12 "Oxidation of Metals and Alloys," by O. Kubaschewski and B. E. Hopkins, Academic Press, New York, N. Y., 1953, p. 4.
13 "Initial Oxidation Rate of Metals and the Logarithmic Equation," by H. H. Uhlig, *Acta Metallurgica*, vol. 4, 1956, pp. 541–554.

Discussion

W. Hirst.[5] The writer greatly appreciates the compliment which the author pays to this research group in basing his paper on experimental work by one of its members, Mr. Kerridge. Since the discovery by Burwell and Strang[6] that wear particles may be as small as 100 Å units, it has seemed possible that some wear mechanisms may be confined to processes occurring within the surface skin of oxide, and the like, which cover most metals. Until that time, many of the fundamental studies of the mechanism of surface damage had been made with scaled-up systems using heavily loaded sliders. The scale of the damage which then occurs is relatively great and the mechanism of damage may differ from that producing wear particles as small as 0.000001 cm diam. For this reason, we have attempted to devise methods of studying wear processes without resource to scaling-up and with the load distributed over a number of regions of contact.

At the present time, our approach is mainly experimental and is directed toward obtaining a more detailed picture of different types of wear and of the various stages which eventually lead to the production of a loose wear particle. An account of the stages in a severe type of wear has just been given by Mr. Kerridge and Dr. Lancaster,[7] and Dr. Archard[8] and the writer hope soon to publish an account of the stages in a mild form of wear.

The author's analysis is noteworthy in that it is the first theory which offers a reasonable hope of predicting the absolute magnitude of a wear rate. To do this, when wear is due primarily to oxidation processes, one needs to postulate the conditions under which the oxide films become removed; the great deal of work already done on the corrosion of metals should make it fairly easy to find a reasonable postulate. Thus although the type of wear studied by Kerridge may be somewhat unusual, its suitability for theoretical treatment makes it deserve further experimental study. However, the experiments would require to be devised more carefully to meet the theoretical requirements, and the author's suggestions for further work are most interesting.

One of the conditions which needs to be considered is that of the maintenance of the temperature of the pin and ring. In Kerridge's experiments, the specimens cooled during the interchange of pins and some minutes of running would be required to restore equilibrium-temperature conditions. Perhaps this may be the cause of the horizontal portion of the curve in Fig. 2 of the paper.

It may be wondered why the gray transferred layer is harder than the pin. In Kerridge's conditions, the frictional heating sufficed to induce the martensitic transformation in the soft tool steel. Sections of the pins have been examined by the writer's colleague, Dr. Welsh, and he has observed that some of the pin material also transforms to martensite. It is the formation of martensite which is presumably the cause of the absence of back transfer.

[5] Head, Surface Physics Section, Associated Electrical Industries Ltd., Research Laboratory, Aldermaston, Berkshire, England.
[6] Reference (3) of the Bibliography of the paper.
[7] "The Stages in the Process of Severe Metallic Wear," by M. Kerridge and J. K. Lancaster, Proceedings of the Royal Society of London, England series A, vol. 236, 1956, pp. 250–264.
[8] By J. F. Archard and W. Hirst, to be published in the Proceedings of the Royal Society of London, England.

Author's Closure

The author wishes to thank Dr. Hirst for his clarifying remarks, particularly in regard to the martensitic transformation of the pin material.

Experiments similar to those of Kerridge are being carried out at M.I.T. The only difference in the geometries of the two machines is in the ring specimens, the diameter of the author's ring being five times that of Kerridge's ring. These experiments show an incubation period of about the same number of revolutions as in Kerridge's tests at the same surface speed, although the incubation time is fivefold larger. It seems likely, therefore, that the incubation period is not merely a result of nonequilibrium temperature conditions, as suggested by Dr. Hirst, but rather that a certain number of rubs is needed to induce formation of friable oxide.