Comparable Study of Fullerene, Diamond, Graphite and Other Carbon Powders

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This article describes the result of our efforts in the field of carbon powders, such as fullerenes and single-wall nanotubes. We have been able to generate a library of high resolution transmission electron microscopy images, together with x-ray patterns, analytical electron microscopy, selected area electron diffraction, electron energy loss spectroscopy data to arrive at some conclusions about the structure and agglomeration of micro- and nano-particles, and compare them with the structure of basic carbon materials: graphite and diamond. The main goal of this study has been to develop a theoretical understanding of why some carbon powders can be easily agglomerated, compacted and sintered into highly dense soft or hard materials, whereas others fall apart, no matter what experimental procedure or methodology for densification is used.

We list below some carbon powders that have been studied: (1) fullerene C_{60} , 99.9+wt.%; (2) fullerene C_{60}, 99.95wt.%; (3) refined mixed fullerenes; (4) single-wall nanotubes; (5) multi-wall nanotubes; (6) refined fullerene soot; (7) as-produced fullerene soot; (8) carbon black from acetylene; (9) activated carbon powder; (10) synthetic graphite, 99.9wt.%; (11) natural graphite, 99.9995wt.%; (12) glassy carbon powder; (13) synthetic diamond; and (14) natural diamond.

Fig. 1 shows a 0.2 nm resolution TEM image of a fullerene C_{60}, 99.95 wt.% particle. The particle consists of well-arranged and close packed C_{60} fullerenes. There are some defects in the arrangement, and inclusions of non-arranged regions are also visible. Fig. 2 is a similar TEM image of a particle of carbon powder that has been named refined mixed fullerenes. This particle also consists of arranged zones of carbon atoms, but there are other regions where amorphous disordered regions prevail. X-ray patterns show that the ordering of the atoms is different from that of fullerene C_{60}, but there are a lot of nano-sized zones where the arrangement is very similar to Fig. 1. Fig. 3 is a TEM image of a particle of natural graphite powder. This particle consists of a well-arranged layered structure of carbon atoms. The regions of arrangement are nano-sized and randomly oriented.

The fullerene, graphite and diamond powders consist of particles of “dense” carbon (densities of 1.6, 2.2, 3.5 g/cm^3, respectively). The particles of other powders are “not dense” carbon. The nano-regions of well-ordered or amorphous carbon surround the nano-regions that have nothing but gaseous molecules present. The volume fraction of relatively empty space varies from 20- 200%.

Fullerene powders can be sintered, giving a new line of dense and hard carbon materials [1-3]. Density and hardness vary with sintering pressure and the grade of the initial powder. A new line of carbon ceramics that we call “Diamonite” has a density in the range 2.2-3.0 g/cm^3, and hardness in the silicon carbide-diamond range. Less studied sintered carbon ceramics that we call “Fullertubite” have a density in the range 1.6-2.2 g/cm^3 and hardness in the range of hardened steel-silicon carbide. The properties and possible applications of these materials are under study. Diamond powders can also be sintered under high pressure. Sintered diamond ceramic has a density in the range 3.0-3.5 g/cm^3. Other listed powders (numbers 5-12) could not be sintered at all.

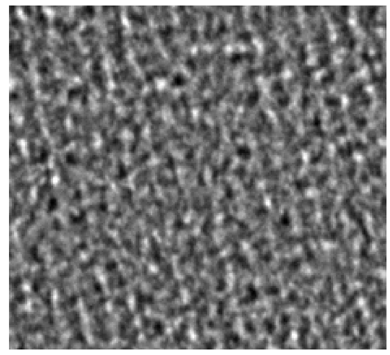

Fig. 1. TEM image of fullerene C_{60} powder.

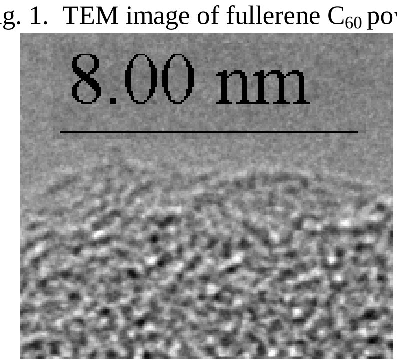

Fig. 2. TEM image of refined mixed fullerene powder.

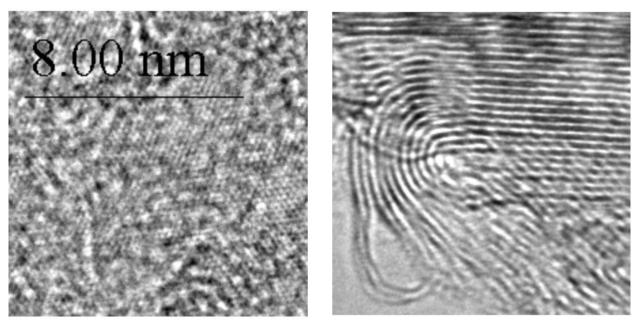

Fig. 3. TEM image of natural graphite powder.

Acknowledgments

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