Hopkins[26] and Lees[27] have recently measured the thickness of the Beilby layer on polished metals. Hopkins thinned the polish layer by cathodic sputtering under conditions permitting of measuring the rate of removal, and he found that a hand-polished gold surface gave a pattern characteristic of crystalline gold after a layer of about 30 A. had been removed by sputtering. Lees, in working with gold and copper surfaces, reduced the polish layer by electrolytic etching and arrived at similar estimates of thickness, and also concluded that the polish film was supported by a layer of crystals orientated by the polishing action.

It is natural to suppose that the depth of the Beilby layer is influenced by the vigour of the polishing action, and several observations have been made which confirm this. Thus it is not easy to demonstrate the solution of zinc crystals in a lightly hand-polished copper surface, though the effect is so striking when the final polishing is preceded by a vigorous machine buffing. Also, Finch, Quarrell and Wilman[25] have examined the working surfaces of four aeroplane engine cylinder sleeves. Two were honed and ready for service whilst the others had been run-in for 40 hours and 140 hours respectively. After removal of the protective grease layer by washing with petrol-ether, the external and internal surfaces of the virgin sleeves both yielded patterns characteristic of a random crystal structure and in which α-iron rings were prominent. The run-in surfaces, on the other hand, after degreasing gave the halo pattern typical of the Beilby layer. The thickness of this layer was such that although a single light stroke with No. 000 emery paper sufficed to break through the Beilby layer on a hand-polished steel specimen, several such abrasions were necessary before the haloes gave way to the normal ring patterns of the virgin sleeve surfaces. Thus it seems that the process of running-in an internal combustion engine can be likened to a vigorous polishing action, in that it consists in the formation on the working surfaces of an amorphous Beilby layer of considerable depth.

[1] Hooke, "Micrographia", Observation II (1665).
[2] Herschel, quoted by Rayleigh, *Proc. Roy. Inst.*, **16**, 563 (1901).
[3] Rayleigh, *Proc. Roy. Inst.*, **16**, 563 (1901).
[4] Beilby, "Aggregation and Flow of Solids", Macmillan (1921).
[5] Benedicks, *Rev. Met.*, **19**, 505 (1922).
[6] Tammann, *Z. anorg. Chem.*, **113**, 163 (1920).
[7] Desch, "The Chemistry of Solids", p. 164, Cornell University Press (1934).
[8] Gough, Aeronautical Research Committee, Rep. and Mem., 1432 (1930).
[9] Thomson, *Proc. Roy. Soc.*, A, **128**, 649 (1930).
[10] French, *Proc. Roy. Soc.*, A, **140**, 637 (1933).
[11] Wierl, *Ann. Physik*, **8**, 521 (1931).
[12] Randall and Rooksby, NATURE, **129**, 280 (1932).
[13] Germer, *Phys. Rev.*, **43**, 724 (1933).
[14] Kirchner, NATURE, **129**, 545 (1932).
[15] Raether, *Z. Phys.*, **86**, 82 (1933).
[16] Prins, *Z. Phys.*, **56**, 617 (1929).
[17] Hopkins, *Trans. Farad. Soc.*, **31**, 1127 (1935).
[18] Darbyshire and Dixit, *Phil. Mag.*, **108**, 961 (1933).
[19] Miwa, Sci. Rep. Tôhoku Imp. Univ., **24**, 222 (1935).
[20] Hume-Rothery, "The Metallic State", p. 307, Clarendon Press (1931).
[21] Kirchner, *Trans. Farad. Soc.*, **31**, 1114 (1935).
[22] Thomson, *Trans. Farad. Soc.*, **31**, 1116 (1935).
[23] Finch, Quarrell and Roebuck, *Proc. Roy. Soc.*, A, **145**, 676 (1934).
[24] Thomson, *Phil. Mag.*, **18**, 640 (1934).
[25] Finch, Quarrell and Wilman, *Trans. Farad. Soc.*, **31**, 1077 (1935).
[26] Hopkins, *Trans. Farad. Soc.*, **31**, 1095 (1935).
[27] Lees, *Trans. Farad. Soc.*, **31**, 1102 (1935).

Metallic Wear in the Presence of Lubricants

THE sliding of one metal surface over another without the occurrence of an undue amount of wear is a problem which arises in every branch of engineering. Successful lubrication and the maintenance of a bearing surface depend upon a wide variety of factors, including those of a mechanical, a metallurgical and a chemical nature. Wear is largely determined by the affinity of one metal for another, the fouling or adhesion of one to the other leading to a roughness; the extent of this roughening and of the consequent wear is determined by the continuity of the film of lubricant separating the two metals, this continuity in turn depending upon the nature of the lubricant and the load it can support without rupture of the film. Our knowledge of lubricated surfaces was extended in 1932 by the work of Parish and Cammen in America, who found that below the film of lubricant there exists a small quantity of oil in the cavities or pores of the surface layers of the metal. Since this work was carried out, however, very little attention seems to have been given to the problems of metallic wear, despite their great importance to engineers, metallurgists, chemists and physicists.

Major interest in metallic wear centres to-day upon the problems involved in the successful running of automobile and aeroplane engines. Here bearing pressures and temperatures are high, and every endeavour must be made to provide bearing surfaces which will give a satisfactory service life under the stringent conditions imposed. Despite the existence of one or two contradictory examples, the old-established concept of a duplex structure, of hard particles embedded in a softer matrix, still prevails, and shows no indication of being superseded. There is, however, one other aspect of metallic wear upon which a certain amount of attention has recently been focused; this is associated with problems of die-fouling in the pressing of hollow metal products, where pressures are heavy and drawing speeds relatively high. The adhesion of the metal being drawn to the working surface of the die steel resembles the seizure of a bearing, and the effects of load, speed, temperature, lubrication and nature of the metal surfaces in contact all play an important part in the phenomenon as a whole.

A Method of Wear Testing

This interesting phase of the study of metallic wear formed the basis of a paper recently contributed by Dr. H. W. Brownsdon in opening a general discussion on the subject organised by the Institute of Metals. It was found that experimenting on the actual drawing equipment was slow and inconvenient, and that some means for making rapid comparative tests under controlled conditions was required for the fuller investigation of the phenomenon. Accordingly a simple machine was designed and constructed (Fig. 1), consisting primarily of a hardened steel wheel about 1 inch in diameter, rotating in contact with flat samples of the metals under investigation, under known conditions of load, speed, lubrication, time and temperature. A measure of the amount of wear is thus given by the length of the oval impression made in the sample (Fig. 2).

Early in the investigation it was found that alloys differ considerably in the degree to which fouling of the steel wheel occurs, and that wear,

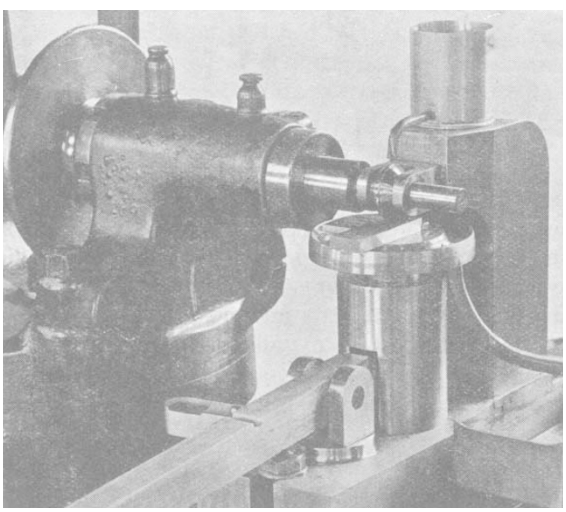

FIG. 1. Wear testing machine.

as measured by the length of the impression, increases with fouling of the wheel. It was also found that the results obtained with a particular alloy when using a mineral oil and a soap solution may vary considerably, and that the value of a lubricant as a preventative of wear cannot be completely determined apart from the metals or alloys with which it is used. The value of additions such as oleic acid and stearic acid to a straight mineral oil in the improvement of lubricating properties was clearly brought out in the experiments made. The effect of time upon wear was also discussed by Dr. Brownsdon, the results indicating that wear occurs in the early stages of

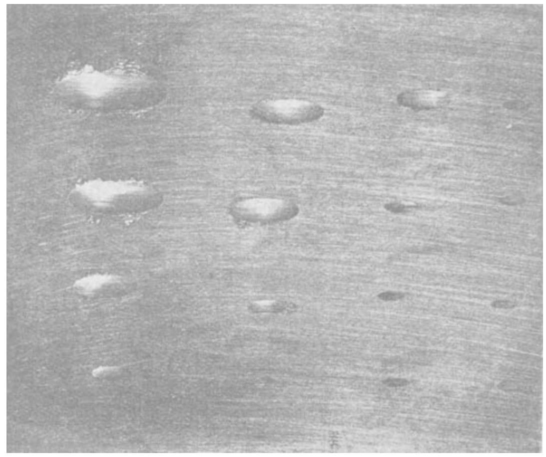

FIG. 2. Form of impression made in wear testing.

the experiment when the load per unit area is high, the film of lubricant later building up to such a thickness as to prevent further serious wear.

Another result illustrating the complexity of the study of wear problems, and one showing that every condition of material and lubricant has to be considered separately, is that when a straight mineral oil is used, the behaviour of cupro-nickel is better than that of the brasses, whereas with castor oil of the same viscosity there is less wear on the brasses than on cupro-nickel.

Experiments with seven different oils on various metals gave widely different results with variations in the roughness of the wheel and of the load. An austenitic stainless steel showed quite good wearing properties when the wheel had an 00 emery finish, whereas, using a wheel with a 1*M* finish, the wear was greater in that material than in any other employed. These tests again emphasised the necessity for carrying out a series of tests under widely varying conditions before attempting to draw wide and general conclusions.

The Mechanism of Wear

An important contribution to the discussion which followed the presentation of Dr. Brownsdon's paper was made by Dr. N. K. Adam, who maintained that the contact between metal surfaces is probably at a very few points only at any one moment. The process of wear is thus a matter of adhesion between the points on opposite surfaces which are in contact; it might indeed be assumed that wear occurs only at points where molecular contact exists. The function of the film of lubricant is to prevent such contact—to provide a cushion between the metal surfaces thick enough to prevent the molecular attractions of one surface reaching across to the other. A high adhesion between the oil and the metal tends to prevent the squeezing out of the film, which accounts for the beneficial effect of certain additions to mineral oils.

Dr. F. P. Bowden referred to some recent experiments showing that the frictional heat developed on sliding can raise the surface temperature of metals sufficiently to cause melting at the points of contact. Measurements had provided direct evidence that the surface flow of metals in polishing is brought about by actual melting, and it was suggested that under many conditions of sliding and rubbing, the high temperature and the melting of the surface are important factors in the wear of metals.

The method of wear testing devised by Dr. Brownsdon was criticised by a number of speakers in the discussion, mainly on the grounds that the conclusions derived from the test were not in agreement with the results of long practical experience of the relative merits of alloys employed for bearing purposes and of the value of the duplex microstructure. Examples were cited of results completely negatived in practice. On the other hand, the test has proved of value with extreme pressure lubricants and is capable of giving reproducible results in the hands of other workers.

Obituary

Prof. C. Lloyd Morgan, F.R.S.

CONWY LLOYD MORGAN, who died at his house in Hastings on March 6, at the age of eighty-four years, was born in London on February 6, 1852, the second son of a solicitor, J. A. Morgan. On reaching boyhood, he was sent to the Royal Grammar School, Guildford, which was in those days an essentially classics school, with Dr. Merriman as headmaster, an Oxford scholar of considerable distinction. On leaving school, and with the view of taking up engineering as a profession, Lloyd Morgan proceeded to the Royal School of Mines, where he was Duke of Cornwall scholar, Murchison medallist and De la Beche medallist. Here in due time he gained his diploma as associate in mining and metallurgy.

But during the period of his professional training, the rector of Weybridge, where his parents were then living, induced Lloyd Morgan to read Berkeley's "Principles" and Hume's "Enquiry", chiefly as an initiation into the realm of philosophy. Indeed, under this guidance he began at length to wrestle with Spinoza, "quite the finest bit of coral", he was told, "for philosophic gums". Immediately after obtaining his diploma, he spent several months on a tour to North America and Brazil, during which time, partly through reading Darwin's "Voyage of a Naturalist", he became deeply interested in biological science. In fact, before setting out on this tour, he was fortunate enough to come under the influence of T. H. Huxley; and when, on one occasion, he told him of his interest in philosophy, Huxley remarked: "Whatever else you may do, keep that light burning. Only remember that biology has supplied a new and powerful illuminant". Accordingly, on returning to London, he followed Huxley's suggestion and took a course under him in biology at South Kensington, working also in his laboratory. A few encouraging words from Huxley lent support to the conviction at which he had gradually arrived, that the borderland problems of life and mind afforded a promising plot for an effort at intensive cultivation under the spade work of careful observation.

The thought of engineering as a profession was consequently abandoned. Yet Lloyd Morgan had somehow to earn a living, and tried his hand at teaching. After occasional work in schools, he obtained in 1878 the post of lecturer (in physical science, English literature and constitutional history) at the Diocesan College, Rondebosch, near Cape Town. There he served for five years. Shortly after his return to England, he was appointed as lecturer in University College, Bristol, to carry on, for the rest of the session 1883–84, the work in geology and zoology relinquished by Prof. W. J. Sollas, who had been called to Trinity College, Dublin. At the close of that session, his appointment as lecturer was renewed; and in due course he became professor, Sir William Ramsay being at that time principal of the College. When Ramsay in 1887 accepted the chair of chemistry in University College, London, Lloyd Morgan succeeded him as principal of the Bristol College and continued to hold this office until 1909. In the capacity of principal he worked assiduously to place the College in such a position as to justify the grant of a university charter; and, when ultimately in 1910 the charter was obtained, it was generally recognised that it was largely through his persistent efforts. He accepted the position of first vice-chancellor of the new University, but only on the understanding that it was to be an interim appointment; and when, after three months, Sir Isambard Owen was chosen for the office, he relinquished it, and became the first occupant of the new chair of psychology and ethics. This chair he held until he retired in 1919, at the age of sixty-seven years.