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discussion

The Friction and Wear of Thin Sintered Fused Fluoride Films[1]

H. E. Sliney.[2] This is a fine paper. Mr. Lavik and his associates have done their customary thorough and high quality investigation of a lubricant-substrate system.

The authors have optimized $AlPO_4$ additions to the CaF_2-BaF_2 basic formulation to reduce cure temperature and to obtain good coating wear life at 1000 deg F. Their recommended cure temperature is 925 deg C (1700 deg F). This is below the melting point of the fluoride eutectic (1875 deg F) and well below the melting point of $AlPO_4$ (>2700 deg F). The coatings are, therefore, probably bonded by sintering. In our studies of the CaF_2-BaF_2 eutectic, longer wear lives were obtained with fusion-bonded coatings (cured at about 1900 deg F) than with sintered coatings. In some early work with CaF_2 (reference [2] of the authors' paper), we found that CaF_2 coatings with about 12 v/o $AlPO_4$ could be sinter-bonded at 1600–1700 deg F. Wear life was appreciable in some cases, but not as good as it was with ceramic-bonded CaF_2 or with fusion-bonded CaF_2-BaF_2 eutectic coatings. The combination of the eutectic and $AlPO_4$ by Lavik and his associates is a variation which appears to have resulted in coatings with good wear life that can be cured by sintering. The advantage, of course, is a reduction in cure temperature which is always desirable for ease and economy of processing.

From a metallurgical point of view, cure temperatures above 1700 deg F are not detrimental to René 41. The hardening phase is gamma prime $Ni_3(Al, Ti)$ precipitate. It does not go into solution below about 1925 deg F. Therefore, any cure up to that temperature should not have a serious detrimental effect on the hardness or strength of this alloy.

Recently, we have developed a silicate-modified CaF_2-BaF_2 coating for use to at least 1500 deg F.[3] It is fusion-bonded at 1800 deg F, well below the solution annealing temperature for René 41. Perhaps sputtering or plasma spray techniques, which do not excessively heat the substrate metal, will put to rest any further worries about the influence of cure temperature on metallurgy.

The beneficial effects of gold additions on the friction at lower temperatures parallels our experience with silver additions (reference [6] of the authors' paper). Unless gold is shown to be a superior additive, the lower cost of silver would seem to make it a more attractive addition to these coatings. This is especially true if the coating compositions (as often happens) are adapted for self-lubricating composites which, of course, require much larger quantities of lubricating material than do coatings.

In conclusion, the authors have developed modifications in coating composition and in processing that are interesting and that should help stimulate the commercial utilization of CaF_2-based solid lubricants.

This discussor thanks the authors for their recognition of and references to the early and continuing research at Lewis Research Center, NASA, with fluoride-based solid lubricants.

Authors' Closure

The authors appreciate Mr. Sliney's discussion of the film-substrate system. We agree in general with those comments regarding the fusion of the CaF_2 – BaF_2 eutectic mixture, the René 41 metallurgical properties, and the cost factor of gold versus silver. However, we wish to point out that the precipitated solids from the mono aluminum phosphate solution used in this film development is specified by the supplier to be Al $(PO_3)_3$ rather than Al PO_4 as inferred by the discusser. We also feel that the aluminum phosphate in combination with BaF_2 and CaF_2 has a different fusion point than the eutectic mixture of the two fluorides. Furthermore, the oxides present on the substrate metal undoubtedly influence the effective fusion point of the film-substrate system. The appearance of cured films suggests that fusion does occur at the metal-film interface and that some of the particles at the free film surface experience only sintering. Unfortunately we were unable to pursue a determination of the melting point of the film composition alone or in combination with the substrate metal oxides.

[1] By M. T. Lavik, B. D. McConnell, and G. David Moore, published in the January, 1972, issue of the JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. ASME, Vol. 94, No. 1, pp. 12–18.

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[3] Sliney, H. E. "An Investigation of Oxidation-Resistant Solid Lubricant Materials," *ASLE Proceedings*, International Conference on Solid Lubricants 1971, ASLE SP-3, pp. 259–269.