Your Guide for Grinding and Abrasives Manufacturing
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Effective Cleaning Methods and Best Practices of Synthetic Industrial Diamond

By Ron Abramshe, Ph.D.

Synthetic diamond is used as a super abrasive in many industries from electronics to medical applications. These industries as well as others require cleanliness of the base product as paramount to a quality end product. One should understand some basic facts about synthetic diamond in order to grasp a better understanding of its abrasive application within the industrial sector. The following is a rudimentary narrative of the synthetic diamond synthesis process.

Synthetic Diamond

In synthetic and natural diamond, impurities exist and are known as inclusions. They appear as dark spots, dispersed clouds, or opaque sections and are composed of many basic elements, such as hydrogen, nitrogen, oxygen, boron, magnesium, aluminum, silica, calcium, and other trace elements. Impurities that occur in synthetic diamonds are elements resulting from other metal catalysts used in production. Main catalysts are a combination of nickel, iron, and cobalt. Other impurities in synthetic diamonds are mainly from the high temperature, high-pressure (1,800 °C at 25–30 GPa) reaction chamber and post processing.

Elements that are commonly monitored in synthetic diamond are aluminum, calcium, cadmium, cobalt, chrome, copper, iron, potassium, magnesium, manganese, sodium, nickel, silica, tantalum, vanadium, zirconium, zinc, and boron. Each of these elements play a role in the end use of the synthetic diamond and the quantity of impurities allowed — dependent on the intended end use. It should be noted, however, that the intended use is as critical as the materials that are being used in part of the overall manufacturing process. In many cases, the base material — synthetic diamond — can cause downstream processing problems for manufacturers. In simplistic terms, it is never good to eat from a dirty plate.

Let us look at some of the reasons why the purity of a diamond surface is important.

Cleaned Mesh or Micron Diamond

The need for surface-cleaned mesh or micron diamond is paramount to post-processing and for final products. The reasons for this can briefly be described as follows. Surfaces that contain certain levels of iron or other magnetic metal impurities can create problems in a nickel- or copper-electroplating operation. Synthetic diamond containing too much iron will make it magnetic, which in turn will result in the diamond attaching to itself instead of to the plating chemical. The final result is the formation of clusters or agglomerates that decrease yields or cause an oversize condition on the final product. Both are undesirable.

Diamond that contains too much of a calcium impurity will leave calcium deposits in a lapping operation that will be difficult to remove. The deposit may require an additional cleaning removal step — resulting in unnecessary cost increases. Diamond that contains too much manganese will cause computer read-write heads to depolarize pole tips in a lapping operation, rendering them useless.

Other synthetic diamond particles that are based on surface attraction forces from upstream processing can easily adhere to one another. This adherence can form agglomerates that can be connected by a network of interconnected pores or surface ions. Agglomerates will create processing problems if they are used in suspensions because they distort the distribution of particles and create unwanted artifacts as scratches on polished surfaces or voids in solid pieces. A medical prosthesis, such as a hip ball, needs to be a solid piece. Tiny voids created by these agglomerates can cause stress fractures that can lead to hip replacement failures. There are numerous other examples where control-of-surface impurities are necessary for proper control of a process or product quality.

In terms of best practices, it would be worthwhile to explain this phenomenon of agglomeration and ionic activity.

As particles get smaller, their surface area increases in sub-micron powders because of the relationship between surface area, particle size, and surface energy. As the surface area to volume area increases, there are a large number of molecules at the interfacial region. These can affect the stability of the process because the larger surface area adsorbs larger quantities of chemicals.

Putting a powder into a liquid system involves a few different steps. The simple act of pouring, slaking, or casting a powder into a liquid involves a process of de-aeration of the powder as it descends into the liquid. There is a proportional amount of air surrounding the particle that must be displaced. It takes a certain amount of time to displace the air, which is dependent upon agitation and/or the length the particles have to travel. Additional particle size due to unwanted surface chemicals will increase the time of de-aeration.

After removing air from the surface, the next step is the actual wetting of the surface. Time can vary since hydration at the surface will be dependent on the amount of chemical and residual surface ions present. If there are only a few ppm of anions or cations, this hydration step can be rapid. If, on the other hand, there are a few weight percent of these cations or anions present, it will take longer as these ions need to dissolve and remove themselves from the surfaces of the particles. It is at this stage that problems can occur. For example, the overall ionic activity of the system is affected if the surface contains too many complexing ions. Generally, overcompensation is made either positively or negatively with dispersants. Over a given period as the final few ions dissolve, stabilization may take place or the system breaks down as a floc or a hard-packed sediment.

Comparatively, if the surface is clean and ionic activity is minimal, we can then reach the final phase of the process, that is, having all the particles immersed in the liquid at an equilibrium point where they are in suspension or in a dispersive state. At this stage, these particles can be mixed in a binder for further processing (e.g., forming shapes or being green machined after pressing operation or used as texturing slurry for hard disk drives).

Fusion Cleaning: The First Step in Removing Impurities

Fusion cleaning involves the use of a chemical reduction method under temperature and pressure. Potassium hydroxide and potassium nitrate in flake form are combined with the synthetic diamond. The mixture is heated past the melting point of both reducing chemicals. The high temperature and aggressive caustic reaction eliminates any residual organic and un-reacted graphite on the diamond surface. These impurities are converted into a nitrite compound and to carbon dioxide — the latter less a part of the overall fusion reaction. This process generally takes about one hour to achieve chemical conversion of the unwanted graphite, organics, and certain metallic impurities. The resultant diamond is then washed to a neutral condition of pH 7 with water; the wash water that contains the caustic byproducts is treated before discharge. Untreated reaction liquids should not enter the waste treatment plant, as untreated streams can be detrimental to the operation of that treatment facility, upsetting the tertiary bacterial treatment of normal waste waster.

Synthetic diamond is then transferred to another vessel where it is treated by mineral acids, such as nitric or hydrochloric acid, to remove any remaining metallic impurities on the surface of the diamond as well as in any included areas. The diamond is then washed to a neutral pH of 7 with water.

New methods of cleaning are currently being investigated to minimize the use of aggressive chemicals. Progress has been slow as the most cost-effective and efficient process today is the fusion method as described above. In comparison, the fusion method represents about 25% of the cost of the other technologies (e.g., high-pressure metallic dissolution using steam or metallic dissociation in liquid nitrogen). In terms of our environment, the use of liquid nitrogen shows the most promise.

Cleaned Mesh or Micron Diamond

The need for surface-cleaned mesh or micron diamond is paramount to post processing and final products. Comparatively, if the surface is clean and ionic activity is minimal; we can then reach the final phase of any process using diamond. In a liquid process, specifically, this means having all the particles immersed in the liquid at an equilibrium point where they are either in suspension or in a dispersive state. Such particles can now be mixed with a binder for further processing. Shapes are made from this process and can be used as armor plates, hard seals for pumps, or washers for faucets, all requiring that the individual particles be clean for optimal density (no voids) when processed. Voids in armor plates will cause failure when ballistically challenged, pump seals will fail, causing stoppages in flow, and washers will leak. All of these items then become a detriment to the consumer and ultimately the producer. Without a clean surface to work with, a process engineer is faced with the task of constantly adjusting the process to keep it stable. Over the long run, this leads to poor quality management and a large amount of rejected parts.

Summary

When using processed micron and sub-micron particles, it is vital to determine what is on the particle surface and in what quantities. This is essential in order to obtain extensive production runs, lower defects, and, ultimately, produce superior quality products that use micron or submicron diamond or other fine particles as a processing step to a final product or a product in and of itself.

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