetic:** Having a temporary magnetization that is induced when an external magnet is applied. Paramagnetic materials have a weaker magnetic response than ferromagnetic materials, and they cannot be permanently magnetized. Many colored gemstone materials (such as garnet) are paramagnetic, showing visible attraction to an N52-grade neodymium magnet.
4. **Ferromagnetic:** Referring to an element such as iron, nickel, and cobalt that retains permanent magnetization in the absence of an applied field. Such materials are picked up by a magnet, and their magnetic attraction is up to a million times stronger than that of paramagnetic materials.
5. **Ferrimagnetic:** Referring to a strong, permanent magnetization that occurs in materials where the magnetic fields associated with individual atoms align themselves—some in parallel (as with ferromagnetism) and others in opposite directions. Magnetite is a ferrimagnetic mineral.
6. **Antiferromagnetic:** A type of ordered magnetism that occurs in a material when electron spins are alternately opposed, resulting in almost no external magnetization. Like ferromagnetic and ferrimagnetic substances, antiferromagnetic materials exhibit strong, direct responses to a magnet.
7. **Magnetic Susceptibility:** The ratio of a material's induced magnetization to the applied field of a magnet, this represents how strongly or weakly a material responds to a magnetic field. The degree of magnetic susceptibility can be measured precisely with instruments such as a magnetometer or magnetic susceptibility balance (Hoover, 2007).

vance of magnet size and strength in separating synthetic diamond from natural.

Natural diamond is considered non-magnetic—or more precisely, diamagnetic (repelled by a magnet), as its primary component is carbon, a diamagnetic element. (See box A for explanations of magnetic terms used in this article.) Previous studies have shown that magnetic minerals are commonly found as inclusions in natural diamond. Yet the microscopic size of these inclusions renders them magnetically undetectable except by ultrasensitive instruments such as a SQUID magnetometer (Rossman and Kirschvink, 1984; Yelisseyev et al., 2008).

The most common magnetic mineral found in natural diamond is pyrrhotite, a ferromagnetic iron sulfide mineral that, like all natural diamond inclusions, generally measures less than 0.5 mm (Clement et al., 2008). Pyrrhotite inclusions are dark, opaque particles that can be mistaken for "carbon spots." Another relatively common magnetic inclusion in natural diamond is chrome pyrope garnet, a paramagnetic gem mineral that may appear as red transparent crystal inclusions.

Other magnetic inclusions such as chromite and hematite (both antiferromagnetic) and native iron (ferromagnetic) are only rarely encountered in diamond (Boyd and Meyer, 1979). It would be difficult to find a natural diamond with magnetic mineral inclusions of any kind large enough to be detected with a handheld magnet (Koivula, 2000, p. 134). Prior to this study, no such cases had been reported.

In Brief

- Simple testing methods using N52-grade neodymium magnets detect a significant percentage of HPHT synthetic diamonds. The detection rate with traditional magnets is substantially lower.
- CVD-grown synthetic diamonds contain no detectable metallic impurities and cannot be separated from natural diamonds using magnetic testing.
- This study documents the first case of a natural faceted diamond attracted to a handheld magnet due to natural mineral inclusions.
- Small diamonds mounted in jewelry, including melee-size gems, can be individually tested for synthetic origin using a small 1/16 in. diameter N52 magnet in conjunction with flotation.

Aside from magnetic mineral inclusions, natural diamonds are subject to surface contamination from tiny amounts of iron deposited by a metal dop stick or polishing wheel during the faceting process. Shen and Shigley (2004) documented a diamond that showed a visible magnetic response due to iron residue deposited inside cavities at the girdle and pavilion facets during polishing. One magnetic natural diamond in the current study was found to contain similar surface inclusions, which appeared to result from contamination during polishing.

Nevertheless, these metallic impurities in natural diamond are typically insignificant compared to those found in synthetic diamond, and normally they are not detectable with a magnet (Barnard, 2000, p. 94). The same applies to surface contamination of bruted (unpolished) girdles, where routine handling with tweezers can leave minute amounts of iron residue. No such contamination of bruted girdles was detected with a magnet during this study.

MATERIALS AND METHODS

Natural Diamonds. A total of 168 natural diamonds were tested as a control group, all ungraded as to type or clarity. The majority were colorless transparent rounds, but a few yellow and brown diamonds and an irradiated blue were among the test samples. All specimens, whether loose or mounted, were floated on a small raft in water to maximize the sensitivity of the magnetic tests.

GIA provided 50 untreated colorless natural diamonds ranging from 0.34 to 0.90 ct (figure 3, left). Most were eye-clean, while some had bruted girdles and one contained numerous black inclusions. GIA also supplied two gray/black carbonado rough diamonds from Sierra Leone (see box B).

Suncrest Diamonds provided 58 faceted HPHT-treated natural diamonds. They ranged from 0.05 to 0.70 ct and included colorless, yellow, pink, and green specimens (figure 3, right). Some of these samples may have been subjected to additional treatment by irradiation. Unlike the HPHT growth process, HPHT treatment of diamonds to enhance or alter color and improve clarity does not involve flux metals. Magnetic flux inclusions are not found in HPHT-treated diamonds.

A private collection of 48 natural diamonds mounted in vintage gold jewelry was also tested. This collection was assembled more than 30 years ago, prior to the use of synthetic diamonds in jewelry. These samples ranged from approximately 0.01 to 2 ct. Two contained microscopic red and orange-red crystal inclusions, possibly garnet. The vintage mounted diamonds and other natural diamond samples not provided by GIA or Suncrest were subjected to thermal conductivity testing, UV testing, and high-power magnification to verify their identity as natural diamonds rather than simulants or synthetics.

After a selective online search, two natural diamonds with exceptionally large opaque inclusions were acquired for this study. Theoretically, if para-

BOX B: NATURAL BLACK DIAMOND

The color of most natural black diamonds found in jewelry results from treatments such as irradiation, heat, or HPHT treatment. Naturally colored black diamond known as *carbonado* is mined in central Africa and Brazil for industrial purposes, but it is also occasionally faceted for jewelry use. These translucent to opaque gems are generally considered diamagnetic, as the black coloration is due primarily to numerous carbon inclusions in the form of graphite. Rough carbonado specimens tested in this study were not attracted to a magnet (figure B-1).

The only type of naturally colored black diamond that characteristically exhibits magnetic attraction is stewartite, a strictly industrial-grade bort from South Africa. This opaque polycrystalline diamond derives its strong magnetic properties from ferrimagnetic inclusions of magnetite (Bibby, 1982).

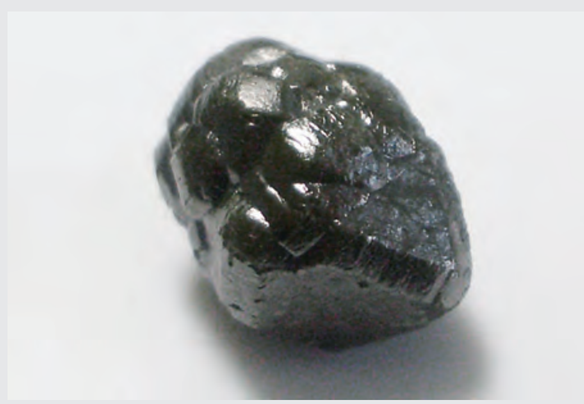


Figure B-1. This 3.11 ct rough carbonado diamond from Sierra Leone is diamagnetic. GIA Collection no. 5914; photo by K. Feral.

Figure 3. Untreated and treated natural diamonds were included in the study. On the left are three untreated samples provided by GIA: 0.64, 0.41, and 0.90 ct. On the right are four HPHT-treated natural diamonds from Suncrest Diamonds: a 0.43 ct colorless round, a 0.63 ct pink oval, a 0.66 ct green shield, and a 0.70 ct yellow round. Photos by K. Feral.

magnetic inclusions of garnet or ferromagnetic inclusions of pyrrhotite were large enough (over 0.5 mm) and concentrated close enough to the surface of a natural diamond, such a diamond could show visible attraction to an N52-grade neodymium magnet if the sensitive flotation method were applied. Both diamonds contained inclusions larger than 0.5 mm, and both exhibited magnetic attraction.

Synthetic Diamonds. A total of 85 HPHT-grown synthetic diamonds were examined, ranging from 0.02 to 3.81 ct. Faceted gems represented 51% of the sample set (figure 4), while the remainder were rough, partially faceted, or tabular in form. A few HPHT synthetic samples were completely colorless, but most showed various intensities of yellow, blue, pink, or red color.

Of the 85 HPHT-grown synthetics, 41 with unspecified acquisition dates were provided by the GIA Museum, 43 were recently supplied by the manufacturer, and one was recently made available by the Morion Company. Of the 41 GIA samples, 27 were from unidentified manufacturers and the remaining 14 were acquired from Sumitomo Electric (Japan), Tairus Created Gems (Russia), Golden Triangle (Russia), and De Beers (South Africa). The sources for the 43 HPHT diamonds recently loaned by the manufacturer were New Age Diamonds (Russia), AOTC Group B.V. (Netherlands), Chatham Created Gemstones (United States), and Gemesis Diamond Company (United States).

An additional 19 CVD-grown synthetic diamonds were tested. Scio Diamond Technology provided 14 colorless CVD-grown samples in the form of unpolished transparent wafers and blocks ranging from 0.25 to 0.57 ct, with 1–2 mm thicknesses. Gemesis Corp. provided five colorless faceted CVD synthetics in various shapes ranging from 0.27 to 0.30 ct.

Magnets. To determine whether magnet strength is a significant factor in detecting ferromagnetic inclusions in synthetic diamonds, HPHT synthetics were tested using five magnets of different strength. (Because they lack flux inclusions, the CVD samples were tested only with the two strongest magnets). The most powerful magnet, a ½ in. neodymium cylinder with a pull force of 18 pounds, was estimated to be more than 30 times stronger than the weakest magnet, a ½ in. ferrite disc. The five magnets are presented here in the order of weakest to strongest relative to pole surface area:

1. ½ in. diameter pole × $\frac{3}{16}$ in. ferrite disc of unspecified grade
2. 1 in. alnico horseshoe magnet of unspecified grade with ¼ in. square poles
3. Hanneman wand with $\frac{1}{5}$ in. diameter pole × $\frac{1}{16}$ in. neodymium disc of unspecified grade

Figure 4. Magnetic attraction was observed in all three of these faceted HPHT synthetic diamonds, but only the 0.22 ct blue and 0.08 ct colorless samples were picked up by a magnet. Flotation was required to detect the weak magnetic attraction of the yellow 0.16 ct synthetic. Photo by K. Feral.

4. 1⁄16 in. diameter pole × ¼ in. N52-grade neodymium cylinder
5. ½ in. diameter pole × ½ in. N52-grade neodymium cylinder

Although the grade of the Hanneman wand was unknown, it exhibited a weaker pull force than an N42-grade neodymium magnet of the same dimensions. Other than the horseshoe magnet, the magnets were assembled as wands by attaching a handle.

Testing Methods. Three methods of magnetic testing were employed: the direct method, the flotation or floating method (Gumpesberger, 2006; see also www.gemstonemagnetism.com), and pinpoint testing. First, the magnet was placed directly against the surface of a sample to see if it would be picked up or dragged along a smooth dry surface. If no response was noted, the flotation method was employed. This test involved placing the sample on a foam raft floating in water, thereby reducing friction and greatly enhancing the sensitivity of the magnetic test. While the observer held the exposed pole end of the magnet near the surface of the sample, movement of the raft toward the magnet was noted as either weak or strong. Movement away from the magnet was noted as diamagnetic. Whenever a diamagnetic response was noted, the sample was subjected to the pinpoint method.

Flotation tests using a ½ in. diameter neodymium magnetic wand showed that the carbon body of a synthetic diamond could induce a diamagnetic (repelling) response that essentially masked localized ferromagnetism of small flux inclusions. Overcoming this problem required a wand that could be directed at specific areas of a sample where small inclusions were located. A 1⁄16 in. (1.5 mm) diameter neodymium magnet, the smallest diameter N52-grade magnet available today, was found suitable for that purpose. A pinpoint wand fashioned with this small magnet and used in conjunction with the flotation method proved effective in detecting small magnetic inclusions in HPHT synthetic diamonds that were not detectable by magnets with larger pole surfaces (see figure 5, left). Responses elicited by this method were at times extremely weak.

This study identified another important use for the pinpoint method. A pinpoint wand was effective in individually testing small diamonds (including melee size) mounted in jewelry for magnetic response. Jewelry pieces containing multiple diamonds were floated on a raft, and a pinpoint wand was directed at individual gems (figure 5, right). Fine jewelry castings of high-purity gold or silver are diamagnetic and therefore do not interfere with pinpoint testing. Because platinum is a paramagnetic metal, gems mounted in platinum castings are not suitable for magnetic testing.

RESULTS AND DISCUSSION

Natural Diamonds. Sensitive flotation and pinpoint testing with strong N52-grade neodymium magnets did not detect a positive magnetic response from any of the 166 transparent natural diamonds, including HPHT-treated natural diamonds and samples containing small inclusions. Any iron residue that might have been de-

Figure 5. Pinpoint testing with flotation may be required to detect magnetic attraction in synthetic diamonds containing tiny metallic inclusions, such as the 1.07 ct yellow HPHT-grown sample on the left. This method can also be used to test individual small diamonds mounted in jewelry, as depicted on the right with a gold and diamond ring undergoing flotation testing. The raft material is Styrofoam. Photos by K. Feral.

Figure 6. These are rare examples of magnetic natural diamond. The translucent 0.37 ct diamond on the left has a large metallic inclusion, likely surface residue from polishing, in and around a central pit in the table. The 0.61 ct translucent stone on the right contains very large natural mineral inclusions (likely pyrrhotite) that are strongly magnetic. Photos by Kevin Schumacher.

posited on the surfaces of these diamonds due to frequent handling with tweezers was not detected either.

The two heavily included translucent natural diamonds containing exceptionally large opaque inclusions (over 0.5 mm) were strongly magnetic. These inclusions were visible with the unaided eye and showed magnetic attraction to a pinpoint wand. Diamonds such as these, with large inclusions and low clarity, are not typically found in jewelry.

One of these magnetic natural diamonds was a translucent brownish red 0.37 ct round with numerous gray-black inclusions visible at the surface but not in the interior (figure 6, left). Several of these inclusions were situated in and around relatively large cavities on the table and pavilion surfaces. The largest one, centrally located on the table facet, measured 0.65 mm. When a ½ in. N52-grade magnet was applied, it dragged this diamond across a smooth, dry surface. A pinpoint wand revealed that only the inclusions were responsible for the magnetism. Alnico and ferrite magnets were not strong enough to elicit a direct response from this diamond. Although the composition of the magnetic inclusions is unknown, their appearance is consistent with that of iron residue from the polishing process, as described in the previously cited report on a natural transparent pink diamond picked up by a magnet (Shen and Shigley, 2004).

The other magnetic natural diamond was a brownish yellow 0.61 ct round containing several large black inclusions (figure 6, right). The largest of them, 1.7 mm across and situated near the girdle, extended well into the interior of the diamond. Another large inclusion located just below the table did not extend to the surface. High-power magnification showed that some of the inclusions were fibrous, while most appeared in velvety black clumps.

This diamond did not respond to the direct method of magnetic testing, but the flotation method revealed a strong overall magnetic response. The largest inclusions were tested individually using an N52 pinpoint wand, and each showed a strong response. The composition of these inclusions has not been analyzed, but we can expect that sulfides are involved, with pyrrhotite as the likely magnetic component. This is the first reported case of a facetable natural diamond attracted to a magnet due to natural mineral inclusions.

Synthetic Diamonds. Like the transparent natural diamonds tested in this study, the 19 CVD-grown synthetic diamonds from Gemesis and Scio Diamond Technology showed no magnetic attraction. Black opaque inclusions were visible on the surface of several rough samples from Scio, but they were most likely composed of polycrystalline carbon, a diamagnetic material (A. Genis, pers. comm., 2012). No detectable metallic inclusions were present. These results indicate that magnetic testing cannot be used to distinguish CVD-grown synthetic diamonds from natural diamonds.

All the HPHT-grown synthetic samples in this study contained inclusions, but many were not detectably magnetic. HPHT synthetics that showed no magnetic attraction often contained clouds of pinpoint inclusions that were colorless, transparent, and visible only with high-power magnification. Yet some opaque inclusions in the HPHT-grown samples were not detectably magnetic either. The composition of these inclusions might involve materials such as silicon carbide and amorphous graphite, two opaque diamagnetic materials known to occur in HPHT products (Yin et al., 2000).

Most HPHT synthetic diamond samples that could be picked up or dragged by a magnet contained opaque magnetic inclusions large enough to be visible with the unaided eye or a 10× loupe. These inclusions appeared brown or black in transmitted light (as shown in figure 7, left). Reflected light would at times reveal a silver sheen indicative of synthetic metallic flux, but this sheen was not always apparent. Metallic inclusions occasionally appeared in layered or striated patterns conforming to crystal growth planes (figure 7, right). Tiny inclusions that appeared as dark pinpoints often elicited weak magnetic responses detectable only with flotation using the strongest wands: a ½ in. neodymium wand or a pinpoint wand. In some instances, these inclusions were visible only with high-power magnification.

Results for magnetic testing of HPHT-grown synthetic diamonds are presented in table 2 according to manufacturing source. These results do not accurately portray the amount of metallic flux content in HPHT-grown synthetic diamonds currently being produced by any particular manufacturer, as the number of samples was not representative of an individual manufacturer's overall production, and approximately half of the samples were not from recent production runs.

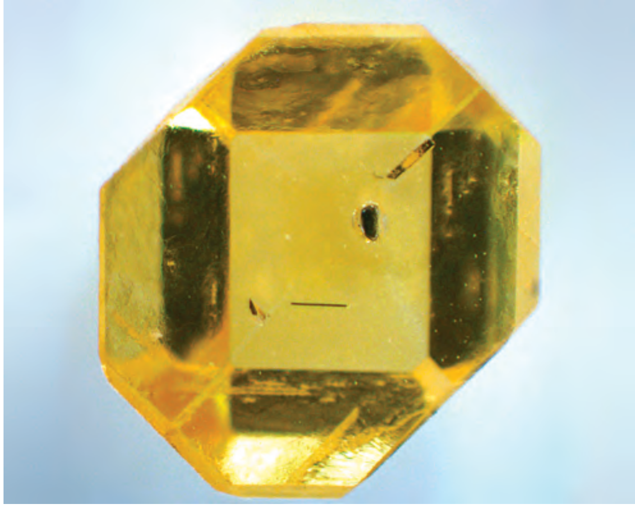
Table 2 shows that of the 85 HPHT-grown synthetic diamonds tested, 58% exhibited magnetic attraction to an N52-grade neodymium magnet. No difference in rate of detection was found between the HPHT synthetic diamonds supplied in 2012 by various manufacturers and the HPHT synthetics acquired in previous years by the GIA Museum. Direct contact with a magnet elicited either a pickup response or drag response in 45% of all samples. An additional 13% exhibited either a weak or strong magnetic response when the more sensitive flotation and pinpoint methods were applied. Alnico and ferrite magnets were adequate for detecting magnetic attraction in 38% of all samples, while another 20% required stronger neodymium magnets.

Of the samples that showed direct magnetic responses (pickup or drag), 76% could be detected with ferrite and alnico magnets, while the remaining 24% required neodymium magnets to produce a response. The three neodymium wands (½ in. N52, 1⁄16 in. N52, and 1⁄5 in. Hanneman wand) were equally effective in eliciting direct responses (without flotation) in synthetic diamonds.

Of the 11 samples that required the flotation method to reveal magnetic attraction, eight required pinpoint testing with a 1⁄16 in. diameter neodymium wand. The Hanneman wand, which is larger and weaker than the 1⁄16 in. N52 wand, detected magnetic responses in only two of these eight samples and was therefore significantly less effective for pinpoint testing. These comparisons of magnet strength prove that N52-grade neodymium magnets achieve the highest rate of magnetic detection when distinguishing natural and synthetic diamonds.

Yellow was the most prevalent color in the HPHT-

Figure 7. HPHT-grown synthetic diamonds that contain large flux inclusions typically show a pickup response. The inclusion in the partially faceted 0.58 ct yellow sample on the left is dark brown in transmitted light. In the photomicrograph on right (magnified 60×), a striated inclusion that formed along crystal growth planes in a 0.22 ct blue sample displays a silvery metallic sheen in reflected light. Photo and photomicrograph by K. Feral.



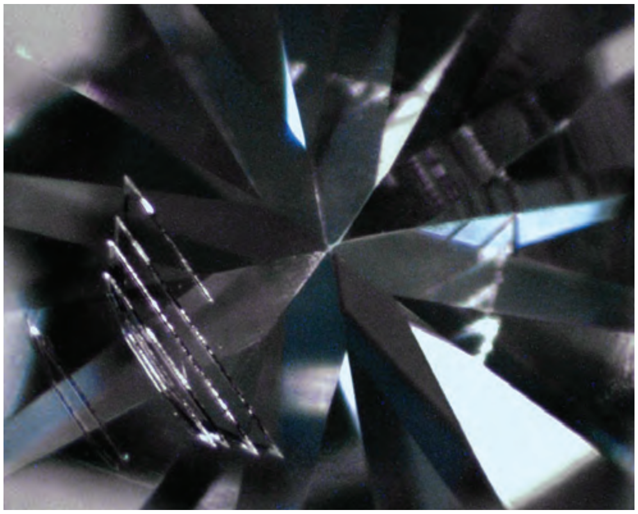


TABLE 2. Magnetic responses of HPHT-grown synthetic diamonds, by manufacturer.

Manufacturer	DeB	TCG	GTL	Sum	Chat	GDC	AOTC	NAD	UIM	Total no.	Percentage detected[a]
Sample quantity	1	3	3	8	10	5	7	21	27	85	
Total magnetic responses	0	2	3	2	3	1	3	19	16	49	58%
Direct responses (pickup or drag)	0	1	3	1	2	0	3	18	10	38	45%
Direct responses requiring a neodymium magnet	0	0	0	1	1	0	1	4	2	9	11%
Flotation required	0	1	0	1	1	1	0	1	6	11	13%
Flotation responses requiring a pinpoint magnet	0	1	0	1	1	1	0	0	4	8	9%

[a] *Percentage of all HPHT-grown samples*

grown samples. The distribution by color was: yellow and brown (51 samples), blue (15), pink and red (13), and colorless (6). No black synthetic diamonds were tested in this study. The blue synthetic diamonds showed the highest rate of detection at 73%. Magnetic detection of yellow and brown synthetics was at 63%, while pink and red samples were at 23%. Of the colorless samples, 33% were attracted to a magnet. These results are consistent with earlier findings that linked the concentration of doping elements such as nitrogen (yellow color) and boron (blue) with the number of inclusions in an HPHT synthetic diamond, and consequently on a sample's magnetic susceptibility (Lysenko et al., 2008).

Coloring agents alone do not induce magnetic attraction in synthetic diamonds. Nitrogen and boron are both diamagnetic elements. Radiation, which may have been used to induce the pink and red colors in the HPHT synthetic samples in this study, does not affect magnetic susceptibility.

Nearly half of the HPHT-grown synthetic diamonds in this study were faceted, and the rest were rough or partially cut. Of the faceted samples, 44% were detectable with a handheld magnet, while the rough or partially cut goods had a higher detection rate of 70%. Though not conclusive, this finding suggests that flux inclusions may be more concentrated near the surface of rough gems, disproportionately reducing the magnetic inclusions during the cutting process.

In HPHT-grown synthetic diamonds, larger size correlated with higher rates of magnetic detection. Approximately half of the HPHT-grown samples in this study were melee-size (0.02–0.20 ct), and 45% of these were detectable with a magnet. Mid-size samples ranging from 0.21 to 0.50 ct (29% of the HPHT-grown test group) had a somewhat higher detection rate of 56%. Large samples ranging from 0.51 to 3.81 ct (24% of the HPHT-grown set) showed a detection rate of 85%. All samples larger than 1 ct were detectable with a magnet.

Test results indicated that lower clarity in HPHT-grown synthetics correlates with higher rates of magnetic detection. Of the HPHT synthetic samples with VS_1 or higher clarity grades, none showed detectable magnetism. Twelve of the HPHT-grown samples had been assigned clarity grades by the manufacturer, and eight of these were diamagnetic. Seven of these eight graded synthetics that showed no magnetic attraction were graded VS_1 (very slightly included) to IF (internally flawless), and one was graded SI_1 (slightly included). The four graded specimens that exhibited detectable magnetism had clarity grades of SI_1 to I_1 (included).

CONCLUSIONS

Inclusions of flux materials such as iron, nickel, and cobalt are commonly found in synthetic diamonds grown under conditions of high pressure and high temperature. Detection of these ferromagnetic particles using a handheld magnet separates HPHT-grown synthetics from natural diamonds, which are typically diamagnetic. In this study, an N52-grade neodymium magnet detected 58% of the HPHT-grown samples. The detection rate varied from 20% to 100%, depending on the manufacturer and the sample's clarity, color, and size, and whether it was cut or in rough form. Synthetic diamond samples grown by the CVD process are free of flux impurities, and consequently cannot be distinguished from natural diamonds by magnetic response.

To maximize the detection rate of HPHT-grown synthetics, magnetic testing must be standardized to the strongest permanent magnet available: the N52-grade neodymium magnet. Sensitive flotation and pinpoint testing methods can also be used to detect a significantly higher percentage of synthetic diamonds than direct testing alone. Pinpoint testing with flotation is also useful for individually testing small diamonds and melee mounted in jewelry for synthetic origin.

Natural diamonds often contain microscopic mineral inclusions with small magnetic susceptibilities that are ferromagnetic and paramagnetic. Faceted natural diamonds may also contain minute amounts of ferromagnetic impurities due to contamination during polishing and handling. Regardless, such particles in natural diamond are rarely detectable with a magnet.

Two rare cases of natural diamond with detectable magnetism were found in this study: one likely due to surface contamination during polishing, and the other due to natural magnetic mineral inclusions of anomalous size. Although the percentage of natural diamond samples that showed magnetic attraction was slightly above 1%, a general sampling of gem diamonds in the marketplace would be expected to yield a far smaller figure.

As growth methods are refined, many gem-quality HPHT-grown synthetic diamonds being manufactured do not contain flux particles in sufficient sizes or concentrations to be detected with a magnet. CVD-grown synthetic gems, which are non-magnetic and often colorless, have also assumed a more prominent role in the marketplace. A lack of magnetic attraction therefore does not rule out that a diamond may be synthetic. But any visible magnetic attraction indicates that it is almost certainly synthetic. A high-grade neodymium magnet remains an important supplemental tool for those who buy, sell, or work with diamonds, particularly yellow gems. As a low-cost instrument that is simple to use, the magnetic wand is effective in detecting a significant percentage of synthetic diamonds.

ABOUT THE AUTHOR

Mr. Feral (San Diego, California) is a gemologist by avocation, with a particular interest in research. His educational website gemstonemagnetism.com presents comprehensive instruction on gem identification through magnetic testing.

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REFERENCES

Barnard A.S. (2000) *The Diamond Formula: Diamond Synthesis: A Gemmological Perspective*. Butterworth-Heinemann, Woburn, MA, 166 pp.

Bibby D.M. (1982) Impurities in natural diamond. *Chemistry and Physics of Carbon*, Vol. 18, pp. 3–81.

Boyd F.R., Meyer H.O.A. (1979) *Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry*. American Geophysical Union, Washington DC, pp. 16–26.

Clement B.M., Haggerty S., Harris J.W. (2008) Magnetic inclusions in diamonds. *Earth and Planet Science Letters*, Vol. 267, No. 1–2, pp. 333–340, http://dx.doi.org/10.1016/j.epsl.2007.11.052.

Gumpesberger S. (2006) Magnetic separation of gemstones. *Canadian Gemmologist*, Vol. 27, No. 4, pp. 120–124.

Hoover D.B, Williams B. (2007) Magnetic susceptibility for gemstone discrimination. *The Australian Gemmologist*, Vol. 23, pp. 146–159.

Kitawaki H., Abduriyim A., Okano M. (2008) Identification of melee-size synthetic yellow diamonds in jewelry. *G&G*, Vol. 44, No. 3, pp. 202–213, http://dx.doi.org/10.5741/GEMS.44.3.202.

Kitawaki H., Abduriyim A., Kawano J., Okano M. (2010) Identification of CVD-grown synthetic melee pink diamond. *Journal of Gemmology*, Vol. 32, No. 1–4, pp. 23–30.

Koivula J.I., Fryer C. (1984) Identifying gem-quality synthetic diamonds: An update. *G&G*, Vol. 20, No. 3, pp. 146–158, http://dx.doi.org/10.5741/GEMS.20.3.146.

Koivula J.I. (2000) *The Microworld of Diamonds*. Gemworld International, Northbrook, IL, 157 pp.

Lysenko O., Novikov N., Grushko V., Shcherbakov A., Katrusha A., Ivakhnenko S. (2008) High-density data storage using diamond probe technique. *Journal of Physics: Conference Series 100*. Part 5, pp. 1–4, http://dx.doi.org/10.1088/1742-6596/100/5/052032.

Matlins A., Bonanno A.C. (2008) *Gem Identification Made Easy*, 4th ed., GemStone Press, Woodstock, VT, 354 pp.

Rossman G., Kirschvink J.L. (1984) Magnetic properties of gem-quality synthetic diamonds. *G&G*, Vol. 20, No. 3, pp. 163–166, http://dx.doi.org/10.5741/GEMS.20.3.163.

Shen A.H., Shigley J.E. (2004) Lab Notes: "Magnetic" natural pink diamond. *G&G*, Vol. 40, No. 4, pp. 324–325.

Webster R. (1970) *Gems: Their Sources, Descriptions, and Identification*, 2nd ed., Butterworths, London, 931 pp.

Yelisseyev A.P., Afansiev V.P., Ikorsky V.N. (2008) Magnetic susceptibility of natural diamonds. *Doklady Earth Sciences*, Vol. 425, No. 2, pp. 330–333.

Yin L.W., Zou Z.D., Li M.S., Liu Y.X., Cui J.J., Hao Z.Y. (2000) Characteristics of some inclusions contained in synthetic diamond single crystals. *Materials Science and Engineering: A*, Vol. 293, No. 1-2, pp. 107–111. http://dx.doi.org/10.1016/S0921-5093(00)01051-0.