Powder Metallurgy Diamond Tools – A Review of Manufacturing Routes

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Abstract

Nowadays the market for diamond tools grows rapidly. The present decline in the price of industrial diamond makes it a commoditised product capable of competing with conventional abrasives. In terms of production volume, the largest group of diamond tools comprises the metal-bonded diamond impregnated tools, such as sawblades, wire saws, and core drills for cutting stone and construction materials, and core bits for mining applications. This article provides a compendious coverage of the powder metallurgy (PM) diamond tool-making routes, and identifies the recent trends towards changing the tool design and composition to render it cheaper and more efficient.

Keywords: diamond grit, metallic matrix, diamond impregnated tool

1. Tool Composition

The chemical composition, particle size and shape of the matrix powder as well as the size, shape, strength and thermal stability of the diamond grit all need careful selection if excellent tool performance is to be achieved.

Except in mining bits that are made by infiltration, fine Co, Cu, Sn, W and WC powders are often used for tools made by the hot pressing and cold pressing/sintering routes.

In regards to the diamond abrasive, its type, size and concentration are factors that have the greatest significance. The major difference between the natural and synthetic diamond is in the particle shape and purity. Irregularly shaped natural grits have lower toughness but excellent bonding characteristics which make them suitable for frame sawing operations. The advantage of using synthetic diamond is that it can be tailor-made to satisfy a broad range of application requirements. By using either Co- or Ni-base alloy as a solvent in the diamond synthesis, crystals of different internal structure and particle properties can be obtained. The *cobalt* grades are characterised by ordered arrays of metal inclusions and hence the crystals tend to fracture in an irregular manner. This imparts free-cutting qualities to the tool. In the *nickel* grades impurities are uniformly distributed throughout the particle, resulting in higher toughness after processing at elevated temperatures.

The particle shape will also affect the crystal breakdown behaviour. A cubo-octahedral shape imparts toughness to synthetic diamonds but harms their retention in the matrix. The best way to minimize the pullout of high-grade synthetic diamonds is by coating them with a thin film of strong carbide former. A proper selection of coating type, matrix composition, and tool fabrication conditions results in a strong hold on the diamond arising from a diffusion-type bond with the matrix. Another benefit of coating is the protection for diamond surface from graphitisation and attack by aggressive matrix components.

The combination of diamond size and concentration governs the number of cutting points on the working face of a tool. The grit size, along with its strength and retention behaviour, determines the crystal protrusion window and thus affects the distance by which the matrix clears the workpiece. For efficient machining it is vital that the cutting grits remain sharp and that there is sufficient space for swarf accumulation and its removal from the cutting zone.

2. Fabrication Process

The common PM routes used to manufacture diamond impregnated tools and tool components are shown in Fig. 1.

Mixing of matrix powders with diamond grits is usually carried out in a Turbula-type mixer. Binding agents and lubricants are added to the mixture at various stages of mixing so as to prevent segregation and minimise wear of steel dies during subsequent cold pressing.

When the mixture is to be compacted by a volumetric cold press the powder has to be granulated. The diamonds may either be used in as-received condition or coated with a suitable powder prior to mixing with the matrix powder.

Cold pressing is a part of the cold pressing/sintering route but it must also be applied when multi-layer segments are produced by hot pressing. Cold pressing is performed in steel dies using either gravimetric or volumetric die filling principle. Gravimetric presses offer higher flexibility in the production of tools and lower investment costs; whereas the volumetric ones are preferred for mass production due to their greater throughput and lower running costs.

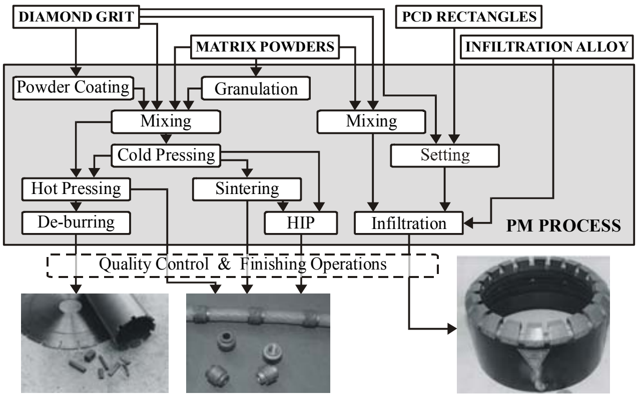

Fig. 1. Diamond tool production process.

Hot pressing of segments is usually accomplished using direct resistance heating equipment and graphite moulds. The principle of resistance heating has, however, limitations with respect to the size and geometry of the consolidated parts. Experience has demonstrated that production of tools having large dimensions, such as continuous rim sawblades, is slow and energy consuming. In addition, difficulties are encountered in assuring uniform temperature distribution across the mould. Therefore the favoured equipment for this application is a furnace press wherein the batch is heated in inert gas by radiation and convection. A typical furnace press enables simultaneous processing of several steel dies, piled one on top of the other, wherein the cutting rims are densified and cemented to steel centres in one operation.

De-burring follows the hot consolidation step. During this operation the edge residuals are removed by means of tumbling the segments with a conventional abrasive grit.

The application of pressure-less **sintering** in the manufacture of diamond impregnated tools is limited by restrictions on the composition, mechanical strength and dimensional accuracy of the final product. The conventional cold pressing/sintering route has, however, gained ground in the production of wire saw beads. Cost savings and high production rates achieved by the use of furnace sintering outweigh, in this case, the shortcomings of this operation.

Infiltration is ideally suited to produce surface-set bits, polycrystalline diamond (PCD) bits, and hybrid bits, used in drilling in earth formations. Depending on the bit type, coarse diamonds, PCD rectangles and various displacement parts are disposed in sockets pre-machined in a graphite mould and secured with an adhesive. A tubular steel blank is also positioned and held in place by a suitable fixture. Then the matrix powder, or its mixture with diamonds, is introduced and compacted by tamping or vibration. To ease mould filling, the powder may be applied in a liquid carrier.

Once the mould has been loaded, a suitable infiltration alloy is positioned adjacent to the matrix powder. Then the mould assembly is placed in a furnace and heated so that the infiltration alloy melts and bonds the powder mass to the steel blank. The process is carried out in a reducing gas, vacuum, or even in air if a suitable flux is applied.

After infiltration the bits undergo a visual inspection to assure correct diamond setting and protrusion. Radiography may also be utilised to detect internal flaws in the bit crown.

The **quality control** of segments and beads is often limited to the hardness test. A properly consolidated material acquires a narrow hardness range, whereas an incompletely densified one has insufficient toughness which results in its rapid wear and poor ability to retain diamonds. Therefore it is advisable that the final density is checked before the segments, or beads, are attached to a suitable steel support.

Wire saw beads are mechanically fixed on a steel cable which is then protected against abrasion with plastic or rubber. Segments are either brazed or laser welded. Brazing is used in the manufacture of sawblades, core drills and grinding tools for wet applications and allows re-tipping of the tool body. Laser welding is employed to minimise the risk of segment detachment in small diameter blades for dry cutting operations. Sawblade steel centres require further processing, by rolling and hammering, to counteract forces acting on the working tool.

3. Present Trends and Developments

The recent cut in diamond prices and fierce competition with low-cost labour countries have brought pressure on the leading edge of the industry to speed innovation and carve a market niche for non-commodity products. In practical terms a lot of effort is going into seeking novel segment compositions and grit distribution patterns so as to improve the tool performance and lower machining costs. To date, several pre-alloyed Fe- and Cu-base matrix powders have been developed and launched commercially under brand names *Cobalite*, *Next* and *Keen* to replace expensive Co-base matrices. Parallel developments have been seen in the diamond coating technology. These days, the toolmakers enjoy a growing freedom of choice of Ti, Cr and Si coated grits that have been designed to suit a wide spectrum of applications and tool fabrication conditions.

It is obvious that less power consumption and longer tool live can be achieved by ensuring even spacing of diamond particles in the matrix. A technological breakthrough in the manufacture of sawblade segments, wherein diamonds are positioned in a regular manner, has been made but the grit setting procedures are a trade secret and this technology has not been implemented on a broader scale yet.

Further Reading

J. Konstanty, Powder Metallurgy Diamond Tools, Elsevier, Oxford, 2005.