Frictional Properties of Metallic Films

DR. HUGHES's recent remarks[1] would appear to be based on the three wrong premises that, first, films of soft metals wiped on to steel surfaces on which a loaded steel ball was made to rotate[2] never decreased the electromotive force ; secondly, the interpretation of earlier observations[3] on the frictional behaviour of such films on a copper surface made on the Bowden-Leben apparatus had been criticized ; and thirdly, frictional decreases due to these films should be taken as an indication that changes in the ploughing contribution to the frictional force were immaterial when such decreases were observed "during the *first* slide" with the Bowden-Leben apparatus.

Dr. Hughes, it seems, has overlooked the difference of the results obtained with the revolving sphere and metallic films wiped out once under 'dry' conditions, and the other time in the presence of an oil. It has been stated[2] that "Even in those cases in which the films reduce the electromotive force under 'dry' conditions, they do not appear to function as a lubricant for a brief interval until normal lubricating conditions are re-established".

The results listed in Table 2 (ref. 3) allow of no misrepresentation, and it is the conclusion drawn by Dr. Hughes and his colleagues[3] from a comparison of Tables 1 and 2 (ref. 3) that "in a heterogeneous bearing metal the soft phase wipes out over the hard phase during sliding" that is regarded as conjectural.

There is a difference between wearing in a groove on the surface of a block of compact metal and of ploughing a track on a film of wiped-out softer metal of sufficient thickness to carry the main portion of the normal load. To choose a homely analogy, it is qualitatively the same difference as between scribing a line with the end of a walking-stick once on a hard rolled gravel path and then on the same path covered with a reasonable amount of loose gravel. One is bound to experience a frictional decrease "during the *first* slide" in the latter case. Just on account of the ploughing action would one expect a smaller friction "during the *first* slide" in the presence of a wiped-out metallic film, the friction remaining little changed by successive strokes in the same track, *until* the wiped-out films would be penetrated, when the friction would be expected to *rise* to values approaching that of steel on the substrate—copper, for example—and on further continued successive strokes in the same track a renewed decrease of the friction would be expected with the wearing in of *one* groove in the substrate.

There seems to be general agreement[1,2,4,5] that ploughing is the essential feature of the Bowden-Leben apparatus when the hemisphere is the harder of the two friction elements, since Dr. Hughes's claim has remained unsubstantiated "that the grooving contribution to the friction, which must evidently be present to a certain extent, is small compared with the contribution of adhesive forces".

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June 11.

[1] Hughes, T. P., NATURE, 151, 533 (1943).
[2] Schnurmann, R., NATURE, 151, 420 (1943).
[3] Heaton, J. L., Bristow, J. R., Whittingham, G., and Hughes, T. P., NATURE, 150, 520 (1942).
[4] Bowden, F. P., Moore, A. J. W., and Tabor, D., *J. Appl. Phys.*, 14, 80 (1943).
[5] Bowden, F. P., and Tabor, D., *J. Appl. Physics*, 14, 141 (1943).

IN the light of Dr. Schnurmann's above remarks, it appears that he is still unconvinced by our original interpretation of frictional data[1] on the Bowden-Leben apparatus, when a small steel spherical surface was slid over copper covered with thin films of soft metals (lead, cadmium and tin), and also by later additional experimental data[2]. It was originally suggested that the reduction in the coefficient of friction, μ, from 0·5 to 0·7 for steel on the bulk metals lead and copper, say, to 0·03–0·08 for films of lead, 10^{-5}–10^{-6} cm. in depth, was due to the combination of a thin soft film on a hard substrate maintaining a small area of contact across which "the adhesion and deformation resistance" was very low. Dr. Schnurmann considers the effect is solely due to a reduction in the "ploughing action".

It would perhaps clarify the argument if an attempt is made to define these terms. The frictional force may be considered to be made up of two contributions[3,4] :

(i) The *adhesion forces* across the real area of contact. This is the shear strength of the metal junctions in Dr. Bowden's recent publications[4,5,7].

(ii) The *deformation forces* required to plough out a groove. This is the ploughing term, the magnitude of which for indium films on steel has been investigated by Bowden, Moore and Tabor[5]. This contribution to the friction may be defined as the force required to deform the metal in the path of the slider, and would contribute to the total friction even if the adhesional forces across the area of contact became zero. The greater drag of a ski on soft snow above that on hard crusted snow is perhaps a simple illustration of a case where the ploughing term is relatively large.

If we consider our original experiments, when a steel ball 2 mm. in diameter was slid over copper and copper covered with a thin film of lead (which recent measurements[6] have shown need only be about 5×10^{-6} cm. in depth for the minimum friction), then since the track width is of the order of 0·02 cm., a simple calculation will show that the area of contact on the bare and lead-covered copper will be practically the same in both cases, since the thin film thickness is only a small fraction of the depth of the sliding groove. This must indicate that the ploughing term is approximately the same in each case. However, since the friction experiments show a tenfold drop in μ to accompany the deposition of this lead film, it must be concluded that it is the lower adhesion (or shear strength) between the lead and the steel slider compared with that between copper and steel which is responsible for the drop in μ.

This argument has been put on a quantitative basis in Dr. Bowden's recent publications[4,5,7]. By comparing different forms of slider on soft indium films deposited on hard steel, he has been able to estimate the ploughing and adhesion contributions to the friction for comparatively wide track widths up to 0·2 cm. Thus Fig. 9 of ref. 5 shows that the adhesion term is much greater at low track widths, that is, for the thinnest films such as those used by us. The proportionality between the square of the track width (that is, the area of contact) and the frictional force has been used to show the dependence of the friction on the shear strength across the area of contact, that is, on the adhesion term. It has not been used to support the ploughing hypothesis, as Dr. Schnurmann implies above.

Dr. Schnurmann's analogy of a walking-stick sliding on a gravelled path is perhaps rather ill-chosen on account of complications due to grain