DISCUSSION

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The authors are to be commended for their use of the accelerated rolling contact fatigue (RCF) test to assess the applicability of hard carbon coatings for RCF applications. This preliminary study demonstrated that further research is necessary, particularly in the areas of understanding coating uniformity, the mechanisms of fatigue life improvement/degradation of diamond-like carbon (DLC) coatings, and of the variables which control coating adhesion and performance. This discusser feels that the main conclusions of the study are that the coating process was non uniform and that perhaps the presence of the DLC coating itself was not necessary for any improvement in RCF life.

The shallow, or even double slope, of the Weibull plot in Fig. 3 for the coated rods indicates extreme variability, the origin of which is not addressed by the authors. Since practically all fatigue spalls initiate at surface defects resulting from either debris dents or contact damage, it is possible that the effect of the cleaning procedure alone may have been responsible for any improvement observed. A check on this would be to run, as the control, some rods which underwent the same cleaning procedure, but were not coated. The effect of the SiC layer alone should also be determined. Additional handling of the rods during processing could also have introduced damage.

Homogeneity of the coating on a single rod was not reported. Indication of the location of each test along the rod with respect to the position of the rod within the sputtering chamber during coating deposition would allow any correlations between coating performance and deposition position to be observed. Similarly, reporting of the degree of decohesion to each point of each test would be helpful.

No mention of any chemical effect is made. EP compound formation may have been suppressed by the coatings. This would have a pronounced impact depending on decohesion of the coating, which might explain the essentially bimodal Weibull plot.

Since the 1 μm thick coatings were reported to have decohered, while the 0.5 μm thick coatings remained intact, and both fatigue life test results fell within the same Weibull "curve," it appears that the presence of coating itself may have little influence on the fatigue life.

The computed depth of maximum reversing stress is from 125 to 150 μm which is considerably greater than the coating thickness. As such the coating will most likely have only a chemical or surface mechanical effect on RCF life. A calculation of EHD film thickness for this geometry, operating conditions, and materials indicates that the lambda ratio is 1.41 for the uncoated rod and the 0.5 μm thick DLC coating, but is only 0.44 for the 1 μm thick coating. This would lead to increased local contact stresses of these coatings and possibly explain their propensity to decohere.

This discusser found many unsatisfactory, or missing, explanations for observed phenomena. The observations concerning the profiles of the wear track do not give any explanation for what might have happened to the material near the edges of the 1 μm thick coating. Was the wear track simply due to removal of the coating, or was it a result of a closing of the porosity of this thicker coating? Are the "slip lines" in Fig. 6 expected to be observable in an SEM at the magnification in this alloy?

Finally, Fig. 3 shows that, while the B_{10} life of the coated rod is clearly lower than that of the uncoated rods, both coated and uncoated rods have overlapping B_{50} lives within the 90 percent confidence bands. Since these bands overlap, one cannot really say with confidence that any significant improvement in the B_{50} life has been achieved. Clearly further work is in order.

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Authors' Closure

The authors appreciate the thorough review and thoughtful comments offered by S. J. Shaffer. The dramatic improvements realized in some samples coupled with the long times required to conduct RCF tests prompted reporting of what are identified in the paper as preliminary results so others who might be interested in the topic would be aware of the potential benefit of these coatings. The need to conduct the additional testing pointed out in the discussion is acknowledge and is in fact in progress.

Tests in which M-50 rods have been sputter cleaned only and sputter cleaned and coated with SiC only have now been completed. Compared to the untreated rods, either of these treatments were found to induce insignificant changes in the Weibull slope and an approximate doubling of the B10 and B50 lifetimes. Additional tests have been conducted on rods that were cooled during the application of a ~ 0.4 μm thick DLC coating with a higher quality than those used in the study reported in the paper. This rod exhibited 5-fold and 10-fold increases in the B10 and B50 lifetimes, respectively, compared to untreated rods.

Correlations between the axial location of a test track and life have been examined for each all of the rods studied and they have all be found to be random. Measurements indicate the variation in film thicknesses between wear tracks is < 10% of the mean film thickness. The influence of the coatings on chemical reaction effects have not been examined.

The wear tracks are formed as a result of (*a*) removal of DLC and (*b*) plastic deformation of the M-50 rod material. Examination of the wear tracks suggests that the porosity of the coatings is not reduced during testing, rather the coatings are simply removed.

