

Yoshitsugu KIMURA and Kazumi OKADA

Institute of Industrial Science, The University of Tokyo

It was reported in the preceding meeting of the IRG-OECD that boron nitride powder effectively reduced wear, but not friction, when added to oil in a sliding system of hardened bearing steel. The present report describes results of observation of the wear scars.

Boron nitride (BN) has a lamellar structure of a graphite-like hexagonal crystal lattice. The bonding within each layer is strong covalent while that between layers is almost entirely weak van der Waals, a particular character which implies a possibility for BN to be used as a solid lubricant.

The mechanism behind the effective lubricating property of graphite and molybdenum disulfide is understood to be owing to the easy shear along the basal plane of their hexagonal crystalline structures. Although BN has a similar hexagonal structure, its lubricating property has been believed inferior to that of graphite or molybdenum disulfide, and this has been attributed to its insufficient adherence to metal surfaces. Differences are also found in its chemical inertness even at high temperatures, and its low elastic modulus and low hardness. Then use of BN as a solid lubricant has been limited practically to high temperature applications where graphite and molybdenum disulfide fail due to decomposition or oxidation.

However, the present authors showed that addition of BN powder to lubricating oil markedly reduced wear in a sliding system under severe sliding conditions. That is, sliding was made between an annular flat surface, 34 mm in outer diameter and 26 mm inner diameter, of HV750 bearing steel JIS SUJ2 (AISI52100) ring and sides of three bearing rollers, 10 mm in diameter) of the same material, under a load of 784 N at a sliding speed of 157 mm/s in VG15 paraffinic oil at 40°C. BN powder of 99.1% purity having 2.85 μm was added by 1 to 4 mass% to the oil without dispersant, and the oil was continuously stirred by a blade fixed to the ring specimen holder preventing sedimentation of BN powder.

Figure 1 compares typical friction traces in sliding with and without BN. The coefficient of friction becomes a little bit higher with the addition of BN, but its erratic increases and fluctuations are eliminated showing smoother sliding. Figure 2 summarizes wear of the rollers in sliding for 3 h in terms of the specific wear rate, where different symbols indicate BN samples of different properties. Making a contrast with friction, presence of BN powder evidently reduces wear. Although some scatter is found, addition of BN by 1 mass% results in its decrease by an order of magnitude and the decreasing trend, though gradually weakened, continues until several percents.

For many solid lubricants, their primary effect is to reduce friction. It is particularly true with lamellar solids like graphite and molybdenum disulfide in that easy shear between their basal planes results in low friction and, possibly in its consequence, low wear. The difference in the present results suggests different mechanism of reducing wear of BN.

A series of EPMA was made on the wear scars. Concentration of boron over the whole wear scar on a roller and a part of a wear scar on a ring are shown in Fig.3, together with their profiles. Although not reproduced here, concentration in different colors indicates the counts in 50 ms from the area of $3 \mu\text{m}$ square, which carries information on the average concentration over 2-3 μm in depth. Observation of the results for the roller (bottom) reveals that light areas in the EPMA map correspond to the plateaus in the profile. This suggests that, since the surface was washed before EPMA, boron which is more or less stagnantly adhering to the surface is seen here. Averaging over the contacts against the three rollers seems to have obscured this effect in the case of the ring (top). We can reasonably assume that only boron which is acting at the interface is seen here. Then how is it?

Figures 4 and 5 give detailed distribution of iron, boron and oxide on the wear scars as shown in the secondary electron image at bottom right of each figure. Nitrogen, though interesting, cannot be detected because of low sensitivity. The light parts in the EPMA maps are the parts seen dark in the secondary electron images, which are on a plateau in the case of the roller. Closer examination reveals that boron and oxygen are present at the same locations, which have rather clear contours showing their granular nature, especially in the case of the ring. Further, these locations are seen dark spots like small cavities in the secondary electron image.

A part of the wear scar on a roller is further enlarged in Fig.6 in which topography image (top) and normal secondary electron image (middle) are compared with the local profile of the same position. Although edges are not sharp, it is clear that the dark spots represent cavities. Then it is concluded that boron and oxygen are present in small cavities on the wear scars.

Chemical state of boron on the wear scar was examined by μ -ESCA, Fig.7. This result shows that little boron nitride is present which should provide a peak at 190.3 eV. Instead, a much higher peak exists at 191.3 eV which, if a single compound is assumed, indicates presence of oxide of boron. Curiously, however, it is different from the stoichiometric oxide of boron, B_2O_3 .

In summary, the followings are concluded.

- (1) Little boron nitride remains on the sliding surfaces.
- (2) Instead, some boron oxide(s) other than B_2O_3 is present.
- (3) The boron oxide(s) is present in small cavities on the sliding surfaces.
- (4) This seems to decrease wear by unknown mechanisms.

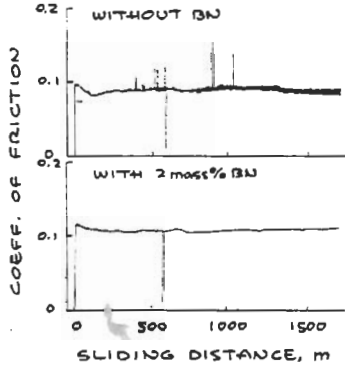


Fig.1 Friction traces

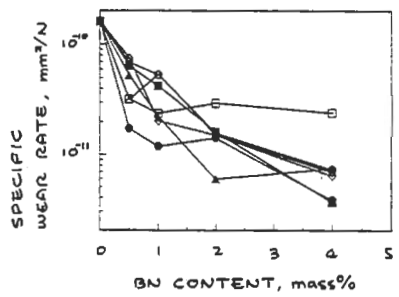


Fig.2 Specific wear rate

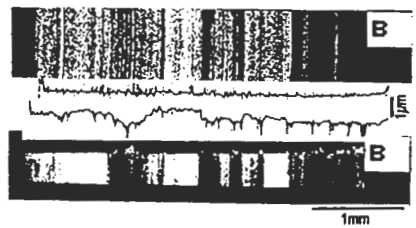


Fig.3 EPMA maps of wear scars

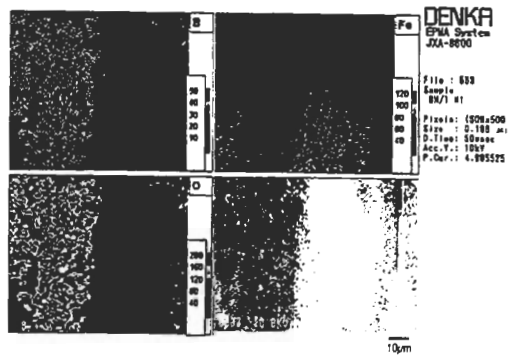


Fig.4 EPMA maps of roller

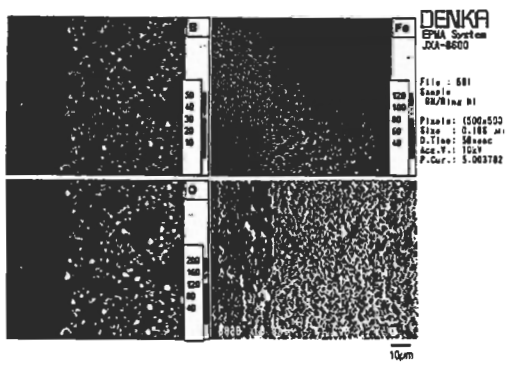


Fig.5 EPMA maps of ring

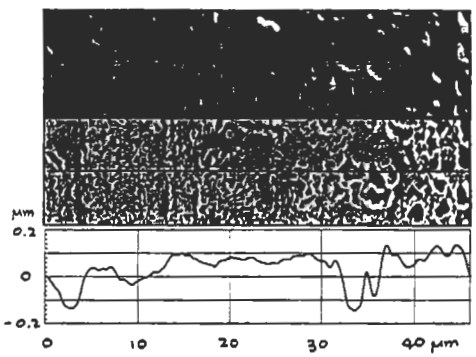


Fig.6 Cavities on roller

Curve	Area	Position	Height	FWHM	% Gauss
1	27	190.30	2	1.26	90
2	23.3	191.31	19	1.57	95

μ -ESCA

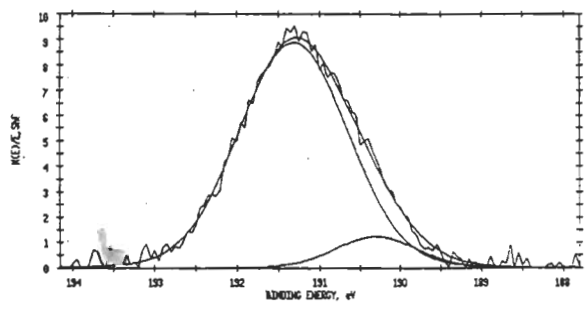


Fig. 7 μ -ESCA of wear scar