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Synopsis:

Hexagonal boron nitride (h-BN), whose structure is a layered structure like graphite, is a material for use as advanced ceramics. The material of h-BN has unique and various features such as lubricity, heat resistivity, corrosion resistivity to molten metals, high electrical resistivity, and good machinability. Kawasaki Steel Corp. has endeavored to establish a production technique of h-BN powder of high purity for its new application, and now possesses optimized synthetic conditions for large-scale production of high-purity h-BN powder with controlled properties including the grain size. As a very unique application, high-purity h-BN powder for cosmetics has been developed for the first time in the world. Furthermore, coating reagents, in which h-BN powder is dispersed homogeneously in water, silicon oil, and organic solvent, have been also developed for the application of a solid lubricant at high temperatures.

1 Introduction

Hexagonal boron nitride (h-BN), a synthetic compound which does not exist in nature, is an advanced ceramic which is now finding a wide range of applications in industry.

h-BN, which has two-dimensional structure, is composed of multiple hexagonal rings formed by the mutual covalent bond of B and N atoms. Because these hexagonal rings in turn form a multilayered structure similar to that of graphite, h-BN is sometimes called "white graphite." Hexagonal BN also possesses several properties similar to those of graphite, including superior lubricity, thermal conductivity, resistance to chemical corrosion, and thermal stability in reducing atmospheres. In addition, sintered bodies of h-BN offer good machinability in lathe working.

Important differences include electrical conductivity, oxidation behavior, and reactivity with molten metals compared with graphite. Graphite is an electrical conductor, while h-BN is an insulator. Graphite oxidizes in air at temperatures of over 500°C, but h-BN does not oxidize at temperatures below approximately 900°C. Finally, graphite reacts easily with various molten metal to form carbides, while h-BN is stable in the presence of molten metals and does not react even at high temperatures.

Because it offers these unique features, h-BN in powered or sintered form has found increasingly broad application in fields where graphite and other conventional materials cannot provide the high level of purity, accuracy, and functional diversity required by recently developed manufacturing technology. Typical applications of h-BN include lubricants and components for molten metal applications, and heat treatment jigs.

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In the diversification program of Kawasaki Steel, the company selected h-BN as a promising advanced ceramic material around 1985, and began to develop synthetic production technology. At present, the development of applications is underway following a variety of research and development work. One result has been the world's first development of high-purity h-BN for cosmetics to the stage of practical application.[1] Hexagonal BN is also contributing to an improved level of production technology in a number of industrial fields. Examples include the use of h-BN in casting and other machining applications for aluminum, and in lubricant and mould releasing applications for glass, and the development of new BN-system composite ceramic materials.[2-5]

This report outlines the physical and chemical properties of h-BN materials, and presents a brief description of the features of Kawasaki Steel's production method in comparison with other industrial methods of producing h-BN powder. New applications of Kawasaki Steel's high purity h-BN powder are also discussed.

2 Features of Hexagonal Boron Nitride

2.1 Crystallographic Structure

A comparison of the crystallographic structure of h-BN and graphite is shown in **Fig. 1**. In h-BN, boron atoms and nitrogen atoms combine chemically and form hexagonal rings by mutual covalent bond. The basic unit of the crystalline structure is formed by flat "plates" in which these rings are linked in two dimensions. These plates characteristically form a multilayered three-dimensional structure by van der Waals bond.[6] The resemblance to the hexagonal structure of graphite is clearly visible in Fig. 1. It may also be noted that like graphite, which transforms into an isotropic diamond under high temperature and high pressure conditions, h-BN also transforms into istropic cubic-BN similarly.

A special feature of the crystallographic structure of h-BN is its anisotropy. As discussed above, the two-dimensional hexagonal ring structure is strongly bonded internally by covalent bond, while the interlayer bond is of the weak van der Waals type. The plate-like crystal grains and resultant lubricant function of the material have their origin in this crystallographic anisotropy.

2.2 Features of h-BN

The basic physical properties of h-BN are shown in **Table 1** for reference purposes.

2.2.1 Lubricity

Hexagonal BN with its layered structure is a typical solid lubricant, and is similar in this respect to graphite

Table 1 Physical properties of h-BN

Item	Value
Theoretical density (g/cm^3)	2.28±0.01
Melting point (°C)	3 300～3 400 (under high pressure N_2)
Pressure of decomposition (Pa)	1.29 (1 587°C) 92.2 (1 887°C)
Specific heat c_p (J/mol·°C)	$6.74+1.67\times10^{-2}T$
Thermal conductivity	
· Parallel to c-axis (W/m·K)	2.9
· Perpendicular to c-axis (W/m·K)	62
Thermal expansion coefficient	
· Parallel to c-axis ($°C^{-1}$)	40.5×10^{-6}
· Perpendicular to c-axis ($°C^{-1}$)	-2.9×10^{-6}
Electrical resistivity (Ω·cm)	10^{13} (R.T.)
Dielectrical constant	4～5 (10^2～10^6 Hz, R.T.～200°C)

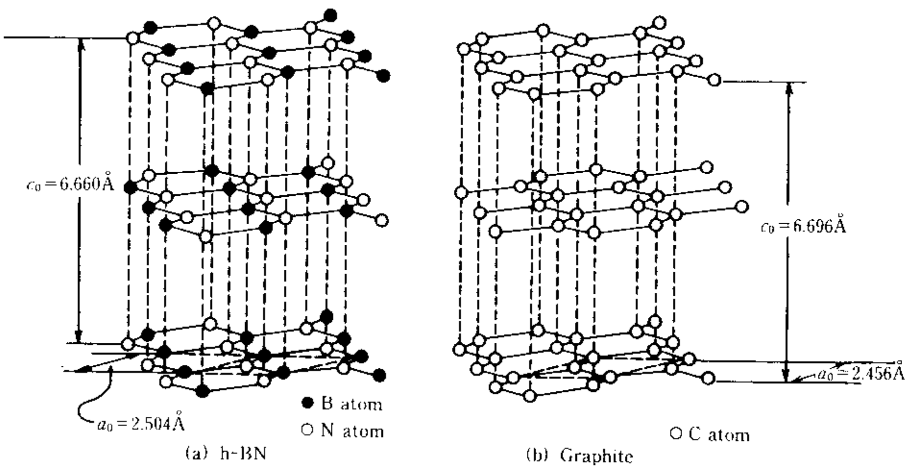


Fig. 1 Crystal structures of h-BN and graphite

and molybdenum disulfide (MoS_2). However, h-BN offers better resistance to oxidation than graphite or MoS_2, and can be used as a solid lubricant at much higher temperatures of up to 900°C.

2.2.2 Heat resistance

Basically, BN is thermally stable. The h-BN has a high melting point of over 3 000°C in a pressurized nitrogen atmosphere, and is thermally stable in non-oxidizing atmospheres. Where anti-oxidation behavior is concerned, h-BN is resistant to oxidation at temperatures of up to 900°C, while graphite shows significant oxidation at 500°C and above.

2.2.3 Resistance to thermal shock

As shown in Table 1, the coefficient of thermal expansion of h-BN is small at $4.05 \times 10^{-6}/°C$ in the *c*-axis direction and $-2.3 \times 10^{-6}/°C$ in the perpendicular direction. In sintered bodies, h-BN provides superior thermal shock resistance in combination with high thermal conductivity.

2.2.4 Mechanical properties

Hexagonal BN does not possess exceptionally high strength. Like graphite, however, it can be processed with cutting machines and is therefore known as a "machinable ceramic." For industrial applications, it can be processed into parts of complex shape with excellent precision.

2.2.5 Corrosion resistance with respect to molten metals

Although graphite readily reacts with a number of metals at high temperature to form carbides, h-BN remains stable and does not react at high temperatures. Hexagonal BN also resists wetting by oxide glass, and shows excellent corrosion resistance at high temperature, particularly in inert atmospheres.

2.2.6 Electrical properties

In contrast to graphite, which is a good electical conductor, h-BN shows excellent insulation properties and has high dielectric strength. Moreover, high-purity h-BN possesses superior insulation properties even at high temperature. Because its dielectric constant is low, as shown in Table 1, h-BN is suitable for applications related to electronic parts.

3 Production Methods for h-BN Powder

3.1 Conventional Methods and Newly Developed Method

Several production methods have been proposed for h-BN powder. In the methods used industrially, borates such as boric acid (H_3BO_3) or borax ($Na_2B_4O_7$) are heated in the presence of a nitrogen-containing compound such as ammonia or urea ($(NH_2)_2CO$) to form a B–N bond.[7,8] By way of example, the reaction in the production of h-BN powder from borax and urea is as shown in Eq. (1).

$$Na_2B_4O_7 + (NH_2)_2CO \longrightarrow BN + NaOH + CO_2 \quad \cdots\cdots\cdots\cdots(1)$$

Special-purpose h-BN is also produced from boric halides and ammonia by the chemical vapor deposition (CVD) coating method when high purity is required, although this is not an industrial production process.[9]

The main industrial production methods are shown in **Table 2**. In method I, the surface area for reaction with NH_3 is small when boric acid is heated to melting. To avoid this problem, calcium phosphate ($Ca_3(PO_4)_2$) is blended into the feedstock as an inert filler to accelerate the reaction.[7] However, in order to obtain high-purity h-BN with this method, the resultant product must be washed to remove Ca and P contaminants originating in the inert filler, making the production process more

Table 2 Production methods of h-BN powder

	Raw materials	Outline of production process	
I (Conventional)	· Boric acid (H_3BO_3) · NH_3 · Calcium phosphate ($Ca_3(PO_4)_2$) etc.	Mixing→Nitrization→Grinding→Washing→Drying→Crystallization→Grinding→h-BN powder	· Contamination of Ca, P · Long and complex process
II (Conventional)	· Borax (Anhydride) ($Na_2B_4O_7$) · NH_3 · Urea ($(NH_2)_2CO$)	Mixing→Nitrization→Grinding→Washing→Drying→Crystallization→Grinding→h-BN powder	· Contamination of Na · Long and complex process
III (Kawasaki Steel's method for HP grade*)	· H_3BO_3 or B_2O_3 · N_2 · Organic compound with $N((NH_2)_2CO)$, etc.	Mixing→Nitrization→Crystallization→Grinding→h-BN powder	· Fittness to high purity powder · Short and simple process

* HP grade: High purity powder

complex. At the same time, the degree of purity which can be achieved is limited. Method II can be expected to involve similar process and product quality problems, since a washing step is needed to remove the Na originating in the borax ($Na_2B_4O_7$) raw material.[7]

In contrast to the conventional production methods described above, the process newly developed by Kawasaki Steel (method III in Table 2) avoids the use of components which would leave residual impurities such as alkali or P in the BN compound, and uses extremely pure raw materials. For these reasons, the Kawasaki Steel's method does not require grinding, washing, and drying steps between nitrization and crystallization, which are necessary with conventional methods I and II. This shortens and simplifies the production process. It must be noted that the Kawasaki Steel's process is by nature a high purity production method.

3.2 Crystallization and Purification Process

In nitrization, h-BN with a low degree of crystallization is synthesized by heat treatment at 1 000°C or below in the presence of NH_3 or N_2. In terms of the crystallographic structure shown in Fig. 1, the two-dimensional propagation of the plate-like crystallites is poor at this stage of crystal growth, and stacking in the direction of the c-axis is irregular. A significant impurity component is also present, composed mainly of B_2O_3.

The fundamental properties in case of evaluating h-BN are purity and grain size, which are strongly dependent on the temperature of heat treatment during crystallization. Naturally, because grain size is strongly affected by the degree of crystallinity, both are important evaluation items. The degree of crystallinity is generally evaluated on the basis of the L_a and L_c values of crystallites. Specifically, L_a shows the degree of two-dimensional propagation of the plate-like crystallites, while L_c shows the degree of stacking along the c-axis.

The values of L_a and L_c are obtained from Eq. (2) using the half-value width of peak in X-ray diffraction pattern.[10]

$$L_a, L_c = \frac{k\lambda}{\beta \cdot \cos\theta} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where,

λ: Wave length
β: Half-value width of peak
θ: Diffraction angle
k: Constant
L_a: (100) plane
L_c: (002) plane

The effect of the crystallization temperature on the crystallite size, L_a and L_c, and grain size are shown in **Fig. 2**.[11] Grain size and crystallite size, L_a and L_c, which represents the degree of crystallinity of BN, are both strongly dependent on the heat treatment temperature. At low temperatures, stacking of two-dimensional layers is irregular and crystallite with a disordered layer structure forms. However, as the temperature increases, grains grow (as graphite forms when carbon is heated) and become highly regular hexagonal crystals. As is clear from Fig. 2, it is possible to control purity and grain size over a wide range by selecting an appropriate temperature for heat treatment, and thus to obtain h-BN powders with a variety of features.

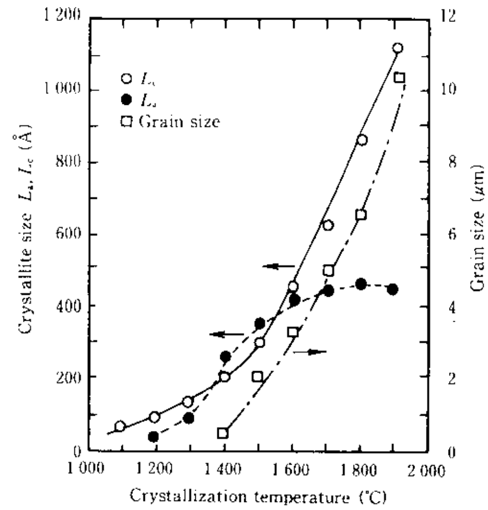


Fig. 2 Effects of crystallization temperature on the crystallite size and grain size of h-BN powder

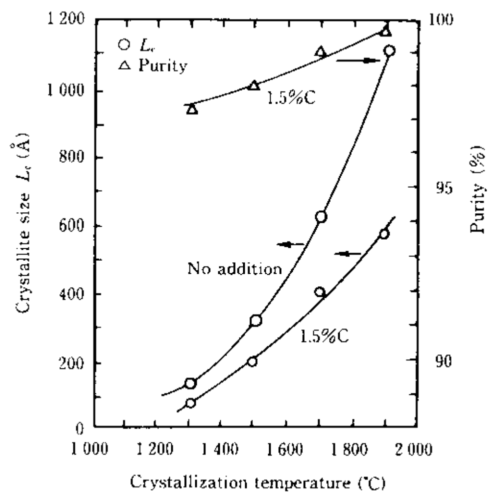
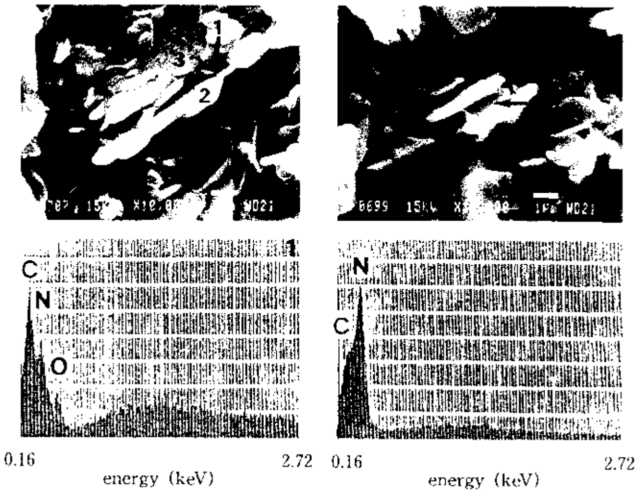


Fig. 3 Effects of crystallization temperature on the crystallite size and grain size of h-BN powder containing carbon

Figure 3 shows the effect of the crystallization temperature on purity and crystallite size L_c in h-BN containing a small quantity of carbon.[11] The addition of carbon is considered to be effective in suppressing grain growth and producing a high-purity powder with a small grain size because the liquid phase component B_2O_3 is



(a) Before washing (b) After washing

Photo 1 Electron-microscopic photographs (SEM image) and EDX analyses of h-BN powder before and after washing in H_2O

volatilized and removed by the reaction shown in Eq. (3).

$$B_2O_3(l) + C(s) \longrightarrow B_2O_2(g) + CO(g) \cdots\cdots (3)$$

High purification is achieved by washing with water (or other substances) after nitrization, as shown in Table 2. **Photo 1** shows the results of washing with water to dissolve and eliminate soluble components such as B_2O_3 and obtain a high-purity h-BN. Photos 1(a) and 1(b) were obtained by scanning electron microscope (SEM) observation of crystal grains before and after washing. The lower portion of the photos shows the corresponding energy dispersed X-ray microanalyser (EDX) analysis results.[12] In Photo 1(a), the number 1 indicates an intergranular area, 2 is the edge of a crystal grain, and 3 is a grain surface. The position of EDX analysis in both cases was the intergranular area, which is shown by the arrow in Photo 1(b). As is clear from the EDX analysis results before washing shown in Photo 1(a), a strong oxygen (O) peak existed between the grains, which are aggregates of plate-like primary grains. The strength of this peak was decidedly higher than that of the O peak of the grain surface.[12] In Photo 1(b), the O peak has completely disappeared after washing.

These results demonstrate that it is possible to obtain high-purity h-BN by washing with water to dissolve and remove the noncrystalline B_2O_3 component, which is a reaction product present after nitrization.

Although high purification is achieved mainly by the washing process described above, powders of even higher purity can be obtained by crystallization at high temperatures of over 1 500°C, since impurities such as B_2O_3 have high vapor pressures and can be vaporized and dispersed in this temperature range.

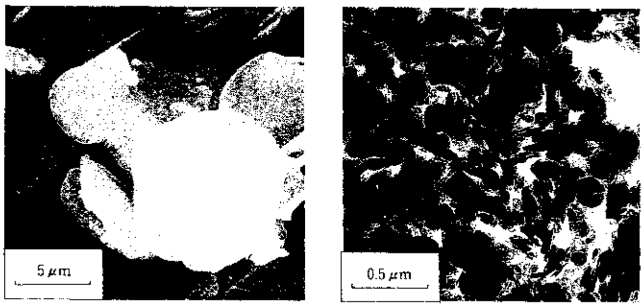
3.3 Properties of h-BN Powder

The features of Kawasaki Steel's main h-BN powder products are shown in **Table 3.**[3] A variety of powders can be produced by varying the crystallization temperature, making it possible to meet diverse user needs. Kawasaki Steel's products offer high purity, and range from large-grained powders for lubricants and mould release agents to extremely fine-grained powders for active sinters. **Photo 2** (a) is an electron-microscopic

Table 3 Properties of Kawasaki Steel's h-BN powder

Application	Lubricant and mould release agents	Raw material for ceramics	High purity powder for cosmetics
Grade	HP^{*1}	FS^{*2}	SHP^{*3}
Purity (BN%)	>98	>94	>98.5
Average particle size (μm)	5~15	0.1~0.5	3~6
Surface area (m^2/g)	3~10	25~90	4~10
Tap density (g/cm^3)	0.2~0.6	0.2~0.6	0.3~0.4
True density (g/cm^3)	2.26	2.26	2.26
Appearance	White powder	White powder	White powder

^{*1} HP: High purity grade ^{*2} FS: Fine ceramics grade
^{*3} SHP: Super-high purity grade



(a) Lubricant and mould release grade (HP) —SEM image (b) Raw material for ceramics grade (FS)—TEM image

Photo 2 Electron-microscopic observations of Kawasaki Steel's h-BN powder photo of h-BN for lubricant and mould release use; Photo 2 (b) is a ceramics grade product for sintering.

4 Application of h-BN Powder

As suggested by **Table 4**, h-BN is being used in an increasingly wide range of applications in various fields of industry. Products also include spray-type powders for processing and others.

Table 4 Applications of h-BN powder

Powder and processed products	Applications
h-BN powder	· Active filler for silicon rubber, resin and plastics · Additive to oils and high-temperature grease · Boron source for preparation of other boron compounds · Raw material for h-BN ceramics and c-BN materials · Raw materials for various h-BN system composite ceramics · Additive to various cosmetics
h-BN dispersion solvent	· Solid lubricant for high-temperature bearings · Mould release for die casting glass and metals · Agents to prevent carburization and oxidation of various metals
h-BN spray	· Lubricant for high-temperature surfaces · Mould release agents for high-temperature molten substance · Mould release agents for press-formed products

The main applications of h-BN powder include filler materials for formed plastic products and silicon rubber, in which h-BN is used to improve heat-related performance; raw materials for sinters and other fine ceramics; and grease additives for high temperature applications. As a powder-type processing product, h-BN dispersed in water, organic solvents, or oil is used as a mould release agent in the casting of aluminum alloys and glass, as a lubricant and mould release agent in the extrusion forming of aluminum alloys, and as an agent for the inhibition on carburization and/or oxidation of various metals. Thus, as manufacturing technologies become increasingly sophisticated, h-BN is finding expanding use in applications where graphite and other conventional materials are no longer adequate.

The following sections describe newly developed areas of use.

4.1 Cosmetics

Table 5 Properties of h-BN powder for cosmetics (compared with conventional powder)

Powder / Property	h-BN (SHP grade*)	Conventional powders			
		Nylon	Mica	Talc	TiO_2
Particle shape	Plate	Sphere	Plate	Plate	Grain
Paricle size (μm)	3~6	4~5	10~20	10~20	0.05
Coefficient of dynamic friction	0.15	0.33	0.43	0.30	0.50
Hiding power (cm^2/g)	84.5	16	22.7	18.6	209
Adhesion property (mg/cm^2)	0.068	0.018	0.038	0.048	0.032

* SHP grade: Kawasaki Steel's super-high purity powder

As the result of a joint development project with the major Japanese cosmetics maker Shiseido Co., Ltd., h-BN powder was applied commercially to cosmetic products for the first time in the world.[1)]

Both inorganic and organic powders are used in cosmetics. Materials for inorganic powders include clay minerals such as talc, mica, and sericite, titanium dioxide (TiO_2), and zinc oxide, while organic powders are produced from nylon, PMMA, and other sybstances. A comparison of the features of representative powders is shown in **Table 5**.[1)]

Spherical nylon and talc have low coefficients of dynamic friction; thus, cosmetics made from these substances are easy to apply owing to high lubricity but low in hiding power. On the other hand, TiO_2 cosmetics provide excellent hiding power, but lack smoothness in application owing to low lubricity. Comparing particle sizes, mica and talc are composed of plate-shaped particles on the order of 10-20 μm, while TiO_2 particles are 0.05 μm in size. Even though powders are suitably selected and blended in the cosmetic manufacturing process, uniform dispersion and mixing of particles of differing size and shape is difficult, and aggregation in the specified powder composition may occur. The development of a h-BN powder with a good balance of the properties required in cosmetic products, such as ease of application and hiding power (see Table 5), was therefore undertaken with the aim of realizing a significant improvement in the performance of the powders used in cosmetic products.

It has been known that crystallizing at high temperatures will produce h-BN powder with a low coefficient of dynamic friction, which is an index of ease of application. This relationship is shown in **Fig. 4**. For use in cosmetic applications, however, the powder must also possess hiding power and "fit." **Figure 5** shows the relationship between crystallization temperature and hiding power,[1)] and indicates that the maximum hiding power is obtained at 1 600-1 800°C. The relationship between the crystallization temperature and the quantity of adhesion, which is an index of fit, is shown in **Fig. 6**,[1)] where

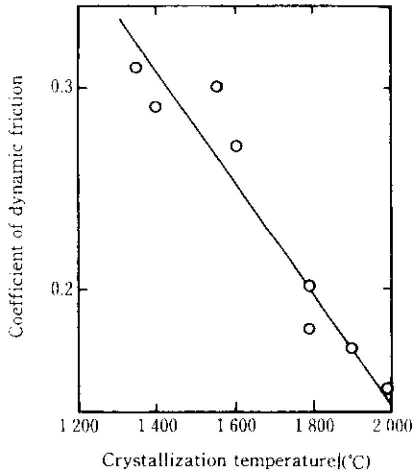


Fig. 4 Effect of crystallization temperature on the coefficient of dynamic friction of h-BN powder

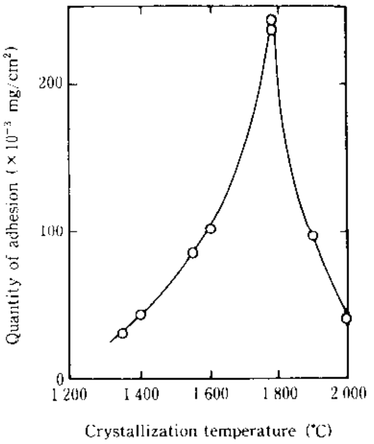


Fig. 6 Effect of crystallization temperature on the quantity of adhesion of h-BN powder as cosmetics use

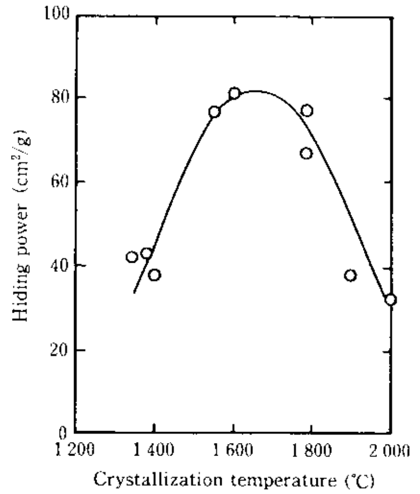


Fig. 5 Effect of crystallization temperature on the hiding power of h-BN powder as cosmetics use

the maximum value of adhesion is obtained in the vicinity of 1 800°C.

The particle size increases as the crystallization temperature rises, increasing the lubricity of the material and lowering its coefficient of dynamic friction (Fig. 4). On the other hand, hiding power and quantity of adhesion show peak values at certain crystallization temperatures (Figs. 5 and 6). A detailed explanation of this phenomenon has not been attempted, but it is believed to be the result of interrelated factors which include the effect of the minute particles in h-BN powders of a certain size distribution, and differences in particle cohesion and dispersion.

In Table 5, the features of h-BN powder crystallized at 1 800°C are compared with those of conventional powders for cosmetic applications. In ease of application, the new material is superior to spherical nylon and talc, which had ranked best in this characteristic. The hiding power of h-BN is not equal to that of TiO_2, but it is greatly superior to mica and talc in this regard, and also outperforms mica and talc in terms of fit.

The development of the material described above was made possible by matching the potential of h-BN powder with the needs of a leading company Shiseido Co., Ltd. in the cosmetics industry to produce an ideal cosmetic product. Moreover, plans are underway for the development of other new products which take will advantage of the distinctive pure white color of h-BN powder.

4.2 Solid Lubricants

Like graphite and molybdenum disulfide (MoS_2), h-BN powder is well known as a solid lubricant with a layered structure. The distinctive feature of the solid-lubricant performance of h-BN is that, unlike graphite and MoS_2, it does not lose its lubricant function at high temperatures.

Figure 7 shows the temperature dependence of the friction coefficient μ of various solid lubricants as measured in air.[13] At room temperature, the value of μ is similar in all three lubricants, at 0.2 or under. However, substantial differences appear at 400°C and above. With graphite and MoS_2, μ increases at temperatures of between 400°C and 500°C, as indicated by the hatched area in Fig. 7. With h-BN, on the other hand, the value of μ remains low even at 600°C. The increase in μ in graphite and MoS_2 is attributed to changes in the surface of the powders accompanying oxidation. Oxidation occurs at approximately 450°C in graphite and at about 400°C in MoS_2, but begins at about 900°C in h-BN, as is clear from the detailed data on oxidation behavior

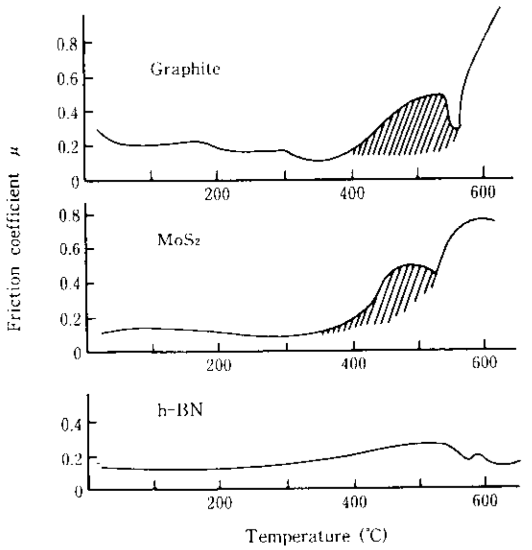


Fig. 7 Temperature dependence of the friction coefficient of various solid lubricants

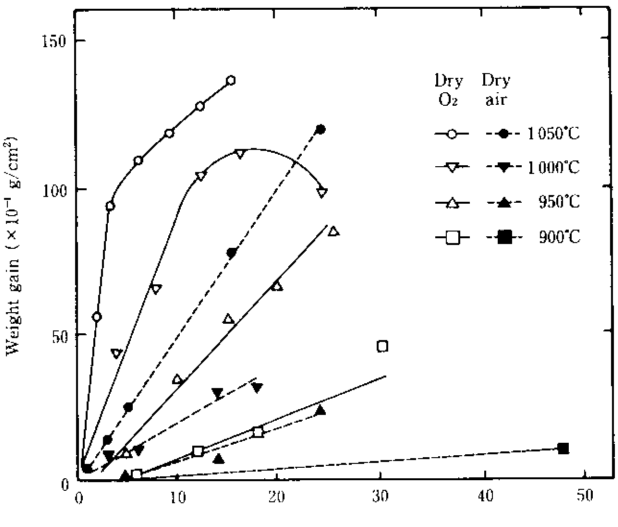


Fig. 8 Effects of oxidation temperature and time on the weight gain by oxidation of h-BN powder

presented in **Fig. 8**.[14] For this reason, h-BN retains its excellent lubricant performance at temperatures of up to approximately 900°C.

Various applications take advantage of the high temperature lubricant properties and resistance to corrosion by molten metals offered by h-BN, including high-temperature lubricants for hot extrusion forming of aluminum alloys and die-core release agents for aluminum die casting.

From the viewpoint of convenience in practical application, coating agents in which h-BN is dispersed in water or an organic solvent, and spray methods are promising. Conventional graphite/organic binder type coatings may cause carburization defects in products due to the reaction between aluminum and graphite, and deterioration of the working environment due to the decomposition gas released by the organic binder.

To solve these problems, Kawasaki Steel has developed a water-based mould release agent using a combination of h-BN, which resists wetting by aluminum, and an inorganic binder.[15] Water soluble phosphate and colloidal silica are used as inorganic binders, and dispersed homogeneously in the aqueous solvent. An oil-based lubricant/mould release agent in which h-BN powder is homogeneously dispersed in a silicon oil solvent has also been developed for applications which do not permit the use of aqueous agents.[16] These water- and oil-based lubricants/mould release agents, together with sprays, are finding wide use in fields of application where high temperature lubricant and/or mould release performance is required, contributing to the improvement of production technology for a variety of products.

4.3 BN-System Composite Ceramics

BN-X has been developed as a new composite ceramic material in which h-BN powder is homogeneously distributed in various types of ceramics. The distinctive feature of BN-X is that the superior properties of h-BN, such as heat resistance, corrosion resistance, and good machinable performance, can be obtained in combination with the respective advantages of the Si_3N_4, AlN, ZrO_2, and Al_2O_3 used as X components in the composite. Various combinations of these component materials make it possible to meet a wide range of requirements.

The principal method of producing BN-X composite ceramics is slip casting followed by sintering at normal pressure. The h-BN material is the extremely fine and active FS grade (see Table 3). The production method also features unique techniques for ensuring homogeneous dispersion of raw materials and forming of the composite.[2-5] Applications center on the following areas at present, with new fields being actively developed by Kawasaki Refractories Co., Ltd.:

(1) Parts for Casting Molten Metals
- Break rings for horizontal continuous casters
- Crucibles
- Nozzles
- Moulds

(Molten metals: stainless steel, steel, Au, Ag, Al, Cu alloys)

(2) Jigs for Heat Treatment
- Muffles
- Base boards
- Moulds

(Materials treated: stainless steel, Al, glass)

5 Conclusions

Hexagonal BN (h-BN), a fine ceramic material with a layered structure which resembles that of graphite, offers a number of functional advantages including excellent lubricity, heat resistance, resistance to corrosion by molten metals, electric insulation, and mechanical workability. This paper has described research and development work in connection with new production technology for high-purity h-BN, and the development of applications aimed at expanding its fields of use. The results may be summarized as follows:

(1) A new method of producing high-purity h-BN powder by heating boric acid or anhydrous boric acid in the presence of urea or other high-purity nitrogen-containing compounds has been established.

(2) By varying the crystallization temperature, it is possible to control the degree of crystallinity and the grain size of h-BN powders over a wide range, and thus produce powders with various properties.

(3) High-purity h-BN powder is mainly obtained by water washing. Observation and analysis of the microstructure in the course of the study reported here demonstrated that this result is achieved by washing out water soluble residual components such as B_2O_3 which are present between h-BN grains.

(4) Following a joint development effort with Shiseido Co., Ltd., high-purity h-BN powder was applied to cosmetics for the first time in the world. This product, in which the crystal grain diameter was optimized for use in cosmetics, is superior to conventional nylon, mica, and titania in ease of application, hiding power, and adhesion, and has been evaluated as a cosmetic material with ideal characteristics.

(5) Sprays and coating products in which h-BN powder is uniformly dispersed in water, silicon oil, or an organic solvent have been developed as high-temperature solid lubricants and mould release agents. These products are finding wide use in applications such as the hot extrusion forming of aluminum alloys, die casting, and the hot forming of glass, where high temperature lubricant and/or mould releasing performance are required.

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