# ABRASIVENESS OF BORON CARBIDE COATINGS

By Matthew Siniawski, Jane Qian Wang, and Stephen J. Harris

Parameters such as coating thickness, counterpart tempering temperature, and coating asperity sharpness in particular influence coating abrasiveness.

Hard coatings, such as boron carbide (B4C), can quickly polish the surface of the mating material during sliding contact. The abrasiveness of such coatings directly relates to their ability to polish and sharply decreases as sliding progresses. The abrasiveness also strongly depends upon the sharpness of the individual coating asperities. Various parameters influence the rate at which the abrasiveness decreases and therefore control the run-in process. Such coatings can serve as finite-life run-in coatings for specific applications such as gears.

## PROBLEM DEFINITION

Erdemir first suggested that hard coatings could polish mating surfaces during sliding contact (Erdemir, 1992). Essentially, these coatings increase the fatigue resistance of a coated part because of their inherent ability to provide polishing of the mating surface. These coatings remove asperities on the mating surface that would have otherwise caused high local stresses, eventually leading to contact fatigue failure. This polishing action occurs in an extremely short period of time for a contact at a Hertzian pressure equivalent to that for a pair of heavy-duty gear teeth (Harris et al., 1997). Furthermore, during the polishing process, the coating abrasiveness dropped to a stable and small value, at which point the wear of the mating surface became negligible (Harris et al., 1997, 1999, and Harris and Weiner, 1998). Even though the polishing action occurred relatively quickly, such coatings still substantially increased the fatigue life of a coated part (Polonsky et al., 1998).

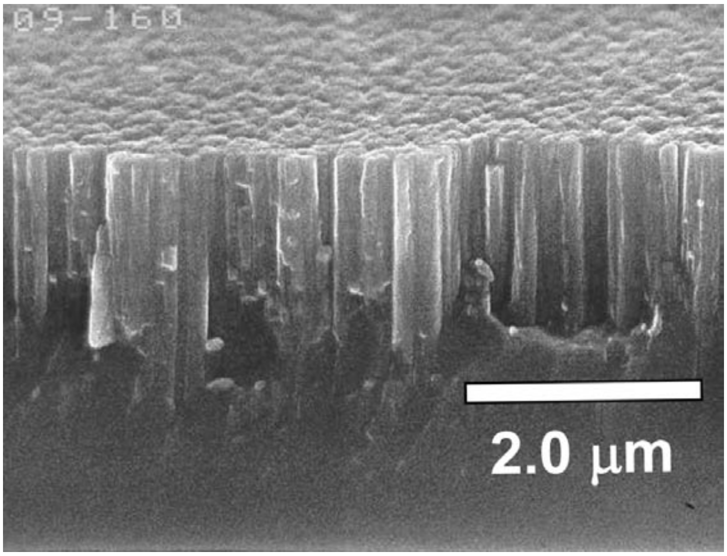

**Figure 1:** SEM image of a 2.0µm thick $B_4C$ coating.

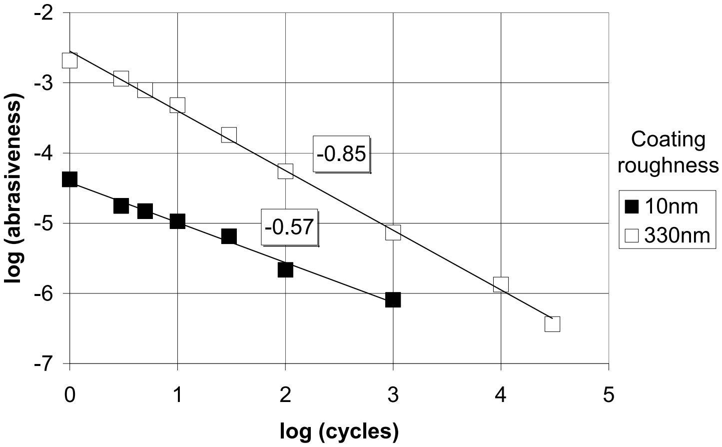

**Figure 2:** Abrasiveness of two $B_4C$ coatings with different roughness values.

Successful design of such fatigue resistant coatings could allow them to serve as finite-life run-in coatings, only providing polishing during a specified amount of time. Ideally, after this specified amount of time, the coating would provide no additional surface polishing. Understanding the changes in the coating abrasiveness during the sliding process is critical for the proper design and implementation of such finite-life run-in coatings. This study investigated both changes in the $B_4C$ coating asperities during the polishing process, particularly the coating asperity height and sharpness, as well as the influence of numerous parameters on the coating abrasiveness, including coating thickness, overall coating roughness, and counterpart material tempering.

## APPROACH

Boron carbide ($B_4C$) coatings (fig. 1), of thickness values ranging from 0.5-2.0µm, were sputter-deposited onto steel coupons. The coupons were made from low carbon steel that was case carburized to about 1 percent carbon and tempered to


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a Rockwell C hardness (HRC) of 59 ± 1 (corresponding to a hardness of about 7 GPa). Prior to the coating deposition, the steel coupons were polished to various finishes, with centerline-average roughness values ranging between $R_a$ = 10-110nm, as measured with a PhaseShift optical profilometer. The $B_4C$ coating had a hardness of about 23GPa and a surface finish ranging between $R_a$ = 10-330nm. The balls were 3.2mm diameter AISI E 52100 steel ball bearings (nominally HRC 60) with a surface finish of $R_a$ = 25nm.

Both dry and lubricated sliding wear tests were performed using a CETR UMT tribometer ball-on-disc machine. Using a specified track radius, the $B_4C$ coated disk was rotated at approximately 10cm/s with a load of 100g for a given number of cycles, ranging from 1 to 30,000. The wear volume of the steel ball was precisely calculated using data from each wear scar profilometer measurement. The volume between the surface measured by the optical profilometer and the surface of an ideal sphere was numerically integrated, which removed errors due to roughness and non-circularity of the wear scar and was independent of viewing angle (Harris and Krauss, 2001). In addition, the coating wear track was also inspected using an atomic force microscope (AFM) with a spatial resolution of 0.167μm/pixel in the horizontal dimensions.

The average coating abrasiveness $\overline{A(n)}$ during $n$ cycles is defined as the total volume of the steel removed divided by the total sliding distance according to

$$\overline{A(n)} = V / d = V / 2\pi rn \qquad (1)$$

where $V$ is the volume of steel removed, $d$ is the distance traveled, $n$ is the number of cycles and $r$ is the ball-on-disc wear track radius.

## RESULTS

Figure 2 plots the coating abrasiveness versus the number of cycles on a log-log scale for two coatings of different roughness values. Coating roughness had the largest effect on the rate at which the abrasiveness decreases, as indicated by the large difference in slope values. The abrasiveness of the smoother coating decreased at a slower rate than the rougher coating, with a slope value of -0.57 as compared to -0.85. Figure 3 illustrates the significant dependence of abrasiveness on the coating roughness, as the coating abrasiveness decreased faster than exponentially with increasing asperity bluntness. Therefore, one potential method for the successful design and implementation of a finite-life run-in coating is through proper control of the sharpness of the coating asperities themselves.

The coating abrasiveness slope reached a maximum value at a counterpart tempering temperature of around 350°C, which behaves as expected for heat-treated steels (Siniawski et al., 2004). Changes in the counterpart toughness were primarily responsible for the observed dependency of the abrasiveness on coun-

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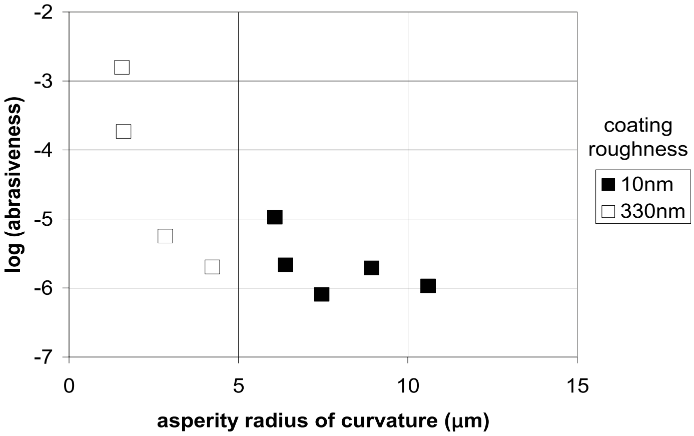

**Figure 3:** Variation of abrasiveness with coating asperity sharpness.

terpart tempering. Tempering of the counterpart material prior to sliding wear is a cost effective and simple procedure to control the abrasiveness. Finally, the coating thickness influenced the initial abrasiveness, but did not affect the slope (Siniawski et al., 2004). Therefore, modifying the thickness is one potential method to control the initial abrasiveness of the coating.

## CONCLUSIONS

Parameters such as coating thickness, counterpart tempering temperature, and especially coating asperity sharpness all influence the coating abrasiveness to varying degrees. Utilizing such parameters can allow for the successful design of a finite-life run-in coating. Since the polishing period of a finite-life run-in coating is very short, poor quality coatings could be just as effective as expensive, high quality coatings.


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