THE ROLE OF ADMIXED HEXAGONAL BORON NITRIDE IN SINTERED STEELS
2. EFFECT ON SLIDING WEAR AND MACHINABILITY

A. Liersch, H. Danninger, R. Ratzi

Abstract
PM steel specimens containing 0.5 to 2.0 mass% hexagonal boron nitride (hBN) were prepared by mixing, pressing and sintering, both fine and coarse BN being employed. The wear behaviour was studied in dry sliding on a pin-on-disk testbed, bearing steel being used as counter material. The machinability was studied in turning, the quality of the machined surface being used as the criterion. It showed that hBN, although it is a solid lubricant, does not improve the wear properties of sintered steels, but in fact lowers the wear resistance while the friction coefficient remains largely unaffected. The main reason for the poor wear resistance of the BN containing materials is the low strength, wear occurring by removal of entire particles or particle clusters. Fine BN is decidedly more detrimental than coarse grade, both to the mechanical properties and the wear behaviour. Similar results were obtained in machining; the quality of the turned surfaces was slightly better with the specimens BN containing than with plain Fe but inferior to materials containing sulfides, in particular MnS. Also in machining the poor interparticle strength caused by the BN addition resulted in rough and irregular surfaces.

Keywords: sintered steels, boron nitride, wear, machinability

INTRODUCTION
Boron nitride in its hexagonal modification (hBN) is a well established solid lubricant, due to its layered lattice structure which is very similar to that of graphite. When admixed to ferrous powder mixes it is superior to graphite insofar as BN is much more stable thermodynamically, decomposing in air at T>3000°C [1]. In contact with a ferrous matrix, BN is stable in atmospheres containing nitrogen, while in N₂-free atmospheres such as H₂ or vacuum it decomposes at temperatures above the Fe-B eutectic, i.e. 1174°C [2]. This reactivity is usually not a problem in practice since sintering of ferrous PM compacts is done commonly in N₂, N₂-H₂ or endogas, in which atmospheres hBN is stable at least up to T=1250°C [3]. On the other hand, BN can be used as a vehicle for adding boron as a sintering activator to ferrous powder compacts or even bulk powder; in this case N₂-free atmospheres are employed, preferably vacuum, to enhance fast BN decomposition [4]. A similar effect has also been described for Ni-BN [5].

The primary application of BN in sintered steels is, however, that of a solid lubricant. Admixing small amounts of BN has been reported to improve the machinability of sintered ferrous components which otherwise are mostly difficult to machine [6], the
phenomenon has been attributed to interrupted cut caused by the porosity [7] or to the work hardening caused by densification of the porous sintered steel immediately in front of the cutting edge. Further reasons are the presence of fairly soft microstructures or at least of heterogeneous ones with soft areas in many sintered steels, which facilitates the formation of built-up edges [8,9]. Here, the addition of solid lubricants is helpful; most commonly MnS is used [10-13] – which according to its crystal structure is not exactly a lubricant -, but also BN is reportedly useful [14,15].

For PM components which are wear loaded in service, an addition of solid lubricants is a common way to improve the friction wear properties. This holds for bearings and friction linings but also for ferrous structural parts such as e.g. valve guides. BN, with its high stability and reported lubricating effect, could be an attractive choice here. On the other hand, experiments with admixed lubricants have shown that the addition of solid lubricants only is not necessarily effective for low friction, at least if significant wear is to be avoided [16]. This has been explained by the fact that at low wear rates the surface is rapidly depleted of the lubricant which cannot be supplied to the tribosystem in the same way as is for example lubricating oil.

In part 1 of this work [3] it has been shown that BN, in particular a fine admixed grade, tends to lower the mechanical strength and also to inhibit dissolution of admixed graphite during sintering. Here, the effect of admixed BN grades on the dry sliding wear and the machinability of sintered Fe and Fe-C were studied.

SPECIMEN PREPARATION

The test specimens were produced from standard water atomized iron powder ASC 100.29 (Höganäs AB, Sweden) and natural graphite UF4 (Kropfmühl). As additives, standard fine BN grade with $d_{50} < 1 \, \mu m$ was used, and in parallel also coarse BN powder (50-180 $\mu m$). The latter grade was not available on the market; it was supplied by HTM AG, Biel, Switzerland, being specially produced by crushing BN compacts manufactured by HIP. SEM investigations showed also that the nominally fine BN grade was in part considerably agglomerated, and some of the agglomerates survived the mixing process, as could be seen in metallographic sections of sintered components (see below). In order to more clearly reveal the effect of hBN, also higher BN contents than industrially used were selected.

Tab.1. Composition of the mixes prepared and pore-free density (including the lubricant).
A 0.5 mass% ethylene bisstearamide (Microwax C) was used as pressing lubricant. The mixes prepared and the theoretical (pore-free) density values are given in Table 1; the mixing rule was applied considering also the volume occupied by the lubricant. The powders were dry mixed for 60 min in a tumbling mixer. Mixing proved to be a difficult task, since in particular the batches containing coarse BN were found to be very prone to segregation, as had been found earlier with coarse graphite [16]. Therefore these batches were further manually mixed just before filling them by hand into the die cavity. Pouring the mixed powder showed to be detrimental since it resulted in immediate segregation, the coarse BN particles ending up at the top of the bulk powder. However, even these measures could not grant a really even distribution of BN, which resulted in the considerable scatter of dimensional and mechanical properties [3].

Compacting was done in a tool with a floating die for standard impact test bars with cavity dimension of 55 x 10 mm (ISO 5754). For the wear tests, 60 x 7 x 7 mm³ bars were produced. The compacting pressure was uniformly 600 MPa.

The compacts were sintered in an electrically heated pusher furnace with Mo heating elements (Degussa type „Baby“) in plain H₂ or N₂-20% H₂ mix, both of technical purity. The carbon-free specimens were embedded in Al₂O₃ granulate; for the carbon containing steels, getter boats with Al₂O₃-5% graphite getter were used to avoid decarburization.

![Fig.1. SEM images of the BN powder grades used.](image)

The properties of the sintered specimens are listed in (Part 1). Micrographs proved that in the case of the fine BN grade the BN distribution was rather fine and even at 0.5% BN, content but was heterogeneous in the case of 2.0% C, in this latter case the micrographs were not very much different from those obtained with coarse BN (see Fig.2) All specimens were investigated and tested in the as-sintered state.
Fig.2. Microstructure of Fe-BN, compacted at 600 MPa, sintered 60 min at 1120°C.

**DRY SLIDING WEAR BEHAVIOUR**

**Experimental procedure**

For determining the dry sliding wear behaviour, a pin-on-disc testbed was used as depicted in Fig.3. The test bars were cylindrically machined one end to 6.5 mm diameter for a length of 7-8 mm, and face turned at the end surface which was used for wear loading. The counter material was bearing steel 100Cr6 (AISI 52100) heat treated to 62-64 HRC, with a freshly ground surface (R_a = 0.2 μm). In order to enhance adhesive wear – to make the lubricating effects stand out more clearly – the comparatively high load of 60 N (equivalent to a pressure of 1.8 MPa at nominal loaded area) combined with rather low sliding speeds of 0.5, 1.02, and 1.53 m.s^{-1} were selected. Following the wear map given by Lim and Ashby for steels [17], these conditions should apply to the transitional area between adhesive and oxidational wear.

The friction coefficient μ was measured through the torque exerted on the specimen which was recorded through a strain gage system. For determining the wear coefficient k, the mass loss was measured in regular intervals. In order to ensure that stable wear conditions had been attained, the tests were performed up to a total sliding distance of at least >10^4 m. Thus, the effect of the run-in period could be safely excluded; as will be shown below, there was no distinct run-in period in most cases in any event. All tests were done in laboratory air without any lubricant being added, and the pin and disc surfaces were carefully degreased prior to testing. At least two parallel runs were carried out for each material. If the k values obtained for a given material differed markedly between the parallel runs – as was the case with some materials, as shown below - further parallel runs were performed.
Results of wear testing

It was shown that the reliability and reproducibility of the wear tests strongly depends on the BN grade and sintering conditions. Specimens produced using fine BN proved to be virtually unmanageable, the specimens breaking in many cases already during machining of the cylindrical pin out of the rectangular bar or, at the latest, at the onset of the wear testing procedure, in which latter case the cylindrical parts came off the rectangular one. For those specimens which had been prepared with coarse BN and sintered at 1120°C, the wear coefficient k showed a very wide scatter between test runs on parallel specimens (see Fig.4a). Those compacts which had been sintered at 1250°C, in contrast, yielded significantly more reproducible k values. The friction coefficient, on the other hand, was rather consistent for all materials (Fig.4b); it was even more stable for those materials which had been sintered at 1120°C. With a few exceptions, the μ values ranged between 0.5 and 0.7, as typical for dry sliding of sintered steels against ball bearing steel [16, 18-20], indicating that even if BN had been present in the friction zone, its lubricating effect was not really noticeable.
Table 2. Dry sliding wear behaviour of Fe-BN-(C), manufactured using coarse BN, sintered 60 min 1250°C in N₂-20% H₂. Pin-on-disk testing, dry run, 60 N, sliding speed 0.5 / 1.02 m/s. (Dimensional change relative to the green size).

<table>
<thead>
<tr>
<th>Composition</th>
<th>Green density [g.cm⁻³]</th>
<th>Sintered density [g.cm⁻³]</th>
<th>Dim. Change [% lin.]</th>
<th>Impact energy [J.cm²]</th>
<th>Sliding speed [m.s⁻¹]</th>
<th>Wear coefficient [10⁶ mm³/N.m]</th>
<th>Friction coeff. [µ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe-0.5%BN</td>
<td>7.17</td>
<td>7.15</td>
<td>-0.21</td>
<td>31.4</td>
<td>0.5</td>
<td>121</td>
<td>0.561</td>
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<td></td>
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<td></td>
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<tr>
<td>Fe-2.0%BN</td>
<td>6.93</td>
<td>6.85</td>
<td>-0.06</td>
<td>3.9</td>
<td>0.5</td>
<td>178.4</td>
<td>0.668</td>
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<td></td>
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</tr>
<tr>
<td>Fe-0.5%BN-0.8%C</td>
<td>7.09</td>
<td>7.08</td>
<td>-0.23</td>
<td>16.1</td>
<td>0.5</td>
<td>22.8</td>
<td>0.551</td>
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<td></td>
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</tr>
<tr>
<td>Fe-2.0%BN-0.8%C</td>
<td>6.86</td>
<td>6.76</td>
<td>+0.09</td>
<td>3.6</td>
<td>0.5</td>
<td>101.3</td>
<td>0.561</td>
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</tr>
</tbody>
</table>

The reason for the poor reproducibility of k in some cases can be linked to the mechanical strength. As has been shown in [3], the addition of fine BN in combination with sintering at 1120°C results in poor interparticle strength, BN being embedded in the pressing contacts and inhibiting the formation of sound metallic bridges. In the case of carbon containing steels this adverse effect is further enhanced by the inhibiting effect of fine BN on carbon dissolution; it can be supposed that graphite also is enclosed in the pressing contacts and, if dissolution is at least in part prevented, remains there as an inclusion, further lowering the local strength. Coarse BN is sufficiently less detrimental to enabling proper pin-on-disk wear testing, but also here the low interparticle strength adversely affects the test results.

In the case of wear loading of sintered steels as applied here, i.e. dry sliding wear against the ball bearing steel in air, the dominating mechanism is commonly oxidative wear and, in the case of high porosity sintered steels, delamination wear, as shown in [18]. If however the interparticle strength is low – as in the case of the BN containing specimens - , entire powder particles or even particle clusters may break loose from the sintered specimen, thus drastically increasing the mass loss. Such effects were observed here; there were even a few cases when the cylindrical pin machined on the bar broke off the rectangular body as a consequence of the bending load applied through friction. These events are of course singular ones, but the removal of particles or particle cluster is basically a statistical process, and it might be assumed that these latter phenomena should result in high but reproducible wear. It was however recorded that in all cases in which larger fragments broke off the specimen in an early stage of the wear test, the further wear was also markedly higher. This might be attributed to the higher effective pressure on the remaining surface; it is however more probable that the fracture of a fragment results in cracks in the adjacent material, which promotes removal of further particle clusters. If thus by chance a larger fragment breaks off a given test specimen, this event determines the subsequent wear process.

The rather irregular relationship between k and µ is discernible from Fig.4 and also from Fig.5 which shows k as a function of µ. In part there is even a positive relationship between k and µ, in contrast to the findings with other solid lubricants for
which high wear resulted in low friction [16]. For hBN it may be assumed that the powder particles which are easily removed as debris due to poor interparticle bonding – as indicated by high k – increase friction in the wear region, acting similar to grinding powder.

![Wear coefficient](image1.png)

![Friction coefficient](image2.png)

![Wear coefficient vs. friction coefficient](image3.png)

**Fig.4.** Wear and friction coefficients for Fe-x%BN-(0.8%C) manufactured using coarse BN, sintered 60 min at 1120/1250°C in H₂, pin-on-disk test, 60 N, 0.5 m/s.
These results confirm that sliding wear testing, at least at fairly high loads; only makes sense if the strength of the specimens are sufficient to result in consistent and reproducible material removal during wear loading. In order to attain this state, further tests were restricted to specimens prepared using coarse BN – which exhibited higher strength in general, see [3] – and sintering at 1250°C. In order to avoid decomposition of BN, sintering was done in N₂-H₂ atmosphere.

Fe-0.5%BN; 0.5 m/s
Fe-2.0%BN; 0.5 m/s
Fe-0.5%BN; 1.02 m/s
Fe-2.0%BN-0.8%C, 1.02 m/s
Fe; 0.5 m/s
Fe-0.8%C, 0.5 m/s

Fig.5. Mass loss graphs for Fe-BN-(-C), manufactured using coarse BN, sintered 60 min 1250°C in N₂-20%H₂, References Fe and Fe-C sintered in H₂. Pin-on-disk testing, dry run, 60 N, sliding speed 0.5 / 1.02 m/s.

Here, the wear tests were mostly well reproducible and in fact showed regular mass loss curves, as shown for some materials in Fig.5. In most cases, there were virtually no run-in periods; only in Fig.5d a graph with a slight run-in can be observed, which underlines that also here the test runs should be carried out for track lengths of >10 km. The range of stable wear is marked here by the line, the slope of which indicates the wear coefficient k.
The results were generally more stable at the lower BN level and for the carbon-free variants; in presence of carbon the segregation of the coarse BN tended to be more pronounced. In any case however, the wear process was not affected by fragmentation, i.e. removal of entire particles or particle clusters, and there were no cases of pin fracture either, indicating that there materials were in fact mechanically more stable than those described above (see Fig.4), which had been prepared from fine BN.

The results show clearly that there is no discernible lubricating effect of hBN on the dry sliding process. The friction coefficient does not show a clear relationship to the BN content; it is however visible that the addition of carbon lowers the µ values. This indicates that there are at least in part adhesive effects which are less pronounced with the harder carbon containing steels. Apparently BN is not as effective against these effects as are e.g. PbS and Pb (see [16]), which indicates that “solid lubricant” is a term that should be used with caution.

Not only for the friction coefficient but also for the wear rate, carbon addition is more effective than is addition of BN, the carbon containing steels showing markedly better wear resistance than their carbon-free counterparts, which agrees well with findings described in [16]. Also here, as with the previous test series, higher BN contents result in higher wear, although fragmentation did not occur in this case. The fact that the higher wear did not result in a positive effect on the friction behaviour once more corroborates that BN is not an effective lubricant here; for other additives it has been observed that there is a negative relationship between µ and k, high wear resulting in low µ and vice versa. As stated above, this has been explained by the fact that solid lubricants, unlike liquid ones, are not transported within the porous sintered body, and if the solid lubricant on a rubbing surface has been consumed, i.e. removed by the sliding process, further lubricant can only be introduced into the tribosystem by wear of the lubricant-containing partner. The fact that even the severe wear observed with the low-strength specimens sintered at 1120°C did not result in lower µ values – although there should be a considerable supply of hBN into the tribosystem – confirms that at least in dry sliding, the lubricating effect of hBN is at best very limited.

MACHINABILITY

Testing procedure

Machinability testing of PM materials is frequently done by drilling numerous holes in a sintered steel workpiece and measuring the lifespan of the drill [14, 21, 22]. Other methods use turning, as for example the face turning test described in [23, 24]. In this work the machinability was tested by finish turning the specimens and measuring the surface quality [25-27], i.e. the roughness of the machined surfaces, as the criterion.

The tools used for the tests were standard indexable hardmetal inserts P20 (Kennametal Hertel). First, the rectangular specimens were rough turned at one end to cylindrical shape at a length of about 10 mm and then finish turned to 6 mm diameter (conditions: feed rate about 0.15 mm.rev⁻¹, cut depth 0.1 mm, dry cut). The cutting speed was selected to be about 16.7 m.min⁻¹ which, as shown by previous tests [26, 27], is not well suited for PM iron, being definitely too low, but was found to aggravate the differences in the surface finish obtained. Thus, the effect of machining aids was more clearly discernible. Due to the same reason, lubrication was not used. The roughness of the as-turned surfaces was measured using the profilometer Hommel-Tester T2000 with diamond tip. At least 4 parallel profiles were taken per material.
Results of machinability tests

Also with regard to machinability, the poor mechanical strength of the specimens containing fine BN was evident; the specimens tended to break already during rough machining. This was particularly common with all specimens sintered at 1120°C. Therefore, proper testing was possible only with specimens prepared from coarse BN, and some with fine BN that also contained carbon.

Fig.6. Finish-turned surfaces of sintered steels containing BN. Compacted 600 MPa, sintered 60 min at 1250°C in N₂-H₂. Turning, \( v = 16.7 \text{ m.min}^{-1} \), \( f = 0.15 \text{ mm.min}^{-1} \), \( d = 0.1 \text{ mm} \). Pin diameter 6 mm.

Fig.7. Finish-turned surfaces of various sintered steels [26]. Compacted 600 MPa, sintered 60 min at 1120°C in H₂. Turning, \( v = 16.7 \text{ m.min}^{-1} \), \( f = 0.15 \text{ mm.min}^{-1} \), \( d = 0.1 \text{ mm} \). Pin diameter 6 mm.

Some typical machined surfaces obtained with BN containing steels are shown in Fig.6; as a reference, the surface of plain sintered iron and of materials containing other machining aids are also given (Fig.7). Here it stands out clearly that BN addition results in
slightly better surface finish compared with sintered plain iron (in which case built-up edge formation was very pronounced at the low cutting speed selected here); however, the surface quality leaves much to be desired and is definitely inferior to that obtained for example with the addition of MnS or MoS$_2$ (the latter compound decomposing during sintering and forming Fe$_{1-x}$S). The machined surfaces shown in Fig.7 exhibit the typical pits where particles have broken off the surface during machining; this effect cannot be found with the specimens containing MnS or MoS$_2$/Fe$_{1-x}$S and clearly indicates that, also in those cases where the BN containing bars could be properly machined, the interparticle strength is unsatisfactory.

The poor surface is also described by the roughness values (see Table 3); in addition to $R_a$, $R_3z$ and $R_z$-ISO are also given (mean values ± standard deviation): Compared with other sintered ferrous materials, only the plain Fe compact resulted in higher $R_a$ values than the BN containing steels; all other additives were more effective, resulting in $R_a = 2.0$ µm maximum while all BN containing grades were in the range $R_a = 5$ µm and above; similar trends were observed with $R_3z$ and $R_z$-ISO as indicated in Fig.8. The excellent agreement between the $R_a$ and $R_3z$ data is clearly visible, and the same holds true for $R_z$-ISO.

![Fig.8. Roughness of machined surfaces of different sintered steels. Compacted at 600 MPa, sintered 60 min at 1250°C unless given otherwise. Finish turned, $v = 16.7$ m.min$^{-1}$, $f = 0.15$ mm.min$^{-1}$, $d = 0.1$ mm.](image-url)
Tab.3. Roughness and appearance of the machined surfaces of various sintered steels. Compacted at 600 MPa, sintered 60 min. Finish turned, v = 16.7 m.min\(^{-1}\), f = 0.15 mm.min\(^{-1}\), d = 0.1 mm.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Sintering temp. [°C]</th>
<th>Sintering atmosphere</th>
<th>R(_a) [µm]</th>
<th>R3z [µm]</th>
<th>Rz-ISO [µm]</th>
<th>Surface quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1120</td>
<td>H(_2)</td>
<td>8.2 ± 1.3</td>
<td>30.1 ± 3.1</td>
<td>43.5 ± 4.3</td>
<td>Rugged, in part shiny</td>
</tr>
<tr>
<td>Fe</td>
<td>1250</td>
<td>H(_2)</td>
<td>6.7 ± 0.9</td>
<td>27.1 ± 2.0</td>
<td>39.9 ± 5.8</td>
<td>Rugged, in part shiny</td>
</tr>
<tr>
<td>Fe-0.8%C</td>
<td>1120</td>
<td>H(_2)</td>
<td>4.3 ± 0.4</td>
<td>18.0 ± 1.6</td>
<td>23.0 ± 2.7</td>
<td>Dull, in part deep tracks</td>
</tr>
<tr>
<td>Fe-0.8%C</td>
<td>1250</td>
<td>H(_2)</td>
<td>5.9 ± 0.7</td>
<td>25.8 ± 4.1</td>
<td>32.5 ± 3.5</td>
<td>Dull, in part deep tracks</td>
</tr>
<tr>
<td>Fe-0.5%BN(coarse)</td>
<td>1250</td>
<td>H(_2)</td>
<td>7.0 ± 0.4</td>
<td>24.8 ± 0.4</td>
<td>37.9 ± 6.3</td>
<td>Dull, deep tracks</td>
</tr>
<tr>
<td>Fe-0.5%BN(coarse)</td>
<td>1250</td>
<td>N(_2)-H(_2)</td>
<td>6.7 ± 0.4</td>
<td>22.6 ± 0.8</td>
<td>33.7 ± 4.9</td>
<td>Dull, pits</td>
</tr>
<tr>
<td>Fe-2.0%BN(coarse)</td>
<td>1250</td>
<td>H(_2)</td>
<td>&gt;&gt;</td>
<td>&gt;&gt;</td>
<td>&gt;&gt;</td>
<td>Very poor finish</td>
</tr>
<tr>
<td>Fe-2.0%BN(coarse)</td>
<td>1250</td>
<td>N(_2)-H(_2)</td>
<td>9.2 ± 0.5</td>
<td>32.9 ± 1.6</td>
<td>50.7 ± 3.3</td>
<td>Dull, poor finish, pits</td>
</tr>
<tr>
<td>Fe-0.5%BN(c)-0.8%C</td>
<td>1250</td>
<td>H(_2)</td>
<td>6.7 ± 2.4</td>
<td>22.1 ± 4.2</td>
<td>34.4 ± 10.2</td>
<td>Dull, deep tracks</td>
</tr>
<tr>
<td>Fe-0.5%BN(c)-0.8%C</td>
<td>1250</td>
<td>N(_2)-H(_2)</td>
<td>5.5 ± 0.4</td>
<td>21.0 ± 1.9</td>
<td>29.3 ± 4.3</td>
<td>Dull, in part deep tracks</td>
</tr>
<tr>
<td>Fe-2.0%BN(c)-0.8%C</td>
<td>1250</td>
<td>H(_2)</td>
<td>6.2 ± 1.2</td>
<td>22.1 ± 3.8</td>
<td>32.0 ± 4.9</td>
<td>Dull, deep tracks, pits</td>
</tr>
<tr>
<td>Fe-2.0%BN(c)-0.8%C</td>
<td>1250</td>
<td>N(_2)-H(_2)</td>
<td>5.0 ± 0.4</td>
<td>18.4 ± 1.4</td>
<td>26.9 ± 2.0</td>
<td>Dull, regular tracks</td>
</tr>
<tr>
<td>(Fe-1.5%Mo)-2%MoS(_2)</td>
<td>1120</td>
<td>H(_2)</td>
<td>1.6 ± 0.5</td>
<td>6.3 ± 2.3</td>
<td>8.9 ± 2.9</td>
<td>Shiny, very fine tracks</td>
</tr>
<tr>
<td>Fe-0.5%MnS</td>
<td>1120</td>
<td>H(_2)</td>
<td>2.2 ± 0.3</td>
<td>10.6 ± 1.5</td>
<td>15.3 ± 2.4</td>
<td>Dull, fine tracks</td>
</tr>
<tr>
<td>Fe-1.0%MnS</td>
<td>1120</td>
<td>H(_2)</td>
<td>1.3 ± 0.2</td>
<td>6.7 ± 0.5</td>
<td>9.3 ± 1.7</td>
<td>Shiny, very fine tracks</td>
</tr>
<tr>
<td>Fe-2.0%MnS</td>
<td>1120</td>
<td>H(_2)</td>
<td>0.8 ± 0.2</td>
<td>3.9 ± 0.8</td>
<td>5.7 ± 0.9</td>
<td>Shiny, very smooth</td>
</tr>
</tbody>
</table>

The results indicate that at least for turning, BN is not necessarily the most effective machining aid. Of course it has to be considered that lower BN contents might be more effective – in [14, 15] no BN contents are given - , but taking into account the rather low effectivity of BN as a lubricant shown above, its effect as a machinability enhancer must be expected to be limited, at least if the lubricating effect really is required for improving the machining process. In any case, careful adjustment of both BN content and particle size will be necessary to at least alleviate the adverse effect of BN addition on interparticle strength.
CONCLUSIONS

The addition of hexagonal boron nitride to iron and iron-carbon powders in concentrations of 0.5 to 2.0 mass% is not effective in improving the dry sliding wear behaviour of sintered specimens thus prepared. This is mostly due to the low interparticle strength caused by the BN particles present in the sintering contacts. Therefore, fine BN is more detrimental than coarse grades, as are lower sintering temperatures. Despite considerable wear in part, the friction coefficient is not markedly lowered by the BN addition compared with sintered plain iron, which indicates that the dry lubricating effect of BN should not be overestimated. Furthermore, the effect of hBN on the machinability was markedly less positive than that of for example MnS or MoS$_2$, the low interparticle strength being responsible also here for the poor surface finish.

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REFERENCES


