tions of carbon. Powder of extremely fine particle size is needed to obtain high density. Sintering can be conducted in induction or resistance-heated furnaces in an inert atmosphere. Additions of sintering aids, notably SiC, have been found to enhance sintered densities.

Uses of B_4C are based on its low specific gravity, extreme hardness and wear resistance, high mechanical strength at both low and high temperature, thermal and chemical resistance, nuclear properties and chemical reactivity. The majority of commercial B_4C goes into abrasive slurries, blast nozzles, neutron-absorbing materials, chemicals and armor.

B_4C is the precursor used for producing most non-oxide boron chemicals because of its reactivity with halogens at high temperatures. The products, especially BCl_3 and BBr_3, form the basis for the synthesis of practically all non-oxide boron chemicals.

These chemicals are applied in the chemical vapor deposition (CVD) production of continuous boron filaments, the manufacture of dyestuffs and in high-energy propellants. No other practical route exists for the production of non-oxide compounds for the stable oxides, except through the carbide intermediate.

B_4C also is used in some reaction schemes to produce refractory metallic borides. Other applications include the use of fine B_4C powder as the generally accepted sintering aid for densification of SiC. Recently, the thermoelectric properties of B_4C have been used in making high-temperature thermocouples.

The unique combination of low specific gravity, high elastic modulus and high hardness of B_4C has led to development of B_4C-containing metal-matrix composites and cermets, which are used for wear parts and armor components.

Advanced Refractory Technologies Inc.

Boron Nitride

A synthetic ceramic material, boron nitride (BN) occurs in two modifications. One is the hexagonal BN (α-BN) that shows a graphite-like layer structure. However, in contrast to graphite, BN shows a white color, thus it is often called "white graphite." The other is the dense cubic BN (β-BN)

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with a structure similar to that of diamond.

BN was first prepared on a large-scale basis by Union Carbide and Carborundum in the 1950s. Today, the following three general reactions are used for the synthesis of α-BN using boron oxide (or boric acid) and a nitrogen-containing compound:

$$B_2O_3 + 2NH_3 \rightarrow 2BN + 3H_2O \quad (T = 900°C)$$

$$B_2O_3 + CO(NH_2)_2 \rightarrow 2BN + CO_2 \quad (T > 1000°C)$$

$$B_2O_3 + 3CaB_6 + 10N_2 \rightarrow 20BN + 3CaO \quad (T > 1500°C)$$

The resulting BN contains 92–95% BN and 5–5% B_2O_3. If desired the remaining B_2O_3 can be evaporated in a second step at temperatures >1500°C in order to achieve BN concentration >98%.

BN production figures are not listed separately in statistical reports; however, we estimate the 2000 production for the western world to be ~350–450 metric tons. Production figures will be similar for 2001 with a slight increase possible. Also, there is a BN production in the Commonwealth of Independent States (CIS) and China, but no reliable production data are available.

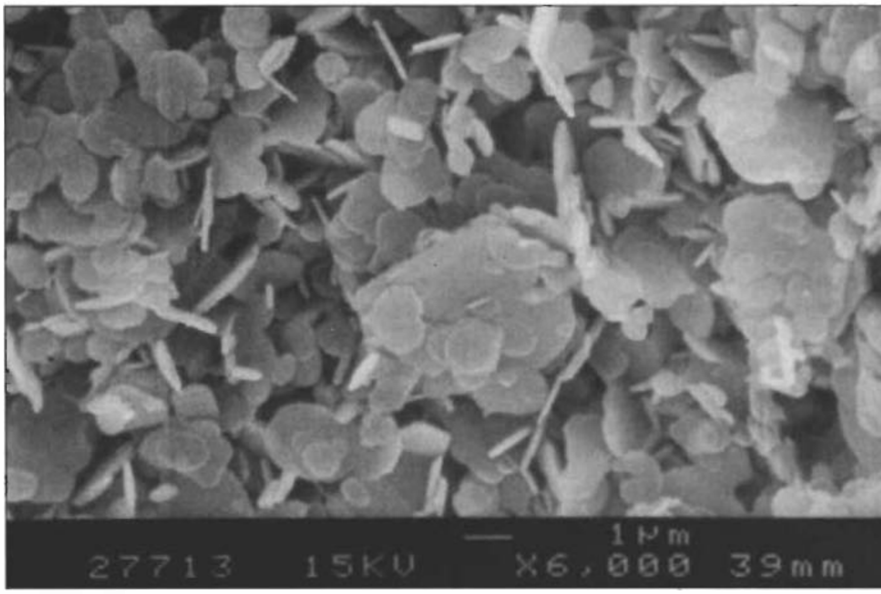
Companies involved in the production of BN include Advanced Ceramic Corp. (formerly Union Carbide) and Carborundum Co. in the United States; Boride Ceramics & Composites (owned by Sintec Keramik GmbH & Co. KG, Germany) in the United Kingdom; Elektroschmelzwerk Kempten and H. C. Starck GmbH & Co. KG in Germany; and Denki Kagaku Kogyo, Kawasaki Steel Corp., Shin-Etsu Chemical Co. Ltd. and Showa Denko KK in Japan.

Prices for hexagonal BN range from ~$80–120/kg for standard qualities depending on purity of BN, and may reach prices up to $200–400/kg for high-purity and tailor-made grades. Because there is a large demand for and shortage of BN at present, price increases are likely in the near future.

For ceramic applications, the hexagonal modification is used because of its outstanding chemical, thermal and electrical properties. It finds application in the metallurgical field because of its good non-wetting behavior against metallic melts. Further applications are high-temperature solid lubricants because of its layer lattice and thermal conductor/electrical insulator in electronic applications. Large quantities of BN are used for the production of engineering ceramics such as brake rings for horizontal continuous steel casting and TiB_2/BN composites used as evaporator boats for vacuum metallization.

Other applications include those in the field of cosmetics, as catalysts and as a starting material for the production of cubic BN. Due to its extreme hardness, second to diamond, cubic β-BN is used as a hard material.

The good non-wetting behavior, as well as the good high-temperature lubrication, makes BN an ideal release and parting agent for the production of aluminum and



SEM micrograph (secondary electron image) illustrating the plate-like particles of boron nitride powder.

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magnesium castings, as well as glass forming and superplastic forming of titanium sheets for aerospace applications. In these applications boron nitride is used as a dispersion in a carrier (water or alcohol) blended with refractory binders, that are applied like wall paint. Such coatings are produced by Advanced Ceramic Corp., Carborundum Co. and ZYP Coatings Inc. in the United States and by Elektroschmelzwerk Kempten and Büro für angewandte Mineralogie in Germany.

Stephan Rudolph
Büro für angewandte Mineralogie

Calcium Aluminate Cement

Calcium aluminate cement (CAC) is a type of hydraulic binder that has been in commercial existence since 1908. At that time a patent was granted for a manufacturing process by which bauxite and limestone were fused in a reverberatory furnace to form the hydraulic mineral $CaAl_2O_4$. This mineral, monocalcium aluminate, is the principal reactive phase in all CACs.

The annual production quantity of CAC is minor in comparison to portland cement (OPC). CAC and OPC are similar in that principally they are both composed of hydraulic minerals. In CAC these minerals are calcium aluminates, and in OPC they are calcium silicates.

The typical applications for these two binders, however, are quite different. While OPC is used in all types of construction work, CAC has unique properties that distinguish it from these applications:

- High-temperature resistance and refractory performance;
- Rapid strength development;
- Resistance to chemically aggressive environments;
- Ability to accelerate the normal chemical reactions of OPC.

Today, CACs are manufactured by either a fusion or a sintering process. Typical starting raw materials are a source of Al_2O_3 and CaO and can include limestone, lime, bauxite and calcined alumina. The resulting clinker is then processed and ground to cement fineness in ball mills resulting in a finished product of fine powder.

The principal reactive phase in all CACs is monocalcium aluminate