Boron Advanced Materials

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Introduction

Boron advanced materials discussed here include a variety of non-oxide boron compounds. These are also called boron advanced ceramics to differentiate them from traditional ceramics, where boron may also be used in oxide form. Boron advanced materials display many remarkable properties that make them indispensable in a myriad of industrial applications. They include the hardest of all manufactured materials, ultra-high temperature materials, and materials that are substantially stronger and lighter than steel. They also include materials that exhibit unique thermal, electrical, lubricating, and protective properties. These boron non-oxide materials are produced from boron oxides raw materials, also known as borates, many in substantial industrial quantities. Some of the more commercially important boron advanced materials and their applications are discussed here [1,2].

1. Boron carbide, B_4C

Boron carbon has the approximate formula B_4C, corresponding to 78% boron by weight. It is one of the hardest manufactured materials. It has a melting point of about 2400 °C and is largely unreactive and corrosion resistant. Some of the more important applications of boron carbide are listed here.

A) Machine parts

In addition to being extremely hard and corrosion resistant, boron carbide also has a relatively low density, about one third that of steel. This combination of attributes makes it ideal for use as extremely hard, abrasion resistant, lightweight parts that can be used in harsh environments. It is often used for extreme wear parts such as sand blasting nozzles.

B) Abrasives

Boron carbide is widely used as an industrial abrasive that can be used even at high temperatures. It is sold in powder form in various particle sizes. It is often affixed to cutting blades, drill bits, and grinding and polishing wheels.

C) Ballistic armor

The extreme hardness and low density of boron carbide makes it an excellent material for mobile armor used in military vehicles, aircraft, and military and civilian body armor. This is one of the largest applications of boron carbide.

It was recently announced that the Chinese company Dalian Jinma is building a boron carbide manufacturing plant in Turkey jointly with Eti Maden, a major borate supplier. Much of the boron carbide production from this plant will be used to bolster the Chinese military's supply of ballistic armor. Construction of the plant began in 2019 [3].

D) Nuclear technology

Boron has a high cross-section for neutron absorption making its compounds useful in nuclear power applications. Since boron carbide is thermally stable and has a high boron content, it is used in nuclear power plants for applications such as reactor control rods and radiation shielding.

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2. Boron nitrides, BN

Boron nitride, BN, contains 43.6% boron by weight. It is isoelectronic with carbon and forms compounds that are analogous in structure to the carbon allotropes diamond and graphite. Although having some similar properties to their carbon analogs, boron nitrides have many unique and useful properties.

A) Hexagon boron nitride and related compounds

Hexagonal boron nitride, h-BN, has a structure composed of well-ordered two-dimensional sheets of alternating covalently bound boron and nitrogen atoms to form a structure analogous to the carbon sheets in graphite. It is a white solid with a melting point of about 3000 °C. Related forms in the h-BN family include turbostratic boron nitride, t-BN, pyrolytic boron nitride, p-BN, and boron nitride nanotubes, BNNT. t-BN has randomly ordered BN sheets. p-BN contains layers running parallel to the surface resulting in exceptional thermal properties, high tensile strength, and the highest dielectric properties among readily available materials. It is also extremely resistant to chemical attack even at high temperatures. BNNT consists of BN sheets rolled into high aspect ratio tubes, a structure that gives rise to exceptional strength, stability, thermal conductivity, dielectric, and piezoelectric properties. BNNT is among the strongest known nanomaterials. BNNT can be prepared as single or multiwalled tubes with varying lengths [4]. Some applications of hexagonal boron nitride are discussed briefly here.

I) Lubricants

Because the 2D sheets in h-BN can slide relative to one another other, it is slippery and has lubricating properties similar to graphite. It is sometimes called "white graphite". However, unlike graphite, h-BN, does not require gas or waters molecules to be trapped between its layers in order to act as a lubricant. For this reason, h-BN can be used in a vacuum and is useful in aerospace applications. It is commercially available in a variety of forms, including aerosol spray cans and greases. h-BN is also used to provide lubricity in cosmetics and skincare products.

II) Electronics

Unlike graphite, h-BN is a good electrical insulator and an excellent thermal conductor. This combination of attributes makes it a useful for heat management in electronic devices. h-BN-containing elastomeric sheets, pads, ribbons, and greases are used to dissipate heat from computer components while providing good electrical insulation. This is important since heat is most frequent cause of failure in electronic equipment. h-BN is also used as a dielectric material in high frequency electronic devices and as a diffusion source in the manufacture of semiconductors.

III) Metallurgy

Boron nitride is not wetted by most molten metals. This property, combined with its high melting temperature, makes it useful as a mold release agent and to fabricate high temperature crucible, boats and implements used to handle molten metals. Pyrolytic boron nitride is especially useful because its anisotropic structure gives it exceptionally good thermal conductivity, enhanced resistance to thermal shock, and exceptional corrosion resistance even at high temperatures.

IV) New and developing applications of hexagonal boron nitrides

❖ **Hydrogen storage**

Hexagonal boron nitride has a good capacity to absorb and store hydrogen. This is especially true for BNNT and other nanostructured forms of boron nitride. This leads to potential for practical use of boron nitride in hydrogen fuel cell vehicles and other portable power applications [5].

❖ **Polymer composites and engineering materials**

Boron nitride nanotubes are roughly *one sixth the weight of steel and about 100 times stronger*. This makes them ideal for construction of extremely strong, lightweight composites. Boron nitride's ability to absorb neutron radiation also makes these materials of interest for the safety of future space missions. BNNT also contributes to the fire retardancy of polymer composites.

❖ **Biomedical**

h-BN is generally regarded as biocompatible and has a range of potential medical applications. The excellent mechanical properties of BN and BNNTs have prompted their use in composite material, some of interest for medical use. BNNTs are also being investigated for use in cancer therapies and selective drug delivery systems [6].

B) Cubic boron nitride

Cubic boron nitride has a 3D structure analogous to diamond. Although the relative hardness of superhard materials are controversial, c-BN is widely cited as the second hardest substance after diamond. It is used as an extremely hard abrasive, much like industrial diamond. It is supplied as a fine powder under trade names including Borazon and Amborite for coating onto cutting tools and as grit for grinding and polishing wheels. c-BN coated saw blades are recommended for cutting steel and other ferrous alloys, which can react with diamond-cutting tools. These saw blades are also used to cut glass and masonry.

3. Metal Borides

In addition to its compounds with the non-metals carbon and nitrogen, boron forms a large number of compounds with metals which are known as metal borides. These are mostly superhard, high melting, refractory substances. They typically exhibit some properties similar to metals, such as good electrical and thermal conductivity, but also display a range of unique properties not available with other materials. Boron-rich metal borides, with compositions ranging from MB_6 to MB_{60} or greater, as well as some multi-metal borides, are among the hardest known substances [7].

Metal borides have many existing and potential applications in electronics, thermoelectrics, and as super-hard and ultra-high temperature materials. Commercial uses include abrasives, wear resistant machine parts, brake pads, cutting tools, magnetic shielding materials, and electronic cathodes and dielectrics. Titanium boride–aluminum nitride crucibles are used to evaporate aluminum by resistance heating in aluminizing. Titanium diboride, TiB_2, cathodes are used in Hall-Heroult cells for aluminum production. Zirconium diboride, ZrB_2, has a melting point of 3246 °C, qualifying it as an ultrahigh temperature ceramic, and also has a relatively low density. This makes it potentially useful for aerospace applications, such as hypersonic missile nosecones and shielding for space reentry vehicles.

4. **Boronizing**

   Also known as boriding, boronizing is a commercial process that creates an extremely hard, corrosion resistant surface layer on metals parts. Through the use of various techniques, boron is diffused into the metal being treated to produce a super-hard metal boride layer near the surface. This process can be applied to a number of metal substrates, including steel, nickel, cobalt, and titanium alloys. Boronized metal parts and tools are highly resistant to corrosion and wear and can last up to five times longer in service than untreated parts. Boronized steel is used for agricultural cutting blades, mining equipment, tools, and machine parts.

Production and Use of Boron Advanced Materials in Europe

There are several producers of boron advanced materials in Europe. Some of these include St. Gobain (France), ESK (Germany - a 3M company), Alfa Aesar GmbH & Co KG (Germany and the UK), CVT GmbH & Co. KG (Germany), and Kennametal Sintec Keramik GmbH (Germany). A significant majority of feedstock material for the production of boron advanced materials (i.e. boric acid, boric oxide, and borax pentahydrate) is imported into Europe from Turkey.

Most of the boron advance materials produced in Europe are purchased within the European Union for applications in the nuclear energy, aerospace and defense, electronics, machine parts, lubricants, and abrasives, or are otherwise shipped internationally. Europe is the third largest end-user market for boron advance materials thanks to its advanced manufacturing hubs.

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