Boron Nitride – Solutions for Aluminum Extrusion

Christiane Klöpfer, ESK Ceramics GmbH & Co. KG,
A Ceradyne Company, Kempten, Germany

ABSTRACT --- Boron nitride is a synthetic material with outstanding release and lubrication characteristics with respect to aluminum. BN is used for two purposes: coating of the billet and/or the dummy block, and protection of the die. For coating the billet and/or dummy block, BN has the following advantages compared to standard solutions such as acetylene or grease: improved safety, since there is no fire risk from a naked acetylene flame; no graphite or oil contamination; no health risks as with acetylene, where the carbon black is carcinogenic. The product quality of the extruded parts is enhanced, as there are no black marks or blisters. BN powder coating is extremely efficient, because the coating does not need to be applied with every pressing cycle, and its thickness is only a few microns. BN-coated dies will not corrode during storage, and provide a higher tonnage of products per die, due to reduced scrap at the beginning of the pressing cycle.

INTRODUCTION

In extrusion, a preheated cylindrical aluminum billet is pressed through a steel die with a pressing ram. At the end of each extrusion cycle, the pressing ram, the so-called dummy block, must separate instantly and cleanly from the billet without pulling the extruded section from the die, as this will cause blisters in the profile. Aluminum alloys at temperatures above 450°C have a tendency to stick to steel. Therefore, it is essential to apply a release agent or lubricant between the aluminum billet and the dummy block, to ensure instant and effortless separation. This is made even more crucial by the trend towards larger extrusion profiles.

Three types of release agents are known:

- Greases and oil-based graphite suspensions for coating the billet
- Acetylene flame to generate carbon black on the front of the billet
- Boron nitride powder for coating the billet or the dummy block.

BORON NITRIDE – THE MATERIAL

Properties

Hexagonal boron nitride (h-BN) is not a natural material. BN (Figure 1) can be used as powders, coatings, or in its sintered form either as pure BN or as a composite. Though first synthesized by W.H. Balmain from boric acid and calcium cyanide in 1842, it took until the 1940s to gain limited economic significance. Process improvements have led to more economical and higher quality BN types. This very versatile material is now used in a number of applications (for example, metallization, the metal industry, cosmetics, the automotive industry, high-temperature furnaces, thermal management, etcetera).\textsuperscript{[1, 2]}
The physical properties of BN are mostly governed by its atomic structure (Figure 2). BN is isoelectronic with carbon, and therefore h-BN is also known as white graphite. A high-pressure diamond-like modification with a cubic zinc-blend structure is also known.[1, 2] Hexagonal boron nitride (h-BN) consists of a layered structure comprising a network of (BN)₃ rings. Whereas graphite has metallic conductivity, boron nitride is an insulator. This is due to the covalent inter-layer bonding of the boron and nitrogen atoms, which localize the free electrons. This also explains the different colors of graphite (black) and boron nitride (white).

The hexagonal BN layers are bonded by weak van der Waals forces (Figure 3), which enables the layers to slide easily against each other. Therefore, h-BN is used as a solid lubricant or release agent, either as a sintered body (for example, side dams for thin-strip casting in the steel industry), or applied as suspensions or powders (for example, in aluminum extrusion or titanium shaping). The poor wettability by many glass and metal melts is another advantage of h-BN for these applications. Liquid aluminum does not wet h-BN up to 900°C (contact angle approximately 160 degrees). BN coatings are therefore widely used in the aluminum casting industry, due to their excellent release and lubrication properties.[3, 4] Other important properties of boron nitride are its high-temperature resistance, thermal shock resistance, high thermal conductivity, its chemical inertness, non-toxicity, and environmental safety.[1, 2, 5] The weak inter-layer bonding also enables all sintered BN materials to be easily machined to produce complex shapes from the hot pressed billets.
Production

There are a number of general methods for producing boron nitride powders. Coatings and sintered materials will be made out of these powders. Only two reactions are used on an industrial scale:

As a first step, boric oxide or boric acid reacts with ammonia in the presence of a carrier, often tricalcium orthophosphate, at a temperature of 900°C:

\[
\text{B}_2\text{O}_3 + 2 \text{NH}_3 \rightarrow 2 \text{BN(O)} + 3 \text{H}_2\text{O} \quad (1)
\]

1st step “raw” BN

Then, a second heat treatment for purification and stabilization is carried out at temperatures greater than 1400°C:

\[
\text{BN(O)}_{\text{amorphous}} \rightarrow \text{BN crystalline} + \text{B}_2\text{O}_3 \quad (2)
\]

2. step stabilized h-BN

As a third treatment, purification can follow in which the required purity and particle sizes of boron nitride are adjusted to the needs of the application.

The second industrial production process is the reaction of boric acid or borax with organic nitrogen compounds, for example, urea or melamine at temperatures greater than 1000°C as a first step:

\[
\text{B}_2\text{O}_3 + \text{CO(NH}_2)_2 \rightarrow 2 \text{BN} + \text{CO}_2 + 2 \text{H}_2\text{O} \quad (3)
\]

The first method usually yields crystalline \( \alpha \)-BN, in the form of thin hexagonal platelets with a thickness of about 0.1–0.5 microns (\( \mu \)m), and a diameter of up to 5\( \mu \)m. The second method can give a turbostratic boron nitride, a hexagonal structure characterized by partial or complete absence of three-dimensional order among its lamellae.

RELEASE AGENTS IN THE EXTRUSION PROCESS

Characteristics of Existing Release Agents

Greases and Oil-Based Graphite Suspensions. These materials can only be applied by hand (Figure 4). They are cheap, but require a worker to be present the whole time. Furthermore, these materials are inflammable at high temperatures. This can cause problems with the electrical equipment. Explosions create blisters in the billet, which then lead to holes of 1-2mm in the extruded profile. This is only tolerable for cheap profiles for the construction industry. Usually the billet is coated, but the dummy block may need to be coated as well. As the coating does not stick on the metal, there is no transfer of release agent from the billet to the dummy block. As a consequence, the coating has to be repeated with every pressing cycle. Handling is messy, and the material is environmentally problematic.
Acetylene. With this method, acetylene is ignited in front of the billet, generating carbon black. Acetylene was the first technology to operate automatically, since the flame is lit as the billet passes the burner on its way out of the preheating furnace to the extrusion press (Figure 5). Carbon black is a good release agent, but there are also negative aspects.

Due to its small size, carbon black (approximately 100nm) is carcinogenic. Workers must be protected against breathing in any powder that does not stick to the billet, or that returns with the cut-off end of the billet (Figure 6). The small size of carbon black causes another problem with the quality of extruded billets. When a profile has distinctive edges, carbon black, with its good release characteristics will stick at these edges, and may create a black mark over a length of 1000 to 2000 meters. This black mark on the profile cannot be removed, and will interfere with anodizing. Using the acetylene method also requires extra tanks for the storage of flammable gas. Open flames always present a fire hazard, and can cause problems with the electrical equipment. It is only possible to coat the billet and not the dummy block. As carbon black does not stick well, it will not be transferred from the billet to the dummy block, and therefore each billet must be coated separately. The automation of the burner requires an initial investment, but the running expenses for acetylene are low.
**Boron Nitride.** BN offers the best performance of all the available technologies. Its release and lubrication characteristics outperform carbon black (Figure 7). BN sticks well to hot surfaces. If a billet is coated with BN, the BN layer that is in contact with the dummy block will also stick to the dummy block. Therefore, it is not necessary to coat the following billet again. Coating of the billets can be reduced to every third to fifth billet. It would be even more efficient to coat only the dummy block and not the billet at all. However, this depends on the extrusion press. Whereas it is comparatively simple to automate the coating of the billet, placed between the preheating furnace and the press, it is more challenging to automate the movement of a spray gun into and out of the moving press.

The 5µm average size of the BN platelets provides another advantage, compared to carbon black. BN is not carcinogenic, and also nontoxic, and chemically inert. Furthermore, the bigger grain size is responsible for a better surface quality of the extruded profile. There will be no white marks on edges, since BN, even inside the die, is not picked up by the profile surface.

BN is a nonhazardous, environmentally safe material and, as an electrical insulator, cannot cause any interference with the electrical equipment.
Application of Boron Nitride to the Billet and/or Dummy Block

![Schematic diagram of electrostatic coating.](image)

**Figure 8.** Schematic diagram of electrostatic coating.

Boron nitride can be applied either as a powder or a water-based suspension. The common method of application is as a powder. Taking advantage of the electrical insulating behavior of BN, it is possible to apply the powder electrostatically to the front face of the aluminum billet, or the dummy block (Figure 8). The coated layer could be as thin as 0.5µm, as one platelet of BN would be enough to assure the release properties, but then the coated surface would be invisible. With a coating thickness of a few microns, the white color of BN is easily visible (Figures 9 and 10).

**Figure 9.** BN coated dummy block.  
**Figure 10.** BN coated billet.

Various types of electrostatic coating equipment are available to meet individual requirements. All equipments is fully automated. Although consumption of BN powder is very economical, and therefore the running costs of BN per press are low, the costs for electrostatic spraying equipment are quite high. Therefore this technology, though the most efficient, is mainly used only for presses with large-sized billets and profiles for customers with high quality demands.

To overcome the investment barrier, a new water-based boron nitride coating has been developed, which can be sprayed with standard commercial spray guns. The initial problem of applying a water-based coating to a hot surface at greater than 450°C is the Leidenfrost effect, which is responsible for preventing sticking of the coating. With the development of a new nano-binder system in combination with a high-speed spraying application, it is possible to apply BN to the metal surfaces, even though the water evaporates immediately. The water content of the coating is not too high, to avoid corrosion of nearby equipment. Once the BN coating has been applied to the surface, it has the same characteristics as the powder.
This coating can also be used to coat the shear blade in the extrusion press and the shear blade after the preheating furnace, if the billet is not cut to its final length before preheating.

**Application of Boron Nitride in the Die**

Dies should always be protected against rust during storage. Rust is harder than aluminum. If there is rust already in the die, it will create marks on the surface of the profile and then scratches inside the die, which can be seen on the profile as well. Besides various different methods, the use of boron nitride sprays (Figure 11) or coatings is the best method of maximizing tonnage of profiles through the die. The BN sprays and coatings are ethanol-based, and therefore dry quickly on the steel surface. The thin BN-containing film inside the die will protect it against corrosion. It will remain inside the die when it is preheated, and therefore improve the quality of the first profiles leaving a newly-installed die in the extrusion press.

![Figure 11. Boron nitride spray.](image)

**CONCLUSIONS**

Boron nitride is the most effective release agent for the separation of the billet and the dummy block. The use of boron nitride can minimize surface defects on profiles and increase productivity. Protecting dies with boron nitride sprays increases the tonnage of profiles per die, since the reject rate at the beginning of pressing will be reduced. Furthermore, BN is an environmentally safe, nontoxic material, and causes no health hazards for workers, or interference with electrical equipment.

**ACKNOWLEDGEMENTS**

The author would like to thank Pierre Emanuel Bach, Olivier Druhen, Emanuel Mandrelli, and Bertrand Schnell of Comexale, Nancy, France, for their support with technical information on the industrial application.

**REFERENCES**