INDUSTRIAL DIAMONDS

By a Special Contributor

Diamond, pure carbon, is the hardest naturally-occurring mineral and this, together with the high refractive index that gives diamond its remarkable brilliance, has meant that diamond is unsurpassed as a gem. However, in addition to hardness and high refractive index, diamond has a number of other physical properties, including the highest thermal conductivity of any mineral, and high electrical resistivity. Hence, in addition to its gem qualities, diamond has a number of important industrial applications. It is used principally as an abrasive and although there are a number of cheaper, competing materials, diamond has proved to be superior in many applications because it cuts faster and lasts longer.

Diamonds vary from colourless to black and can be transparent, translucent or opaque. Most industrial stones are translucent or opaque, gray or brown in colour, and are normally too small, flawed and irregular in shape to be of value as gems. All natural industrial diamonds are produced as a by-product of mining for gem diamonds. They are broadly of three varieties. Ballas comprises masses of minute diamond crystals difficult to cleave. Bort is typically gray to black and massive, but the name is also applied to badly flawed, irregularly-shaped diamonds. 'Drilling bort', small rounded stones averaging 20 to the carat, are used in diamond drill bits, or crushed into abrasive grits for use in grinding wheels, or suspended in oil or water for lapping and polishing. Carbonado, a black, opaque variety of diamond with no cleavage, is suitable for use in diamond-set tools.

Although natural diamonds occur in at least 35 countries, less than 10% of all industrial diamonds used each year (in excess of 720 Mct) are natural stones. The vast majority of industrial diamonds are produced synthetically by subjecting graphite to very high temperatures and pressures. In 1955, the US firm, General Electric Co of Schenectady, New York, was the first company to announce the successful manufacture of synthetic diamonds. Its laboratory subjected graphite to pressures approaching 7 gigapascals and temperatures greater than 1,700^{o} C in the presence of a metal catalyst.

Modern methods of manufacture are much the same. The graphite and catalyst (typically nickel) are subjected to the extreme temperature and pressure for about one hour, with diamonds nucleating at many sites in the mixture, which is then cooled and reduced to atmospheric pressure. The diamond crystals are then separated using an acid wash and graded according to size, shape and impurities. Larger diamonds are used for saws and the smaller diamonds in grinding wheels. They can also be put on a carbide substrate to produce polycrystalline diamond compacts, much used for oil-well drills. Apart from its abrasive and cutting qualities, diamond's high thermal conductivity and high electrical resistance makes it highly suited as a substrate for semiconductors, an application that is growing. The larger synthetics also have an application in bearings because diamond has very low friction.

Chemical vapour deposition (CVD), a low-pressure technique to produce diamond films, also has a growing application. Carbon atoms are put in the form of a plasma at 1,200°C and are then pumped inside a vacuum chamber on to surfaces that need protecting with a film of diamond (eg cutting films and artificial hip joints), or need their properties modified by diamond's unusual electrical characteristics. The individual crystals formed by vapour deposition are tiny but the CVD film comprising the crystals can be grown up to 10 cm in width and 1 mm in thickness. CVD film is now widely used as a hard coating for machine tools and increasingly for heat conductors in high-performance micro-circuits, in short-wave UV, infrared and higher-power microwave sources and in radiation detectors. CVD allows diamond to be built into complicated shapes and with predetermined properties much more easily than the traditional methods that are based on press machinery.

De Beers' industrial diamond subsidiary Element Six says that its CVD-made diamond products account for 5% of its current annual sales of US$200 million but believes that annual sales could build to US$1 billion within five years. The United States Geological Survey (USGS) believes the greatest potential for CVD will be in computing; it will be able to function as a semiconductor at much higher speeds and temperatures than silicon, it says.

The ability to control their quality and to customise their properties to meet specific requirements gives synthetic diamonds an advantage over natural stones, and it has been estimated that the annual world market is worth around US$1,000 million. UK-based Element Six, a company 60%-owned by De Beers and 40% by Umicore of Belgium, is the world's biggest producer of industrial diamonds and it is estimated to have accounted for about 20% of last year's sales of synthetic diamonds.

The US is the world's largest market for industrial diamonds. According to the USGS, the most important industry sectors for industrial-diamond consumption last year were computer chip production, construction, machinery manufacturing, mining services (drilling), stone cutting/polishing and transport infrastructure.

The USGS estimates that annual world production of manufactured industrial diamonds is currently of the order of 655 Mct. The US produces more than half the world total, comprising entirely synthetic grit and powder. Two companies are responsible for the entire US output although there are nine companies producing polycrystalline diamond from diamond powder and four companies recover used industrial diamonds. At least 15 countries have the technology to produce synthetic diamonds, the principal producers, apart from the US, being Ireland, Japan and Russia.

World mine production of natural industrial diamond in 2003 was close to 66 Mct, according to the USGS, compared with 55 Mct in 2002. The main producers were Australia (19 Mct), Democratic Republic of Congo (15 Mct), Russia (11.8 Mct), Botswana (9.0 Mct), South Africa (6.7 Mct), and China (1.0 Mct).

Most industrial diamonds are used for microchip production, construction, machinery, manufacturing, mining (drilling) stone cutting and polishing and in transportation infrastructure. The USGS estimates that apparent US consumption of industrial diamonds in 2003 was close to 400 Mct (2002: 330 Mct), including domestic production, secondary (recycled) output, government stockpile sales, imports for consumption of 223 Mct (185 Mct) and exports of 66 Mct (82 Mct). Within the total, only 1.6 Mct were natural stones. The US's net import reliance, as a percentage of apparent consumption, was 39% for manufactured diamonds and 80% for natural diamonds.

Around 4.8 Mct/y of diamond bort, grit, dust and powder were recycled in the US in 2003. The amount of diamond stone recycled was 273,000 ct.

The US is expected to continue as the world's largest market into the next decade and an increase in demand is seen as likely because of the US programme to build and repair the national highway system. The country is in the midst of a US$200 billion transport infrastructure programme and diamond saws are vital for cutting cement in highways construction and repair.

Worldwide, growth in demand for synthetic grit and powder is expected to continue to outpace demand for natural diamond, and the cost of producing industrial diamonds should continue to decline as the technology improves. Prices could decline even more, the USGS says, if competition from low-cost producers in China and Russia increases.