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 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, NY, 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. Individual crystals so formed 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. Research is under way into the use of diamonds as coatings for electrodes and as switches for pulsed-power technology.

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.

The US is the world's largest market for industrial diamonds, and according to the United States Geological Survey (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 world production of manufactured industrial diamonds was at least 614 Mct in 2001. The US produced more than half the world total or some 310 Mct, comprising entirely synthetic grit and powder. Two companies were responsible for the entire output although there were nine companies producing polycrystalline diamond from diamond powder. At least 15 countries have the technology to produce synthetic diamonds, the principal producers, apart from the US, being Ireland, Japan and Russia.

World output of natural industrial diamond in 2002 was close to 49 Mct/y, according to the USGS, the main producers being Australia (13.1 Mct), Russia (11.9 Mct), Democratic Republic of Congo (9.1 Mct), South Africa (6.7 Mct), Botswana (5.1 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 including domestic production, secondary (recycled) output, imports for consumption of 197.2 Mct and exports of 82 Mct, US apparent consumption of synthetic and natural industrial diamond was some 434 Mct.

Around 8.4 Mct/y of diamond bort, grit, dust and powder are recycled annually in the US. The amount of diamond stone recycled is falling – just over 0.2 Mct last year – because of lower prices and greater competition.

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 mid-way through 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.

