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FRICTIONAL BEHAVIOUR OF SURFACES COMPOSED OF MULTI-LAYERS

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ABSTRACT

This work presents an experimental investigation into the frictional behaviour of surfaces composed of multi-layers. The effect of using single or multi-metalic layers adhered to a hard or soft substrate on frictional behaviour has been fully analyzed under dry orlubricated situations.

Asteel substrate covered by copper layer, or electrically coated by chromium, nickel, or copper, and brass substrate covered by aluminium layers were used. The coefficient of friction couldbe recorded under a sliding speed ranging from 0.26 m/s to 2,54 m/s and a load ranged up to 540 N.

It could be concluded that the existance of layers affect the frictional behaviour in a manner dependent on layer material, layer thickness, the applied load and operating speed.

INTRODUCTION

Friction is the resistance to motion which is experienced whenever one solid body slides over another. The nature of the frictional behaviour and the mechanisms by which the sliding friction have explained are the subject of many theories [1-4]. However, the adhesion theory as pro-osed originally by Bowden and Tabor [2] gets high academic appeal. In their work, Bowden and Tabor [2], showed that the frictional resistance is a function of the area of contact and shear strength of the cold welded joint. Hence, by coating a hard substrate with a relatively soft coating the frictional resistance should be expected to display lower values; a situation which has been confirmed experimentally [2]. On the other hand, it has been shown

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experimentally [5-6] that hard metals display low values of frictional resistance compared to soft metals; a situation which assumes that coating of hard substrate by a relatively hard one would also reduce the frictional resistance.

On the effect of surface coating on the frictional resistance, it has been illustrated that depending on layer thickness, two general regimes could be identified, namely thin films and ultrathin films. In further studies [8-11] the effect of surface film thickness has been studied. A load dependency of friction, has been recognized in the surfaces covered with soft films [1,7-11], and either soft or hard metals [5,6].

Although the problem of coating a surface by either soft or hard layers has got a good deal of attention, little has been, so far, given to the study of using epoxy resins as an adhesive media to build up a single or multi-layered coating over a hard or soft substrate. Hence, it has been ,herein, decided to investigate the effect of using a built - in multi - layered surfaces on the frictional behaviour. Add to this, the effect of electric depositing as a way of forming surface layer, has been also studied. Dry and lubricated contacts have been considered.

EXPERIMENTAL SET-UP

Test Rig

A standard TIMKEN MACHINE (ASTM D2509) has been used in conducting friction tests. 50 mm diameter ring is allowed to rotate and rub, under load, a station flat specimen. The frictional resistance is thus recorded as a function of the specimen properties, applied load and running speeds.

Test Specimens

Two basic materials have been used as the substrate materials, namely, steel and copper base alloy (Brass) Copper, Aluminium, Nickel and chromium have been used as coating (layer) materials. Full specifications of the used materials including the epoxy resin adhesive and lubricating oil are given in Table 1.

Test Conditions

Two sets of tests have been arranged, dry contact tests and lubricated contact tests. Follows are the operating conditions in each test:

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Table 1. Testing Materials.

Materials		Characteristics
Block	Steel	- Carburised steel (DIN 17006) C 22 - Dimensions: 12.3 x 12.3 x 19.05 mm - Hardness : 416.5 Hv.
Block	Brass	- Alloy of copper and lead (58.72 % Cu, 2,073 % Pb). - Dimensions: 12.3 x 12.3 x 19.05 mm - Hardness : 163.28 Hv
Layers	Copper	- Alloy of Copper (99.932 %Cu,0.004 %.Fe) - Dimensions: strips of 0.125 mm thickness - Hardness: 22.5 Hv.
Layers	Alumenium	- Alloy of alumenium (99.4% al, 0.432% Fe) - Dimensions: strips of 0.35 mm thickness - Hardness: 35 Hv.
Copper Nickel Chromium		- By electric coating.
Ring		- Carburised steel (DIN 17006) C 22 - Dimensions: 13 mm width, 50 mm diameter - Hardness: 416.5 Hv
Adhesive		Its commercial trade name:(Praktikus-2 -Komponenten- kleber - glasker) Art 7092
Lubricant		Haiboid oil 85/140 Viscosity: 400 Cst.

-Dry contact test:
- Speed : 0.26 m/s
- Load : 68 - 94 N

-Lubricated contact test:
- Speed: 0.625 m/s to 2,54 m/s
- Load : 90 N to 540 N

RESULTS AND DISCUSSIONS

It has been shown that the frictional properties of surfaces covered with soft metal layer differ from those with surfaces without layers. Figures (1,2) show experimental example of the coefficient of friction variation with load obtained by using a steel rubbing in lubricated contact with steel block with and without copper layers. The values of coefficient of friction presented experimenally are relatively higher than that which would expected under similar lubricated situations. Meanwhile, the role of lubricant in reducing the coefficient of friction is though to partially demonstrate the effect of using layered surfaces on the friction behaviour. This means that full lubricant film under such nonconjegate contact is not expected to exist and some influence of the metallic interaction between contacting surfaces on the frictional resistance is predomenant. In case of rubbing the hardened steel ring with the steel block, the coefficient of friction is almost constant. In case of conducting the friction test on a steel block with 0.125 mm copper layer, the coefficient of friction exhibitis higher value than the value of steel block without layer under light loads. The values of coefficient of friction decreased with increasing the load value but still having lower values than in case of steel block without layers. It can be seen that the soft thin metal layer is effective as a friction reducing agent under high load conditions. In the same figures, it can be shown that the values of coefficient of friction are increased by using a double surface layer of copper to sum up a thickness of 0.25 mm.

Comparing the graphs in Figures (1,2) it can be seen that the variation of the sliding speed from 0.635 m/s to 2.54 m/s has affected the frictional resistance by slightly increasing its coefficient. Such effect, although is negligibly small, may be attributed to the effect of the speed on the formation of a hydrodynamic lubricant film i.e. the contribution of lubrication becomes more significant.

Lubricated brass blocks with and without aluminium layer were tested, as shown in Figures (3,4) and it can be observed that the coefficient of friction behaves qualitatively in a manner similar to that in case of the steel block, Figures (1,2).

For dry friction tests, steel blocks electro-plated by copper, nickel or chromium layers were examined. A constant value of the coefficient of friction has been recorded using steel block, Figures (5,6), whereas for cases using coated blocks, the values of the coefficient of friction are characterised by a low value of friction at light loads compared to the case of using steel block without layers, (Fig. 5). However any increase in the applied load, is followed by a decrease in the coefficient of friction.

The observed results can be explained in light of adhesion theory [2] as such:

When the load increased the hard substrate would bear the load and the area over which metallic contact occurs, expands proportional to the applied load. When a thin layer

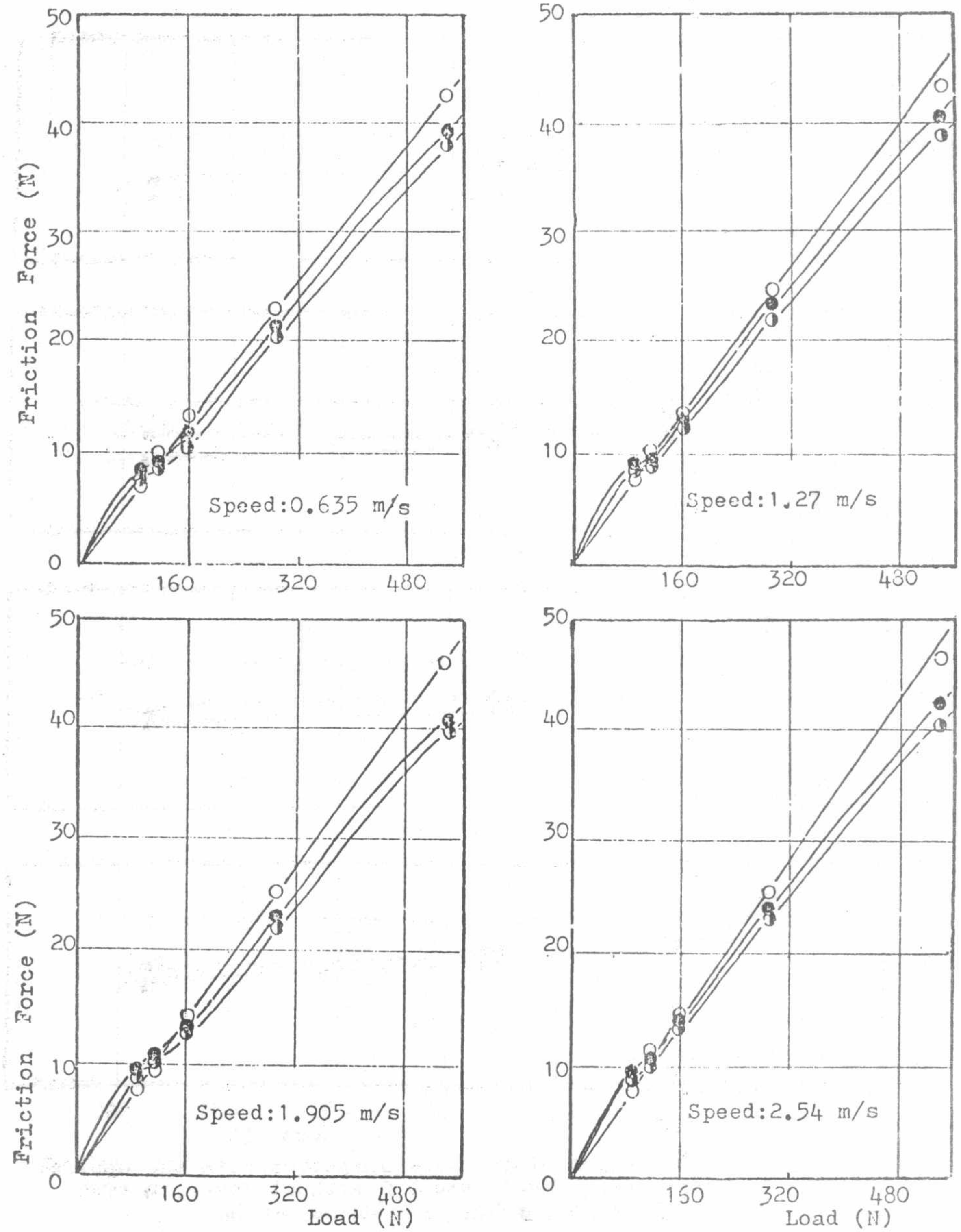

Fig.1: Friction force variation with the applied load using steel substrate (o without layer, ◐ with one Cu layer, ● with two Cu layers).

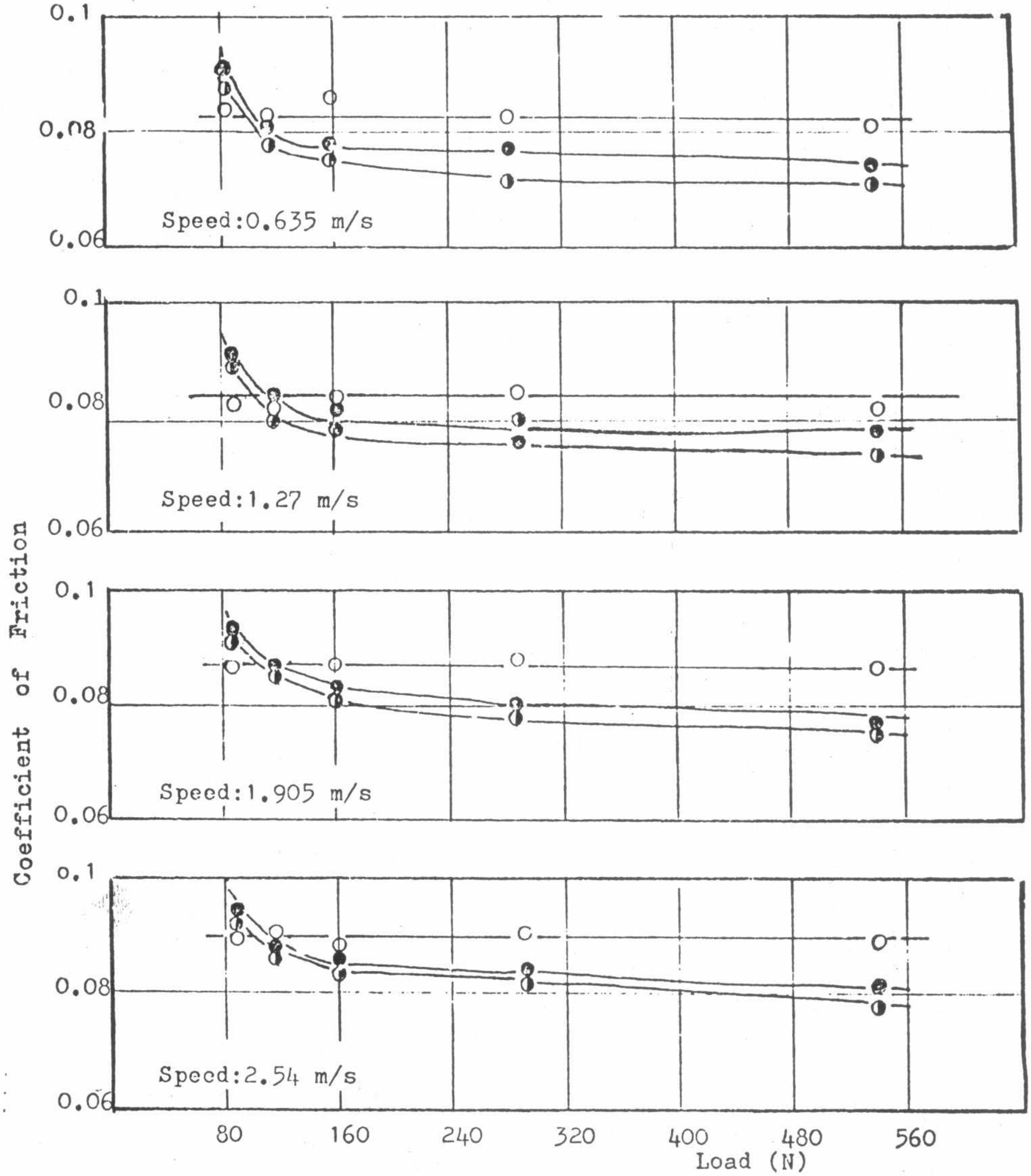

Fig.2: Coefficient of friction variation with the applied using steel substrate (O without layer, ◑ with one Cu layer, ● with two Cu layers).

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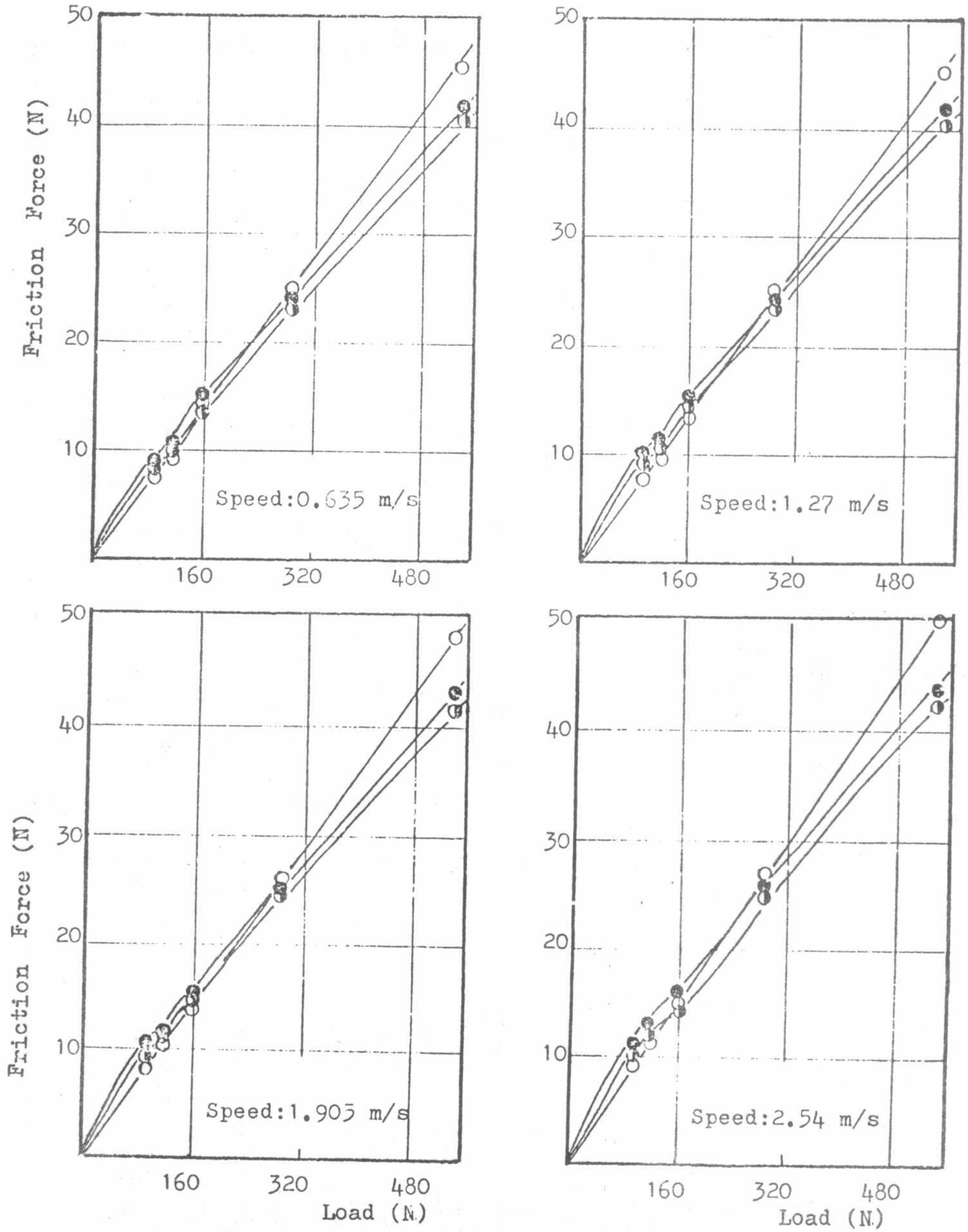

Fig.3: Friction force variation with the applied load using brass substrate (O without layer, ◑ with one Al layer, ● with two Al layers).

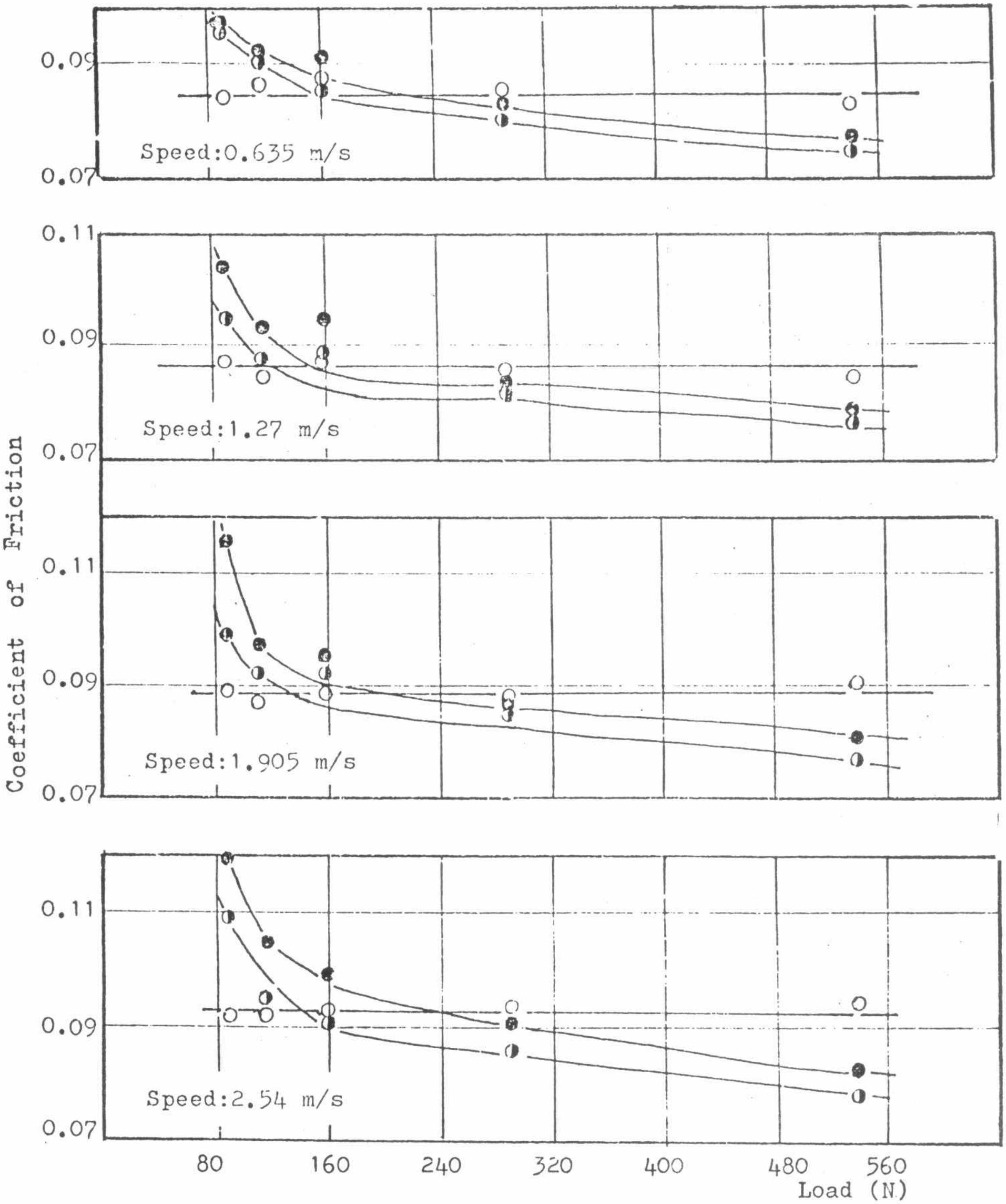

Fig.4: Coefficient of friction variation with the applied load using brass substrate (o without layer, ◑ with one Al layer, ● with two Al layers).

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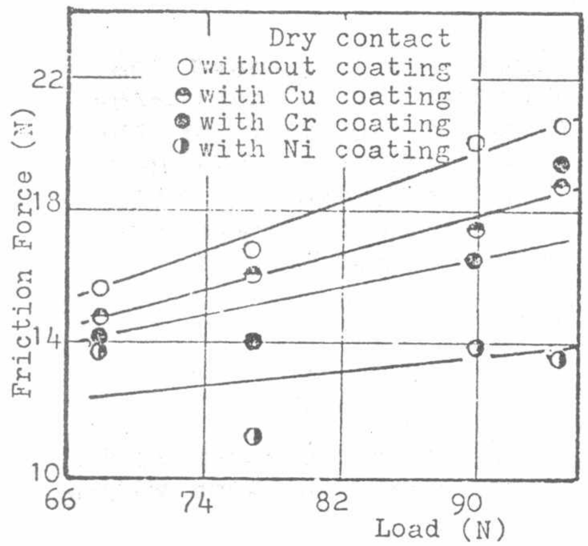

Fig.5: Friction force variation with the applied load using steel substrate

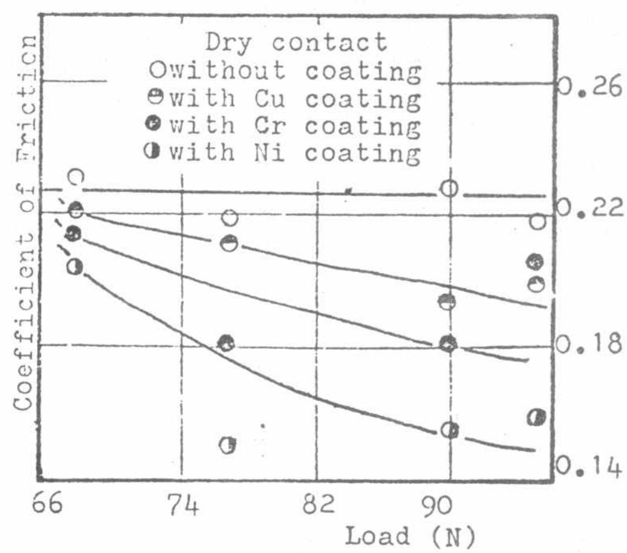

Fig.6: Coefficient of friction variation with the applied load using steel substrate

of a soft metal is used over a hard substrate, however, the increased deformation of the hard substrate metal resulting from an increase in load would produced only a relatively small increase in the area of real contact. Consequently there is only a slight increase in the shear force at contact (frictional force) as the load is increased, Figures (1-4) for lubricated tests or for dry test Figures (5,6).

From the results shown in Figures (1-6), it is clear that using multi-layer gives larger frictional force than using single layer. However, the use of two layers gives frictional resistance less than using the hard substrate without layers. This would be expected as with the increase in the coating thickness the contribution of soft coating as a sole metal becomes more pronounced with little effect of the hard substrate. This would lead to higher friction coefficients.

Of interest to note that the coefficient of friction has been reduced as a result of coating either using soft coating (case of copper coating on steel substrate or Aluminum coating on brass substrate) or hard coating (Nickel or Chromium coating on steel substrate). This may be explained in terms of the contact situation. In case of soft layer, the contact area is a function of the hard substrate giving relatively lower area of contact coupled with lower shear strength of copper to render relatively low coefficient of friction.

On the other hand, using nickel or chromium as a hard coating affects the contact by also reducing the contact area as, in these cases, the contact area is function of the harder layer. With both chromium and nickel being hard metal with low adhesion ability, the resultant friction traction is expected to be reduced to a value lower than that of steel block without layer (Figures 5,6).

CONCLUSIONS:

The following points can be drawn:

1. The frictional properties of surfaces covered with soft metal layer differ from those with surfaces without layers.

2. Although it is known that the frictional coefficient is almost constant regardless of the applied load in contact of surfaces without layers, a load dependency of friction has been found in the friction of surfaces covered with soft surface layers. The coefficient of friction obtained experimentally decreases considerably with the increase of applied load.

3. The coefficient of friction is affected by the surface layer thickness. In general, the less the layer thickness is, the smaller the coefficient of friction.

REFERENCES:

1. Sarkar, A.D., "Wear of metals", Pergamon Press,Oxford 1979.

2. Bowden, and Tabor, "The friction and lubrication of solids" Part I, Oxford University Press, 1964.

3. Rabinowicz, E., "Friction and wear of materials", Wiley Pub., 1965.

4. Kragelskii, I.V., "Friction and wear", Butterwurths (London), 1975.

5. Mokhtar, M.O.A. and Radwan, M.A., "The influence of quenshing techniques on frictional behaviour of carbon steels" Published in "Heat and Mass Transfer in Metallurgical systems" Ed. D.B. Spalding and N.H. Afgan, Hemisphere Pub. Corporation, USA, 1981,pp.545-551.

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6. Mokhtar, M.O.A., Zaki, M. and Shawki, G.S.A., "An experimental Re-examination of kinetic friction", Tribology International, Vol. 12, No. 6, 1979, pp.261-264.

7. Finkin, E.F. "A theory for the effects of film thickness and normal load in the friction of thin films", Trans. ASME, Journal of Lubrication Technology, July 1969, Vol. 91.

8. Kato, Yamaguchi K., "Frictional properties of a surface covered with a soft metal film" Part I, Vol. 103 April 1981 and Part II, Vol. 104, January 1982, Trans. ASME, Journal of lubrication Technology.

9. Bowers R.C. and Zisman W.A. "Pressure effects on the friction coefficient of thin film solid lubricants" Journal of Applied Physics, Vol. 39, No. 12, 1968.

10. Tsuya Y. and Takagi R., "Lubricating properties of lead films on copper" Wear, Vol. 7, 1984.

11. Berry L.M. "Solid lubricant coatings", Trans. ASME, No. 58-Av-20.