AD NUMBER
AD479930
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1966. Other requests shall be referred to British Embassy 3100 Massachsetts Avenue, NW, Washington, DC 20008.
AUTHORITY
MOA notice, 15 Jun 1966

TR 66012

JANUARY 1966

AD 479930

479930

ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL REPORT No. 66012

ABRASION BY LAMELLAR SOLID LUBRICANTS

by

J. K. Lancaster, Ph.D., F.Inst.P.

Patricia A. Grattan

MINISTRY OF AVIATION

FARNBOROUGH HANTS

U.D.C. No. 539.576 : 539.216 : 621.892.9 : 539.22 : 546.774.2 : 669.35.6.779

ROYAL AIRCRAFT ESTABLISHMENT

Technical Report No. 66012

January 1966

ABRASION BY LAMELLAR SOLID LUBRICANTS

by

J.K. Lancaster, Ph.D., F.Inst.P.
Patricia A. Grattan

SUMMARY

The extent to which lamellar solid lubricants (graphite, MoS_2, BN, etc) are abrasive has been determined by measuring the rate of wear of phosphor-bronze sliding against PTFE in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder in order to avoid complicating effects due to transfer of the solid lubricant to the sliding surfaces. There are significant differences in the abrasiveness of samples of MoS_2 conforming to standard specifications and it is suggested that the major factor responsible is the degree of perfection of the crystal structure. This aspect is particularly important for boron nitride and may largely account for its inability to function as an effective solid lubricant.

Departmental Ref. CPM.56

CONTENTS

1 INTRODUCTION

It is now well known that in certain conditions of sliding graphite can exhibit abrasive properties and cause appreciable wear of metals. This behaviour appears to be a direct consequence of the anistropy in mechanical properties of graphite, resulting from its lamellar structure, and is shared by other materials with similar structures, e.g. MoS_2, talc, SnS_2, etc[1]. The extent to which any lamellar solid is abrasive depends upon its intrinsic properties, such as particle size and shape, maximum hardness, etc, but the presence of impurity is also likely to be a major factor. The possibility therefore arises that measurements of the abrasiveness of lamellar solids could serve as a criterion for purity, or for quality control in relation to their function as lubricants. The experiments described in this report were made to examine this aspect with particular reference to MoS_2.

Silica and iron oxides are the major, potentially abrasive impurities present in natural MoS_2 and considerably attention is given to their removal during refining. Thus, both MIL-M-7866A and CS 2819 Specifications limit the maximum amount of insoluble impurity in MoS_2 to about 1%, and the latter specification further restricts the content of SiO_2 and iron to 0.02% and 0.1% respectively. It seems somewhat surprising that greater attention has not already been paid to the development of a mechanical test for assessing directly the significance of abrasive impurities in solid lubricants. The only recognised method seems to be an A.S.T.M. Standard for graphite in which the wear of a rolling element bearing is determined by weighing before and after operation in a graphite dispersion in oil[2]; this procedure is both insensitive and time-consuming. An attempt has recently been made to use the same method for MoS_2 [3], but the reproduciability was poor and difficulties were encountered due to lubricant transfer. The approach adopted in the present work has been to determine the effect of solid lubricants on the wear of a hemispherically-ended pin sliding against a rotating disc. By a suitable choice of materials, it is possible to ensure that the major component of the wear process is directly attributable to the solid lubricant itself.

2 APPARATUS

The apparatus used is shown in Fig.1. A hemispherically ended pin, A, is mounted eccentrically in a chuck, B, and rotated slowly (≈ 10 rpm) against a more rapidly rotating disc, C, (≈ 200 rpm). The axis of rotation of the pin is offset from that of the disc, and the contact region on the latter is consequently an annular ring, of width 0.6 cm and mean diameter 1.1 cm. In experiments with dry lubricant powders, it was observed that the particles were displaced towards the sides of the container, D, and a stationary paddle, E, was therefore provided to re-direct the powder towards the centre of the disc. Preliminary experiments showed that the rate of supply of powder was not particularly critical.

3 DEVELOPMENT OF EXPERIMENTAL PROCEDURE

3.1 Rubbing materials

The choice of rubbing materials is critical. This is because the sensitivity of detecting the abrasive effects of a solid lubricant will be dependent on the magnitude of the rate of wear in the absence of lubricant. Experiments were first made with copper pins sliding on polished synthetic sapphire discs and Fig.2 shows the variation in the friction and wear of the copper before and after the addition of solid lubricant. It may be noted that MoS_2 causes a transient increase in wear, but phthalocyanine is completely innocuous in this respect; both materials however, ultimately reduce the rate of wear of the copper. Duplicate experiments showed that the transient increase in wear with MoS_2 was not very reproducible and was greatly affected by the rate of formation of a transferred film of MoS_2 on the sapphire disc. To minimise the effect of the disc material on the wear of the pin, experiments were made with a number of polymer discs, and a somewhat harder pin material, phosphor-bronze. Table 1 shows the mean rates of wear of bronze, during 10000 revs, against various polymers and it may be noted that, in the absence of MoS_2, PTFE, Nylon, and Delrin cause virtually no wear. The addition of MoS_2, however, significantly increases the rate of wear of the pin on these polymer discs, in contrast to the result obtained with a sapphire disc.

Examination of the worn surfaces of the bronze pins after sliding against the above three polymers in the presence of MoS_2, showed that the wear scars were curved, rather than planar, presumably as a consequence of the deformation of the polymer. Examples are shown in Figs.3(a), 4(a). Attempts were made to minimize this curvature by using harder reinforced PTFE and thin PTFE layers on a hard substrate. Table 1 shows, however, that in the former case, the reinforcement itself induced an appreciable amount of wear of the bronze and, in the latter, the thin PTFE layers did not remain intact on their substrate for a sufficiently long period. The Table also shows that abrasion of PTFE with carborundum paper greatly increases the rate of wear of the bronze, presumably due to the pick-up of abrasive grains. Each subsequent experiment was therefore made with a fresh sample of bulk PTFE ($\frac{1}{8}$ in. thick sheet), the surface merely being wiped with a tissue, moistened in acetone, to remove atmospheric contamination.

3.2 Measurement of wear

The curvature of the wear scars produced on the hemispherically ended pins after sliding against PTFE and MoS_2 precludes measurement of the volume of wear by the usual microscopic method. This volume was therefore estimated from superposed profilometer traces, as shown in Fig.4. Since the wear scars were essentially symmetrical, it was convenient to compute the worn volume from diametral profiles by the integration of elemental areas around the scar. The repeatability of this procedure was assessed by superposing nominally identical profiles, and the limiting sensitivity in wear rate (based on 10000 revs of the disc) was about $5 \cdot 10^{-12}$ $cm^3/cm/kg$.

Wear on the PTFE disc was not, in general, measured. Qualitatively, however, it appeared to vary with the type of solid lubricant in the same way as the wear on the metal pin. Figs.4, (g) and (h), for example, show profiles of the annular wear tracks on PTFE produced by two samples of graphite. The volume worn is clearly greatest for the impure sample, which, as will be shown later, also causes most wear of the pin.

3.3 Effect of pin hardness

The variation with pin hardness of the mean rate of wear during 10000 revs of various metals and glass on PTFE using one particular grade of MoS_2 is shown in Fig.5. The rate of wear is inversely proportional to the hardness, and this relationship is typical of that usually observed in similar experiments with conventional abrasives[4]. For convenience, all subsequent experiments were made with phosphor-bronze balls as the pin material, the balls being $\frac{1}{4}$ in. diameter and held in a small chuck. The nominal composition was 95% Cu, 5% Sn, and 0.2% P, and the hardness 185 V.P.N. The balls were used as received, apart from wiping with solvent-moistened tissue.

3.4 Effect of load

Fig.6 shows the effect of load on the wear of bronze by one particular grade of MoS_2 powder. The rate of wear is proportional to the load up to about 1.2 kg, implying that the wear process remains unique in character over this range of loads[5]. Above 1.2 kg, however, the rate of wear begins to decrease and it was noted that at these heavier loads wear and deformation of the PTFE greatly increased. All subsequent experiments were made at a load of 1 kg.

3.5 Dispersions of solid lubricants

During a number of experiments with some solid lubricants, to be described more fully later, a transferred patch of the solid was sometimes observed on the bronze surface. Examples are shown by the profiles in Figs.4(d), (e) and (f), and by the photomicrograph in Fig.3(b). Transfer presumably protects the underlying surface from wear and to avoid this complication, additional experiments were made with dispersions of solid lubricant in MS 200 silicone fluids as inert carriers. Fig.3(c) shows the wear scar on bronze after sliding in a 20% wt dispersion of high purity graphite, and it may be noted by comparison with Fig.3(b) that transfer is completely prevented. Figs.3(d) and (e) show that the presence of fluid also inhibits the formation of a transferred film on the PTFE disc.

The variation of the wear of bronze with MoS_2 dispersion concentration is shown in Fig.7. Over a wide range of concentration (4% - 100%), the rate of wear increases almost linearly. Further experiments showed that the viscosity of the silicone fluid did not significantly affect the wear rate (Fig.8) and, in all subsequent tests, the 20 cs fluid was used.

4 RESULTS

4.1 Molybdenum disulphide

Using the procedure developed above, the rates of wear of bronze were determined for a variety of different grades of MoS_2, both as dry powders and as 20% wt. dispersions in silicone fluid. Details of the various grades are given in Table 2, together with a code number to facilitate subsequent identification. The rates of wear are plotted in Fig.9 and the following points may be noted:

(i) In general, the wear rates with dispersions are lower than those for the dry powders. Three exceptions, however, occur with micronated grades where, under dry conditions, there was appreciable transfer of MoS_2 to the bronze.

(ii) There do not appear to be any significant differences, in general, between the abrasive properties of "standard" and "micronated" grades, nor between grades conforming to the two specifications MIL-M-7866A and CS 2819. Particle size is not, therefore, a major variable in abrasion by MoS_2.

(iii) There is a general trend towards increasing wear with increasing impurity content. The impurity concentration, however, is by no means the only important factor in abrasion because 'super-purity' MoS_2 (A-5) is significantly more abrasive than most of the less-pure commercial products. The particular sample of synthetic MoS_2 examined is also highly abrasive, as noted elsewhere[1].

(iv) MoO_3 is not an abrasive, again confirming earlier work[1,6].

The relationship between the natural impurity content of MoS_2 and its abrasive properties is shown in more detail in Fig.10. The impurity contents are expressed as the total weight % of Cu, Fe, and SiO_2 and are based either on data provided by the suppliers of the various grades or on analyses by C.I. (Harefield). The large scatter presumably results from differences between grades other than impurity content, and to eliminate the effect of those extraneous factors, experiments were made in which impurities were deliberately added to particular grades of MoS_2 (A-2 and D-14). Results are shown in Fig.11, curves B and E for additions of 3μ Al_2O_3 and curves C and D for additions of 0.5μ Fe_2O_3. Fig.11, curve A, also shows the effect of added Al_2O_3 on the wear of copper on a compacted pellet of MoS_2 and Al_2O_3, as described in an earlier report[1]. In all cases, the presence of the impurity increases the rate of wear and the results exhibit considerably less scatter than those already described for different grades (Fig.10). The effects of added impurity on abrasion, in general, become significant at concentrations exceeding 0.1% wt, whereas the natural impurity appears to be significant (from tests with dispersions) only above about 1% wt (Fig.10).

4.2 Graphite and other lamellar solids

Experiments similar to those described above for MoS_2 were also made with graphite, sulphides and selenides of Mo, W, Nb, and Ta, and miscellaneous lamellar solids including talc, mica, phthalocyanine, etc. The results are shown in Figs.12 and 13. Complications arising from transfer of the dry solid lubricant to the bronze were present with high purity graphite, synthetic nuclear graphite, and NbS_2 but were not apparent with the other materials. NbS_2 transferred to bronze, even from a dispersion. With dry SnS_2 powder, there was evidence of reaction between the bronze and free sulphur liberated by disociation during sliding, but this no longer appeared to occur in dispersion. Perhaps the most interesting feature of the results is the very high rates of wear induced by talc, mica, and boron nitride when these materials are dispersed in silicone fluid. The precise reason for this increase in wear is not known, but it could be related to the function of the fluid in preventing aglomeration of the particles. It was noted that, with talc in particular, the dry particles formed into relatively large aggregates which were pushed aside by the periphery of the ball and its holder before they were able to enter the contact zone.

4.3 Boron nitride

The rates of abrasion produced by various samples of boron nitride, originally obtained for earlier friction experiments[7], are shown in Fig.14. These tests were made with 10% dispersions in silicone fluid because of the pronounced 'thickening' effect of the BN when present in higher concentrations. The major impurity in all these samples was B_2O_3, which is itself abrasive (Fig.14) and much more so, in fact, than the corresponding oxidation product of MoS_2 (MoO_3 - Fig.9). Despite this, however, there is no general relationship between purity and abrasion. Boron nitride, leached with HCl to remove B_2O_3, shows a higher rate of abrasion than the impure material (samples H-3 and H-2 respectively) and similarly, powder which had been purified by heating in NH_3 at 1100°C (sample J-7) is also more abrasive than the original material (sample J-6). B_2O_3 impurity does not therefore appear to be the primary factor responsible for the abrasiveness of BN.

5 DISCUSSION

The limiting sensitivity of the method described above for measuring the abrasiveness of lamellar solid lubricants corresponds to a rate of wear of bronze of about 5.10^{-12} $cm^3/cm/kg$. This value is based on only 10000 revolutions of the PTFE disc and could be significantly reduced by extending the period of sliding. Since the wear rates of various metals are inversely proportional to their hardness (Fig.5), increased sensitivity could also be obtained by using a metal softer than bronze. A very high sensitivity, however, is not necessarily required if the present method is to be used merely for routine examination or quality control of solid lubricants. Because lamellar solid lubricants are intrinsically abrasive, the major difficulty here is to establish a base line above which abrasion is considered to be excessive. In the absence of a precise relationship between the abrasiveness of lamellar solids and their performance as solid lubricants, this line can, at present, only be drawn arbitrarily. Since MoS_2 samples conforming to the two standard specifications may be presumed to be effective lubricants, tentative limits for acceptable rates of abrasion can be fixed at about 10.10^{-11} $cm^3/cm/kg$ for dry powder and 2.10^{-11} $cm^3/cm/kg$ for a 20% wt dispersion of powder in silicone fluid.

With dry solid lubricant powders the abrasion process is complicated by four factors; transfer to the bronze ball, transfer to the PTFE disc, orientation of the transferred layer on the PTFE, and compaction of the powder into aggregates without the formation of a transferred layer. Transfer to the ball, or to the

PTFE, is influenced not only by surface roughness and the humidity of the environment, but also by properties of the lubricant itself; the results in Fig.9, for example, suggest that transfer of MoS_2 to bronze is most pronounced with the micronated grades. Transfer to the bronze ball will protect the surface from wear to an extent depending on the life-time of the material within the transferred layer, i.e. on the adhesion to the substrate and the cohesion between the particles. Transfer and orientation on the PTFE disc, on the other hand, may tend to increase, rather than reduce, the wear of the bronze. It was shown in earlier pin and disc experiments that the rate of wear of the pin increases when transferred solid lubricant on the disc begins to blister and flake away from the surface[1,8]. The transferred films on PTFE in the present experiments were only weakly bonded and could usually be removed either by adhesive tape or by rubbing with tissue. Patches of transfer are not, therefore, likely to remain intact for very long on the PTFE surface and the contribution to wear resulting from their detachment will tend to be greater than that observed with metal discs. The effect of aggregation of dry powders in reducing the wear of the bronze was observed only with mica, talc, and boron nitride, but it is possible that a similar phenomenon might have occurred to a smaller extent with other lamellar solids. The relative importance of this factor in the wear process, therefore, remains somewhat obscure.

The above features of the abrasion process with dry lamellar solid lubricant powders make it difficult to assess the fundamental significance of the differences between the rates of wear obtained with different solids or even with different samples of the same solid. Fortunately, however, all the complications resulting from transfer or aggregation are either eliminated or greatly reduced when using dispersions rather than dry powders. The only example of transfer observed from a dispersion was with NbS_2 (Fig.13). It is therefore suggested that routine determinations of abrasion by solid lubricants should preferably be made using dispersions.

A comparison between the results obtained with MoS_2 samples containing natural impurities (Fig.10) and those to which abrasive impurity was deliberately added (Fig.11) suggest that the natural impurities must be either very finely divided or contained within the individual MoS_2 particles, possibly at the crystallite boundaries. Natural impurity does not appear to be a significant factor in abrasion (with MoS_2 dispersions) below at least 1% wt. The large scatter in the rates of wear with samples containing less than 1%

of natural impurity suggests that the effect of other differences between various grades of MoS_2 are more significant than the impurity content. The most important of these is probably the crystal structure. An examination by X-ray diffraction and electron microscopy of samples of synthetic and natural (D-14) MoS_2 demonstrated that there were, in fact, appreciable differences in structure. The synthetic material showed broadening of selected diffraction lines, indicative of the incidence of stacking faults, and in addition included a small proportion of rhombohedral crystallites. Transmission electron micrographs are shown in Fig.15, obtained by smearing the MoS_2 between two glass slides and attaching the resulting film to a Formvar backing. From a comparison of these micrographs, it is clear that the synthetic MoS_2 is much more resistant to shear than the natural product. This particular sample of synthetic MoS_2 is known to be ineffective as a solid lubricant[9]. The boron nitride samples used in the present work are also known to be ineffective lubricants[7], and Fig.14 shows that all these samples are appreciably more abrasive than MoS_2 (conforming to specification), bearing in mind the lower concentration of the dispersion. X-ray examination of one particular boron nitride sample (J-4), reported by Kinner[7], showed a marked degree of crystallite imperfection, with a stacking fault occurring about every fourth layer. It therefore appears that the perfection of the crystal structure of a lamellar solid may well be a major factor in determining its abrasiveness, as well as affecting its performance as a lubricant.

6 CONCLUSIONS

(i) The abrasive properties of lamellar solid lubricants can be assessed by measuring the rate of wear of a metal sliding on a PTFE disc in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder, in order to avoid complications due to transfer to one or both of the sliding surfaces.

(ii) One of the most important factors affecting the abrasiveness of lamellar solids appears to be the degree of perfection of the crystal structure. Natural impurities in MoS_2 cause relatively little abrasion when the amounts present are less than about 1% by weight.

(iii) All the samples of boron nitride examined were significantly more abrasive than those of MoS_2 conforming to Specifications MIL-M-7866A and CS2819. The imperfect lamellar structure of boron nitride is considered to be one main reason for its inability to function as an effective solid lubricant.

Table 1

EFFECT OF DISC MATERIAL ON THE WEAR OF PHOSPHOR-BRONZE

Substrate	Mean wear rate in 10^4 revs. 10^{-11} $cm^3/cm/kg$	
	Without MoS_2	With MoS_2 (D-14)
Sapphire (> 1μpin CLA)	58	20
PTFE ($\frac{1}{8}$" sheet on tool steel)	<0.5	23
Polyacetal (Delrin)	<0.5	18
Nylon 6	<0.5	17
Filled PTFE (Fluon V102)	8000 (first 200 revs) 4 (5-10000 revs)	- -
PTFE-mica (Fluorosint)	7	-
PTFE sheet, abraded	20	-
PTFE sprayed on tool steel (0.0005 in) and sintered	Persisted only for a few hundred revolutions.	
PTFE-self adhesive tape on tool steel (0.003 in)	Persisted only for a few hundred revolutions.	

Table 2

MOLYBDENUM DISULPHIDE SAMPLES

			Supplier	No.
Impure MoS_2	79%	9.5% Fe_2O_3 and SiO_2	A	1
Impure MoS_2	90%	6% Fe_2O_3 and SiO_2	B	6
Commercial MoS_2	98.5%		C	7
High purity $MoS_2 \simeq 99\%$ (Standard grades)		MIL-M-7866A	C	8
		CS 2819	C	9
			C	10
			C	11
			E	15
			E	16
		MIL-M-7866A and CS 2819	A	2
			A	3
			D	14
Micronated MoS_2		MIL-M-7866A	C	12
		CS 2819	C	13
			E	17
			E	18
			F	19
		MIL-M-7866A and CS 2819	A	4
Super purity MoS_2 99.5%		< 0.07% insolubles	A	5
Synthetic MoS_2		Prepared by reacting K_2CO_3, S, and MoO_3 at 1000°C (10)		20
MoO_3		Analar		21

Table 3

GRAPHITE AND OTHER SOLID LUBRICANTS

Ceylon graphite, 2% mineral ash.

Purified natural graphite, << 1% mineral ash.

Synthetic graphite (electrographite) Nuclear quality.

Spectroscopically pure graphite.

Talc	Ignited
Mica	Fine powder. < 200 mesh.
SnS_2	Technical.
CdI_2	Analar.
CaF_2	Precipitated.
Phthalocyanine.	Metal-free, 98.6%.
WS_2	Micronated
NbS_2, TaS_2, $MoSe_2$, WSe_2, $NbSe_2$, $TaSe_2$	Prepared by direct reaction between the elements at about 400°C in vacuum and annealed at 750°C. Ground to pass 200 mesh[11].

Table 4

BORON NITRIDE SAMPLES

	Supplier	No.
96.1% BN, 0.1%C	G	1
63.9% BN, 0.3%C	H	2
88.5% BN, above, leached with HCl to remove B_2O_3	H	3
96.2% BN, 0.3%C	J	4
95.2% BN, 0.2%C. Above heated in O_2 at 700°C to oxidise C	J	5
94.1% BN	J	6
98.5% BN. Above, heated at 1100°C for 2 hrs in NH_3	J	7
94.2% BN	K	8
B_2O_3 Technical grade.	L	9

REFERENCES

No.	Author	Title, etc
1	J.K. Lancaster	Anisotropy in the mechanical properties of lamellar solids and its effect on wear and transfer. RAE Tech. Report 65102. May 1965
2	-	Lubricating qualities of graphites. ASTM D-1367-64. ASTM Standards, Part 18, 455, 1965
3	C.F.D. Durbridge	The effect of particle size on the lubricating effect of molybdenum disulphide. Scientific Lub. June 1965, 14
4	M.N. Krushchov N.A. Babichev	Resistance to abrasive wear and hardness of metals. Dokl. Akad. Nauk. SSSR. 88(3), 445, 1953 Trans. NSF-tr-15, 1953
5	J.F. Archard W. Hirst	The wear of metals under unlubricated conditions. Proc.Roy. Soc. A.236, 397, 1956
6	G.J.C. Vineall A. Taylor	Oxide formation from molybdenum disulphide. Scientific Lub. Sept. 1961,21
7	G. Kinner	An experimental assessment of boron nitride as a solid lubricant. RAE Tech. Note Chem.1377. Dec. 1960
8	A.W.J. de Gee G. Salomon J.H. Zaat	On the mechanisms of MoS_2 - film failure in sliding friction. ASLE Prep. 64-LC-30, 1964
9	Edna Kay	The effect of humidity on solid lubricant films. RAE Tech. Report 65047. March 1965
10	R.E. Bell R.E. Herfert	Preparation and characterisation of a new crystalline form of molybdenum disulphide. J. Am. Chem. Soc. 79, 3351, 1957
11	D.J. Boas	New solid lubricants: preparation, properties and potentials ASLE Prep. 65-AM-5C3

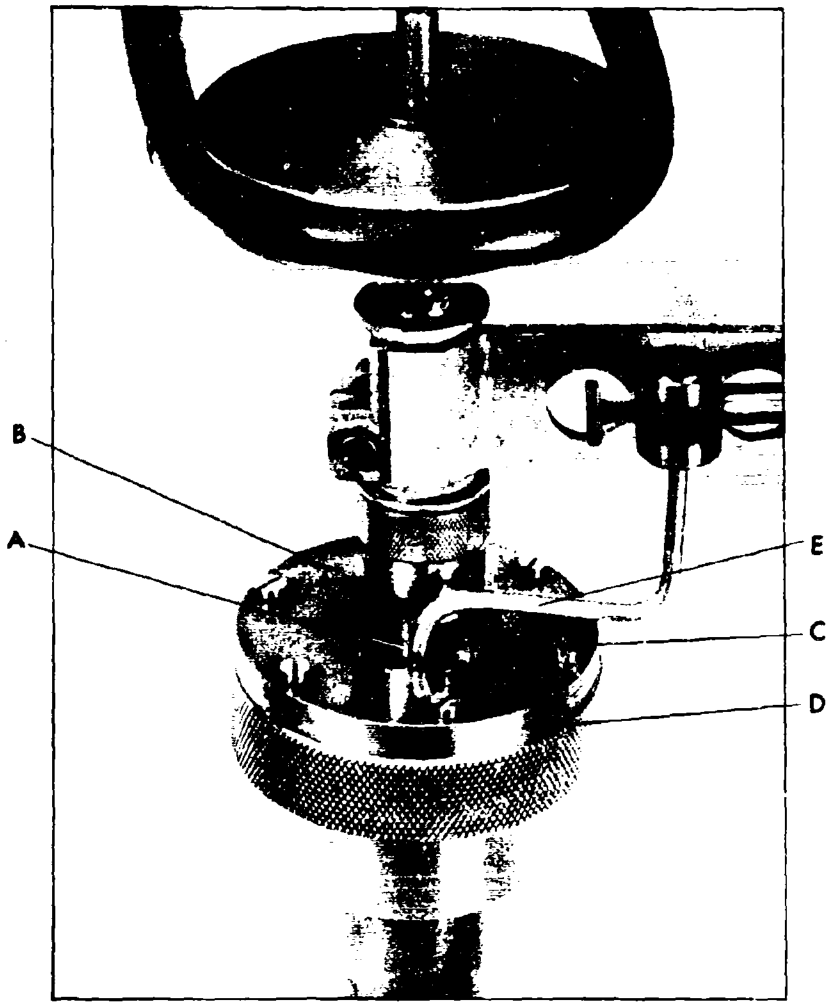
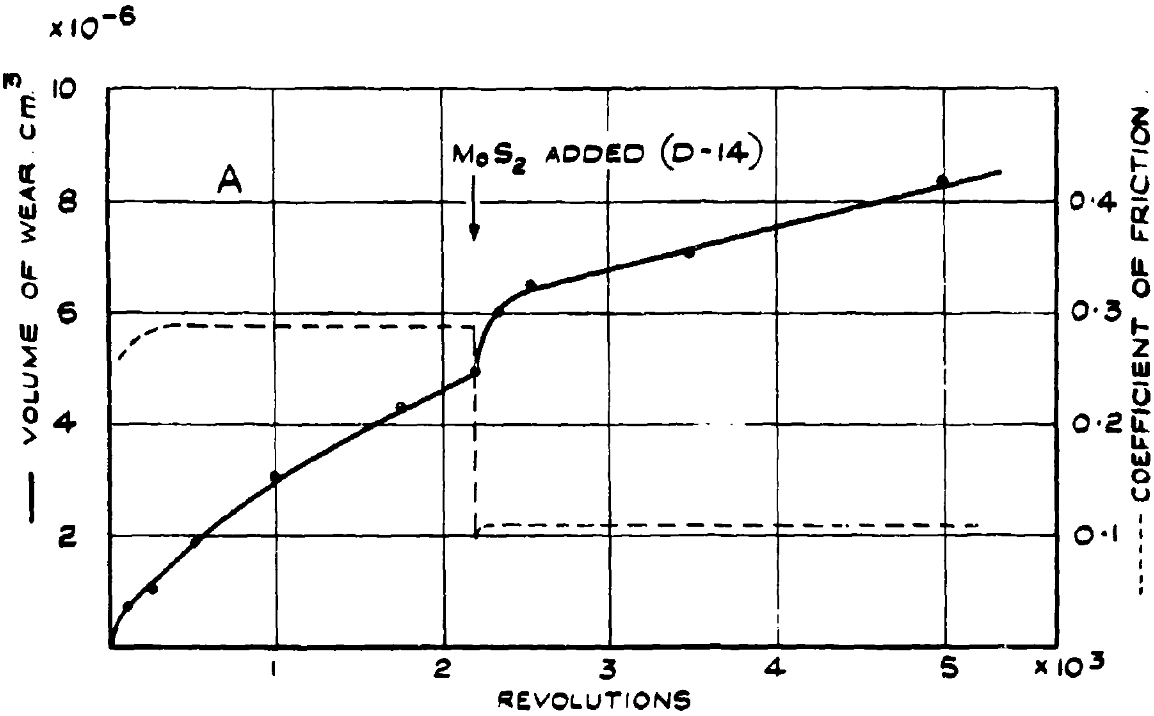


Fig.1 PIN AND DISC APPARATUS

Fig.2

014 900007



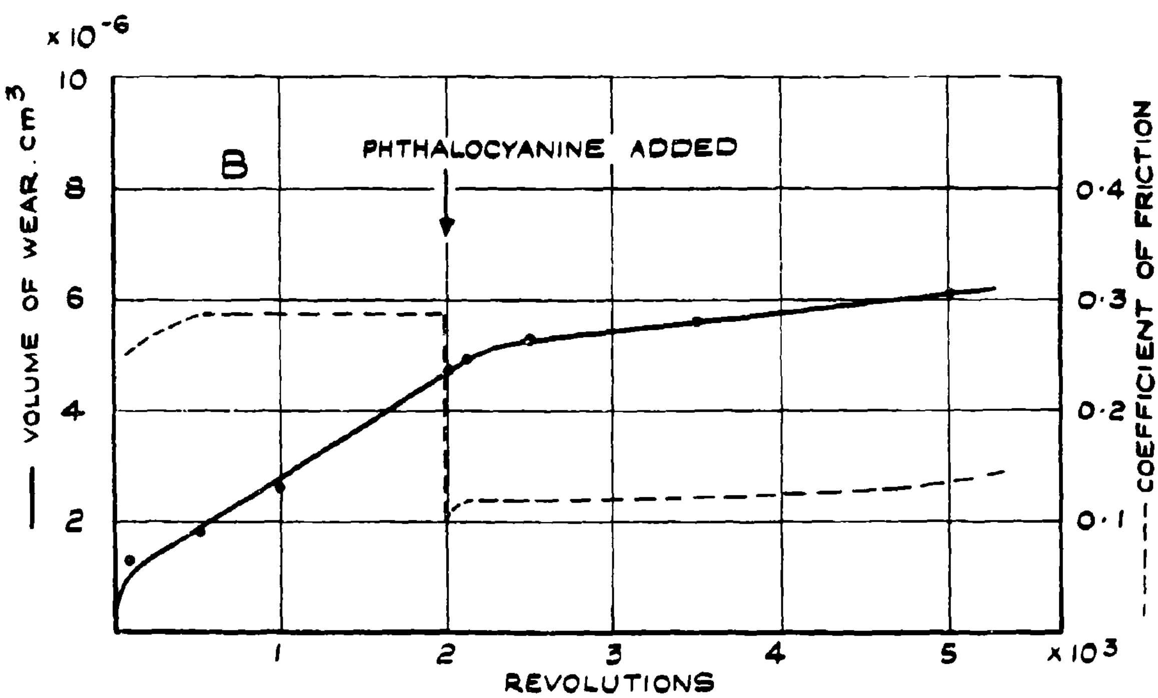
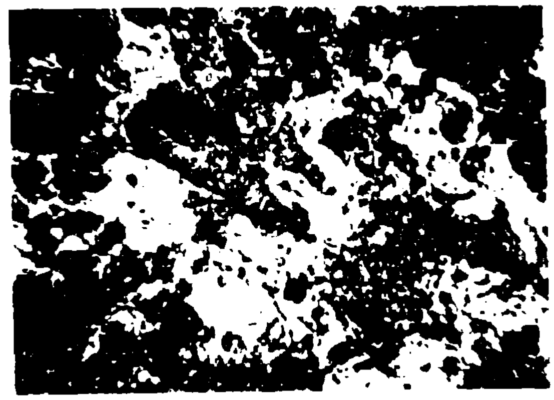


FIG.2 FRICTION & WEAR OF COPPER ON POLISHED SAPPHIRE.
LOAD = 1 Kg

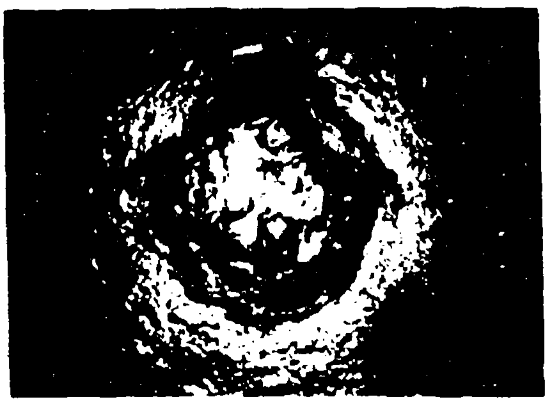
Neg. No. C1535

Fig.3

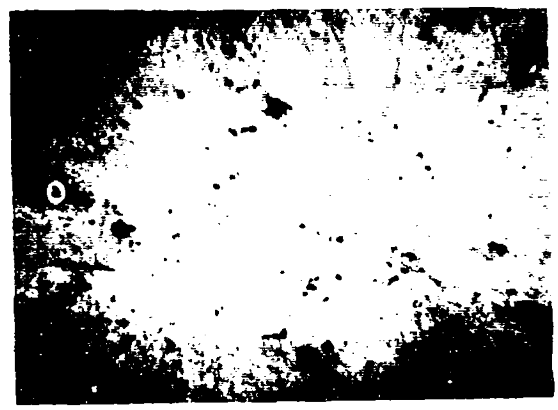
A



D

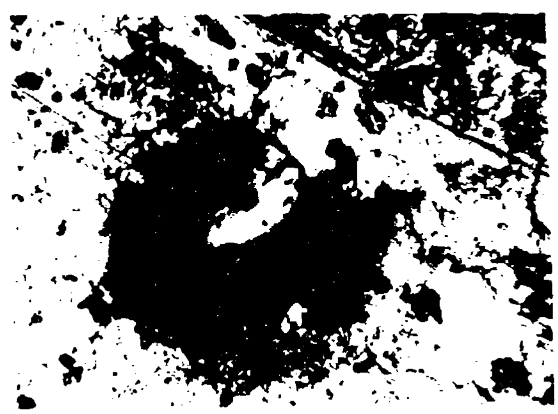


B



E

C



F

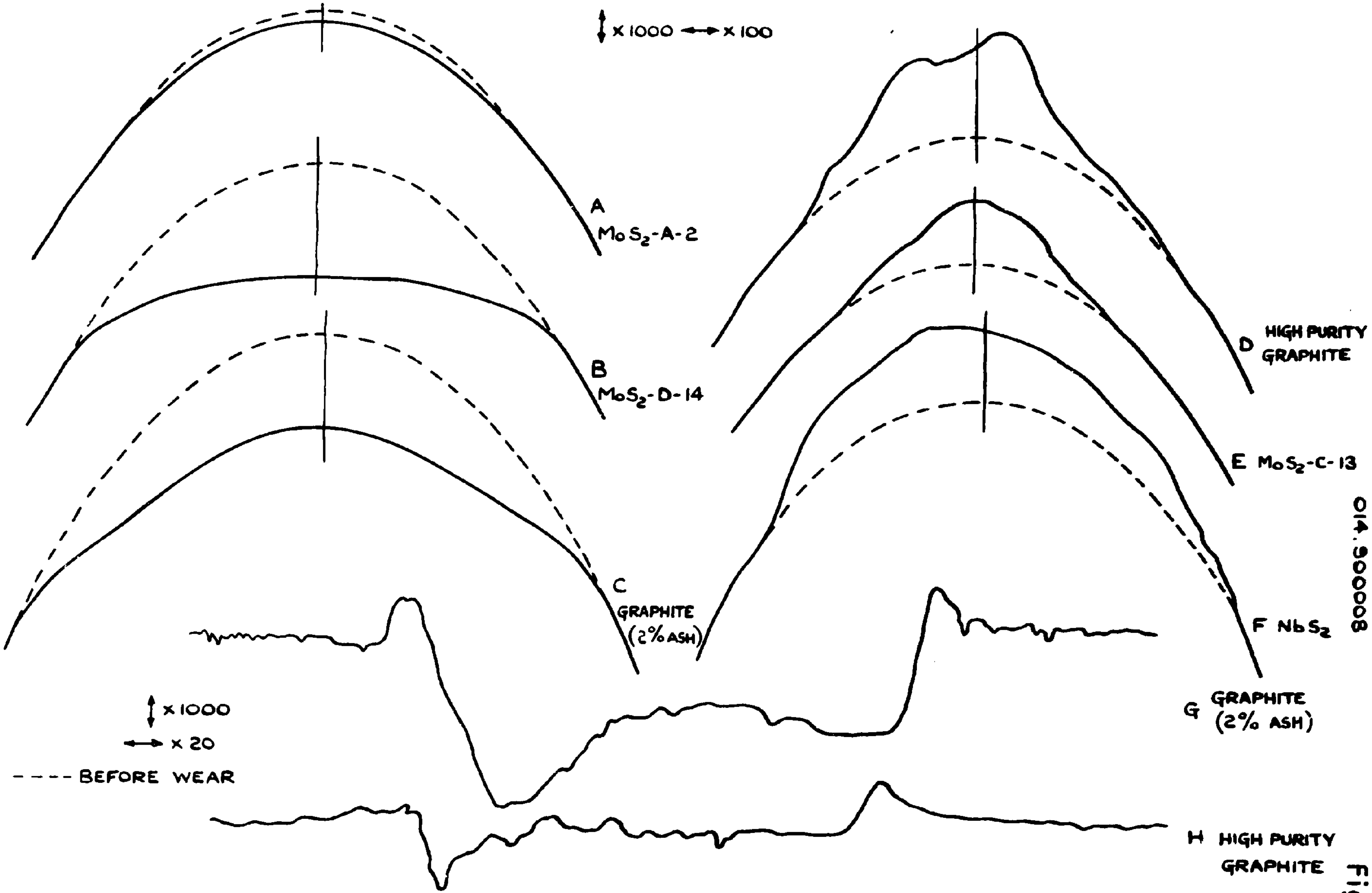
Fig.3 APPEARANCE OF BRONZE BALLS AND PTFE AFTER SLIDING WITH MoS_2 AND GRAPHITE.

LOAD = 1Kg, SPEED $\simeq$ 10 cm/s. 10000 REVS MAG = 50

A. D MoS_2 - D - 14. B, F HIGH PURITY GRAPHITE.

C, E HIGH PURITY GRAPHITE DISPERSION (20% WT) IN SILICONE FLUID (M.S. 200/20)

T.R. 66012



014.900008

FIG. 4 PROFILES OF BRONZE BALLS AND P.T.F.E. DISCS BEFORE AND AFTER WEAR

Fig. 4

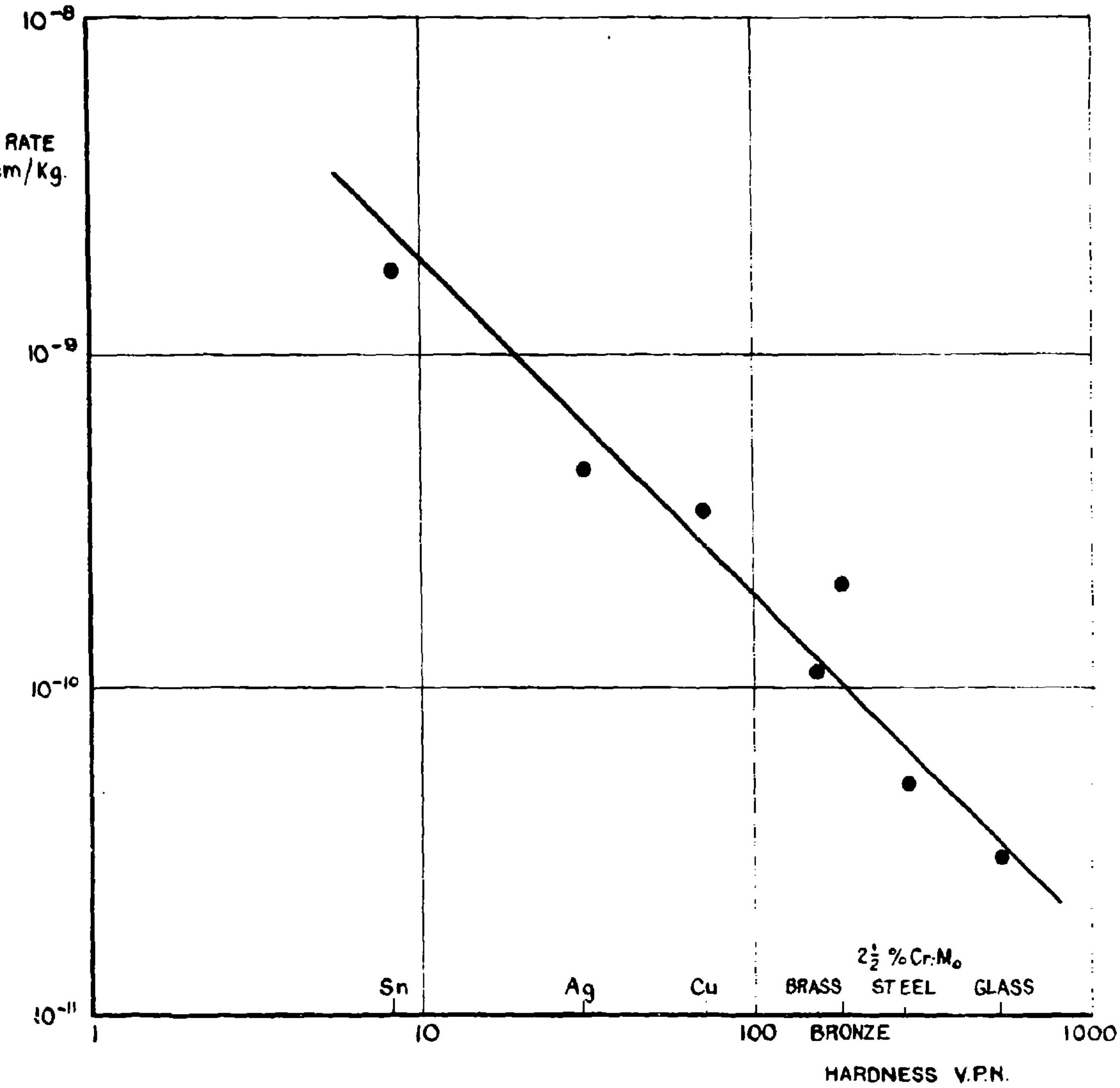


FIG. 5 VARIATION OF WEAR RATE WITH HARDNESS FOR VARIOUS MATERIALS SLIDING ON P.T.F.E. IN THE PRESENCE OF DRY MoS_2 POWDER (D-14)
LOAD =1Kg., SPEED ≏ 10 cm./s

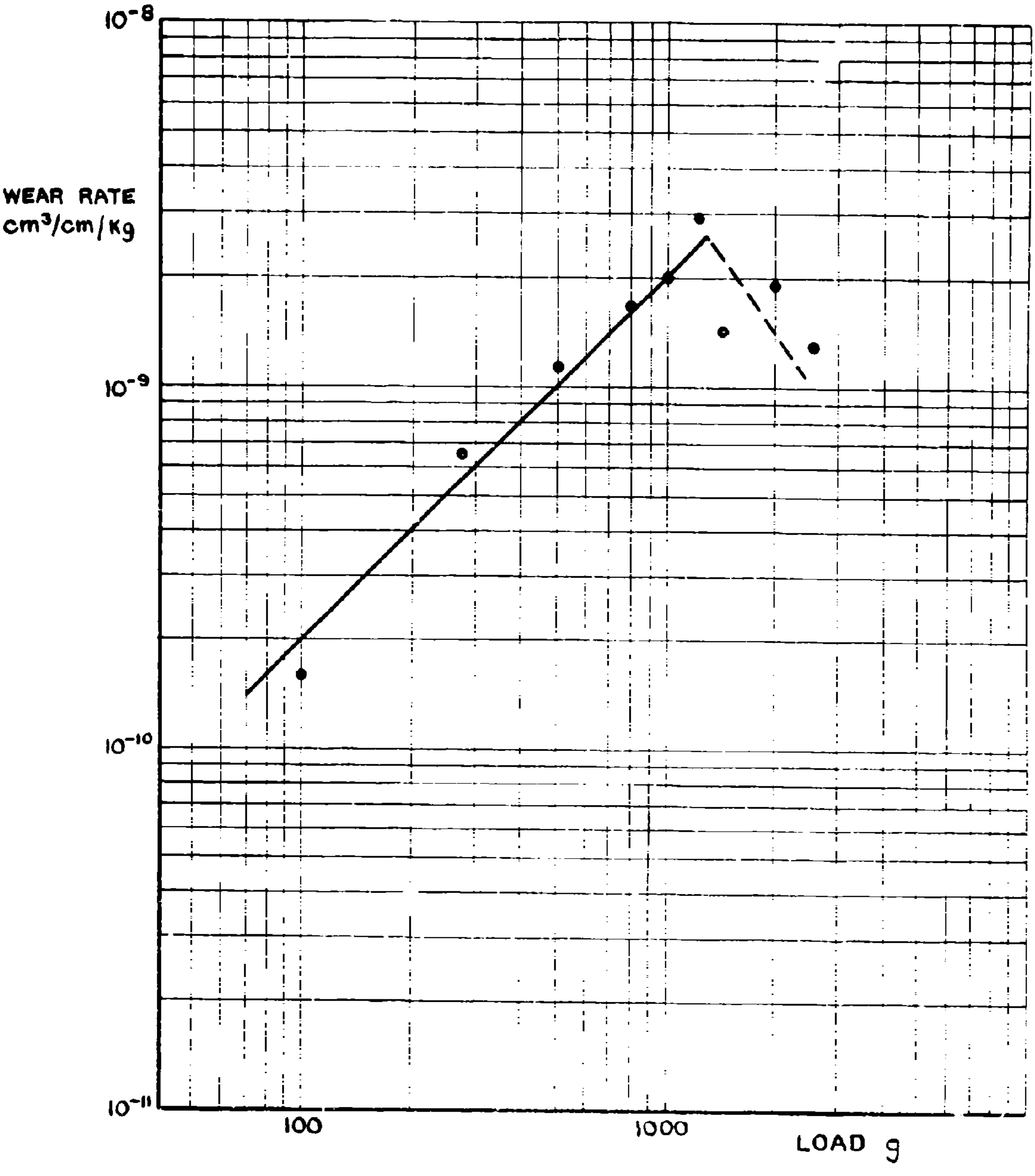


FIG. 6 VARIATION OF THE RATE OF WEAR WITH LOAD FOR BRONZE ON P.T.F.E. WITH MoS_2 (D-14)

Fig.7

014-900011

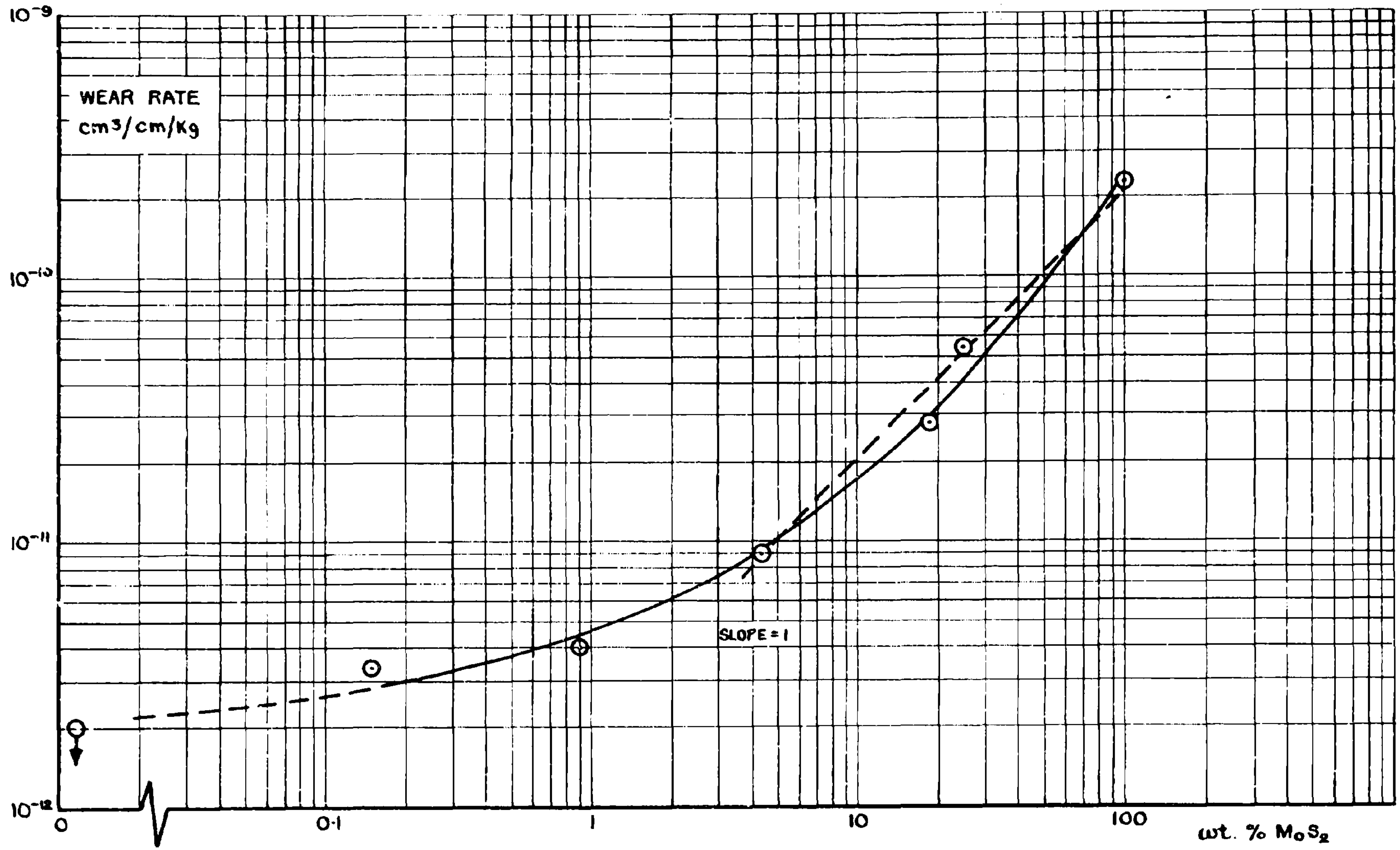


FIG. 7 VARIATION OF THE RATE OF WEAR OF PHOSPHOR-BRONZE ON P.T.F.E. WITH CONCENTRATION OF MoS_2 (D-14) IN 20 c/s SILICONE FLUID

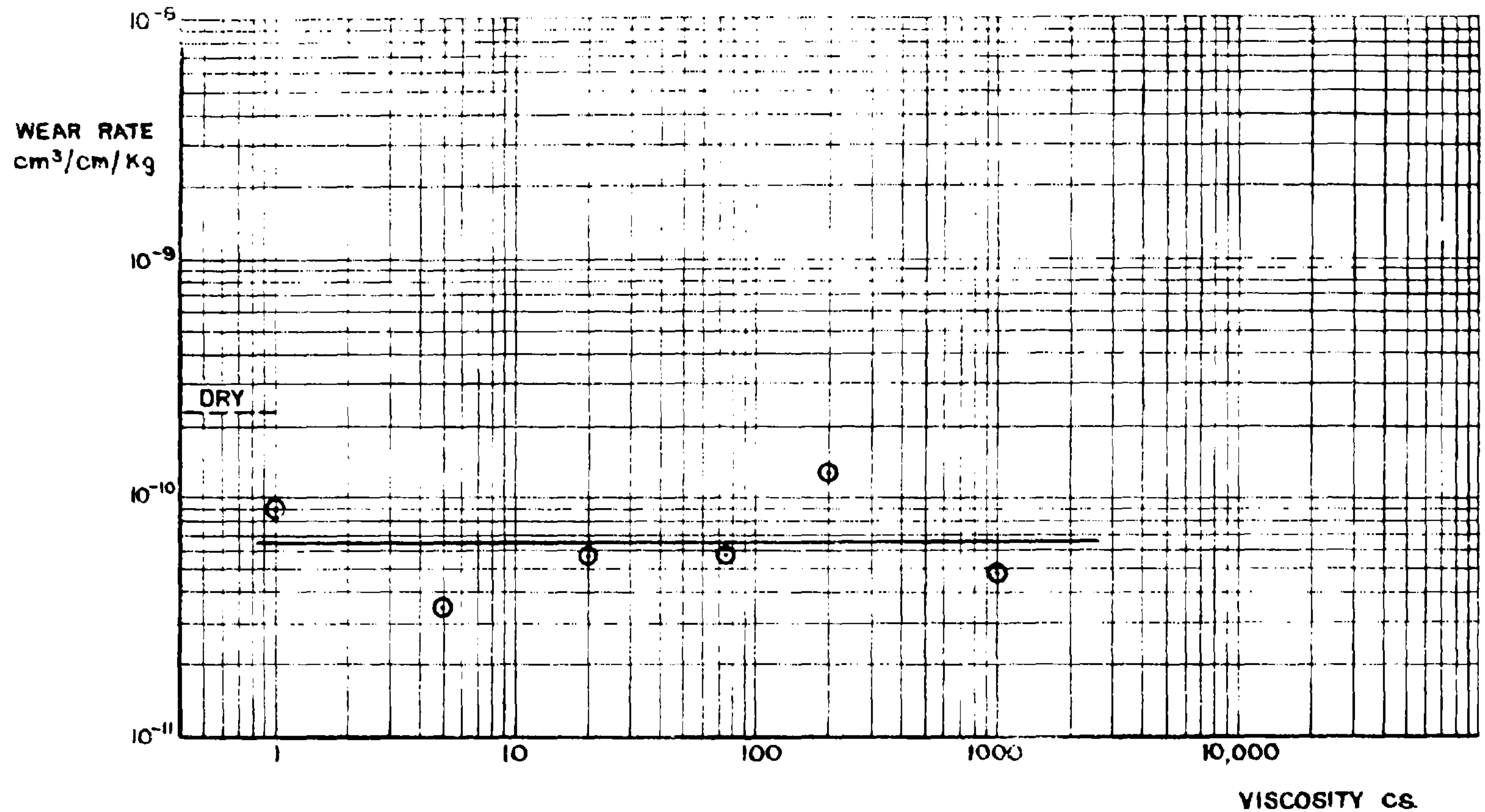


FIG.8 ABRASION OF PHOSPHOR-BRONZE BY MoS_2 (D-14) DISPERSIONS IN SILICONE FLUIDS 20% wt. CONCENTRATIONS

Fig.9

014 900013

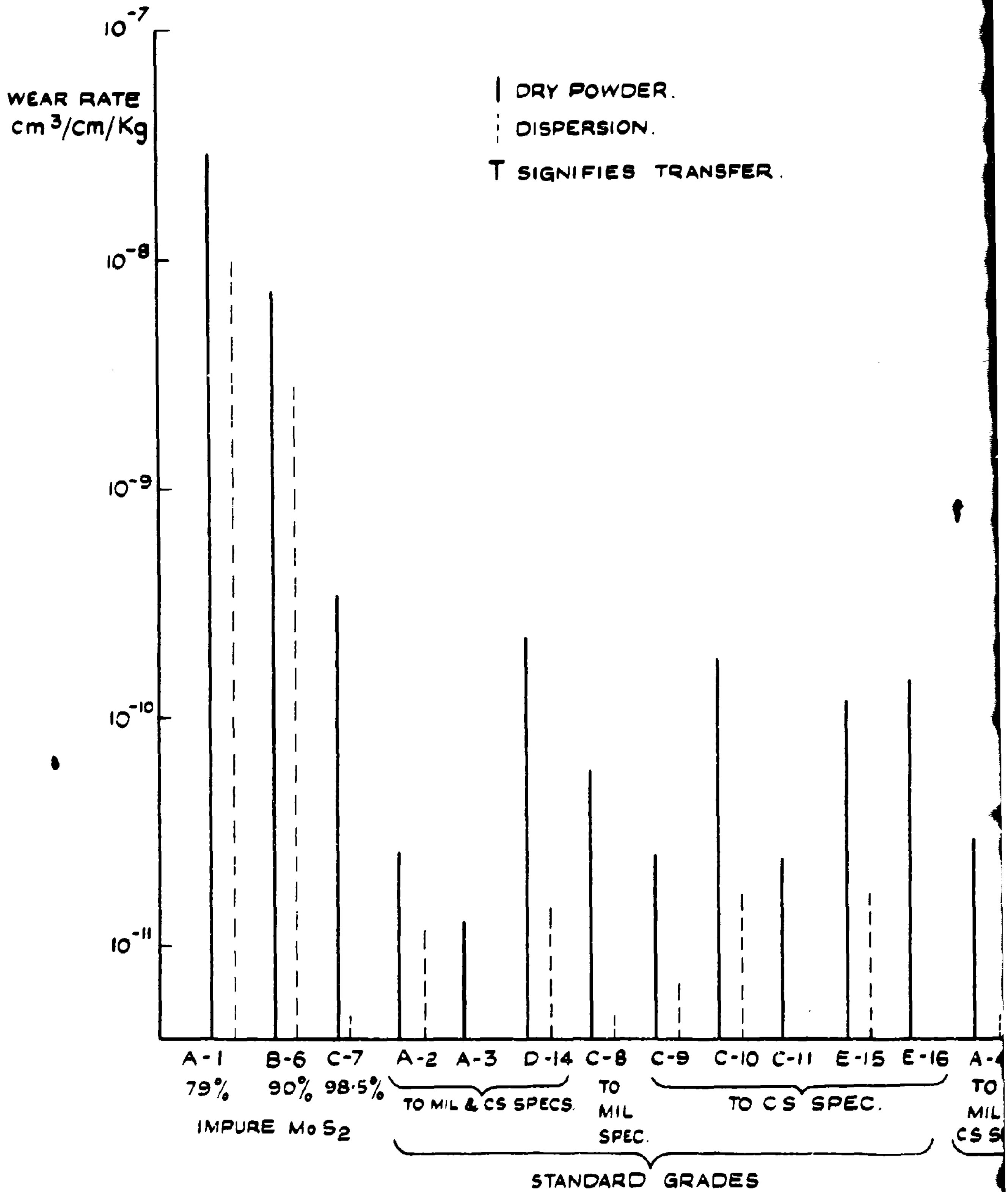
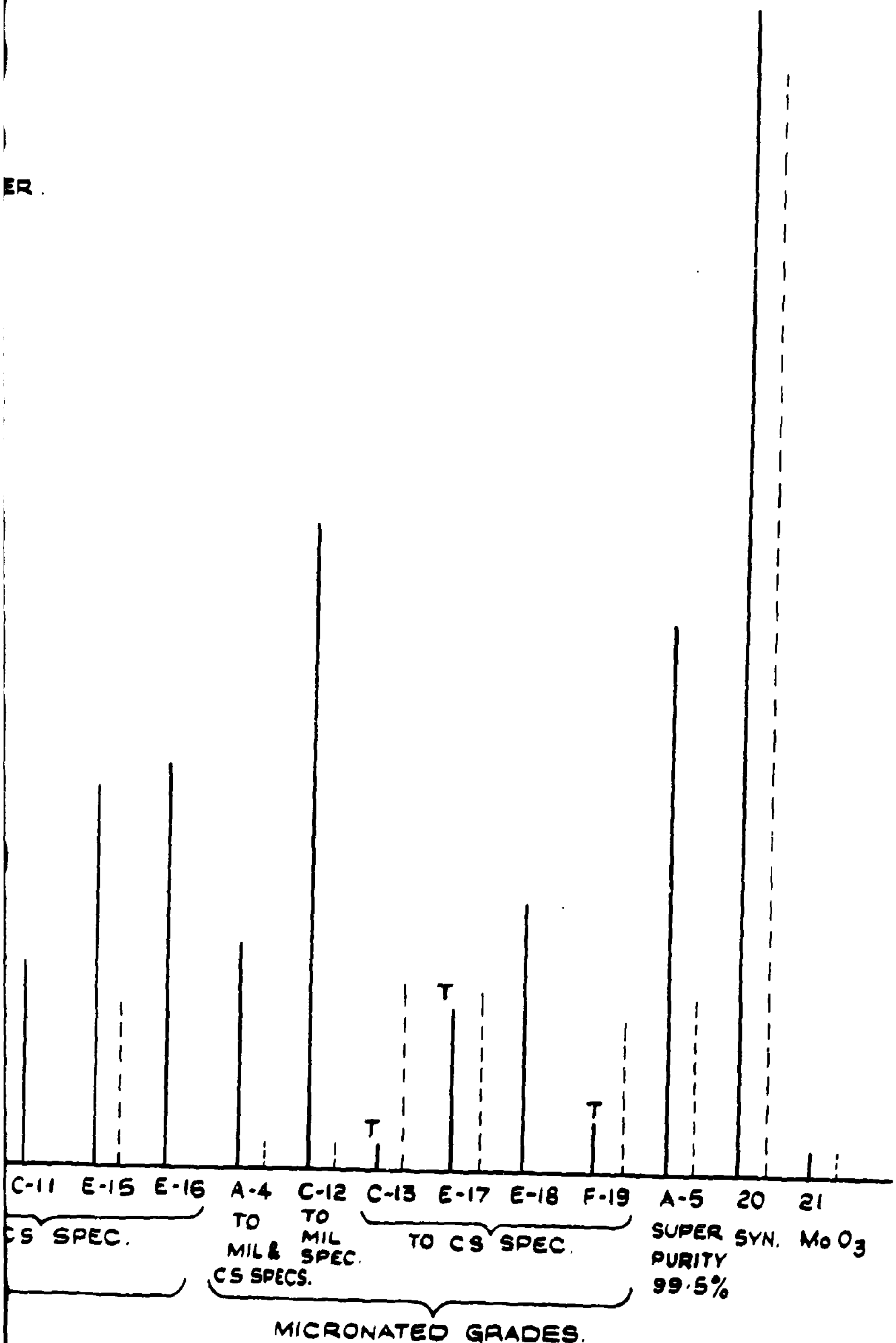


FIG. 9 ABRASION

900013

ER.



ABRASION BY MoS_2

2

Fig.10

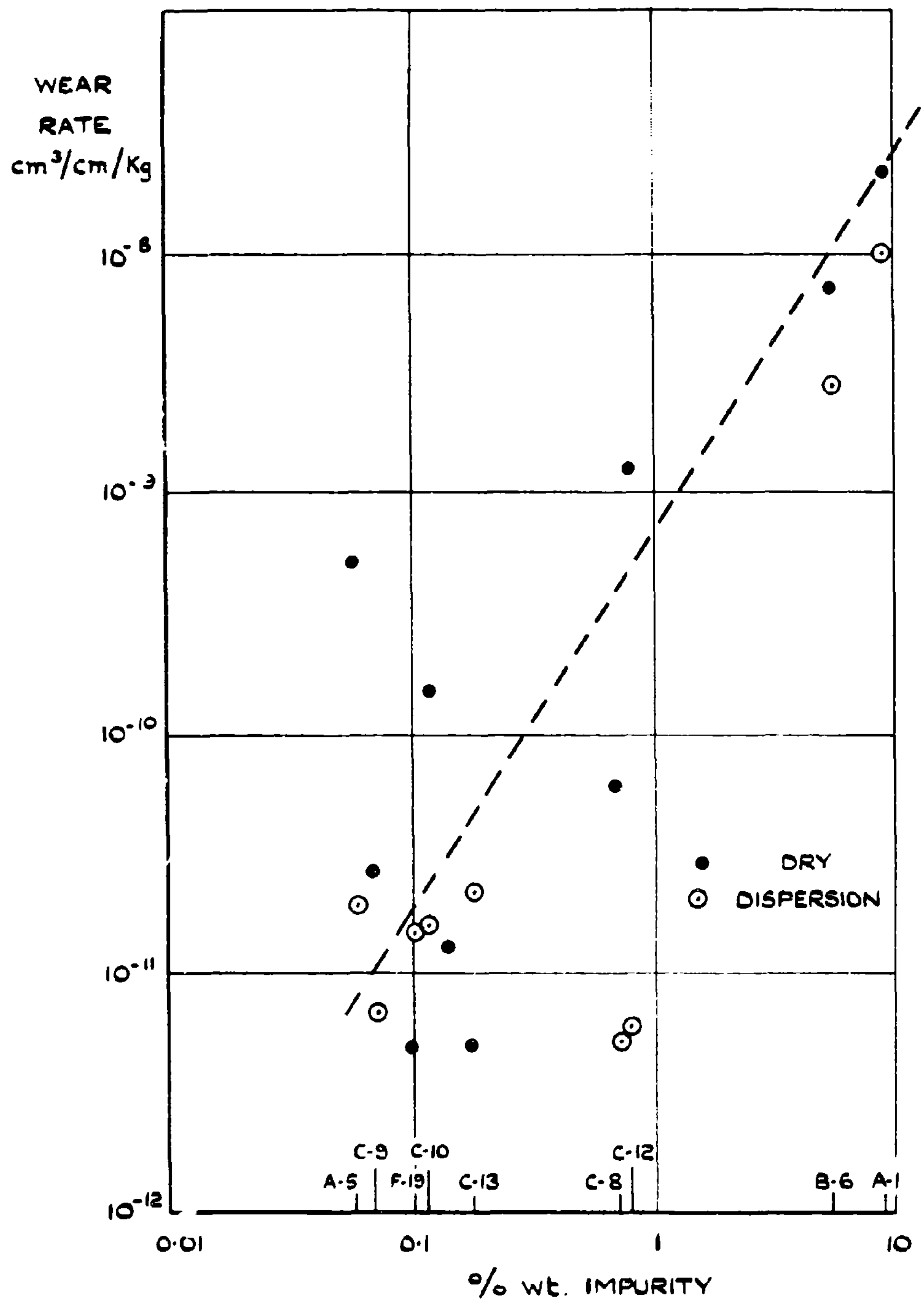


FIG.10 EFFECT OF IMPURITY CONTENT OF COMMERCIAL MoS_2 SAMPLES (Cu, Fe, AND SiO_2) ON THE WEAR OF BRONZE

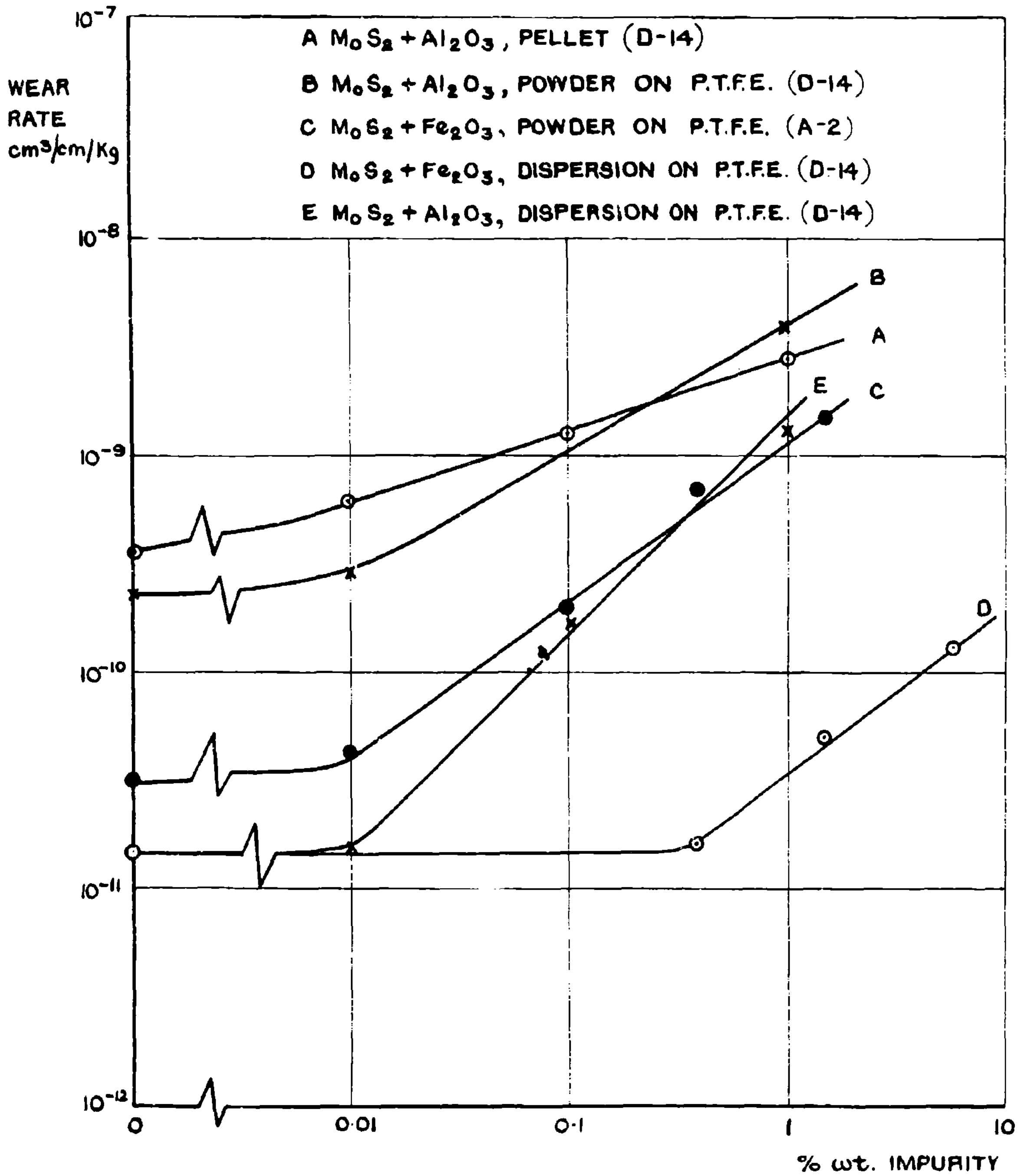


FIG. 11 VARIATION OF THE WEAR RATE OF BRONZE WITH IMPURITY CONTENT OF MoS_2, LOAD = 1 Kg., SPEED $\simeq$ 10 cm./s

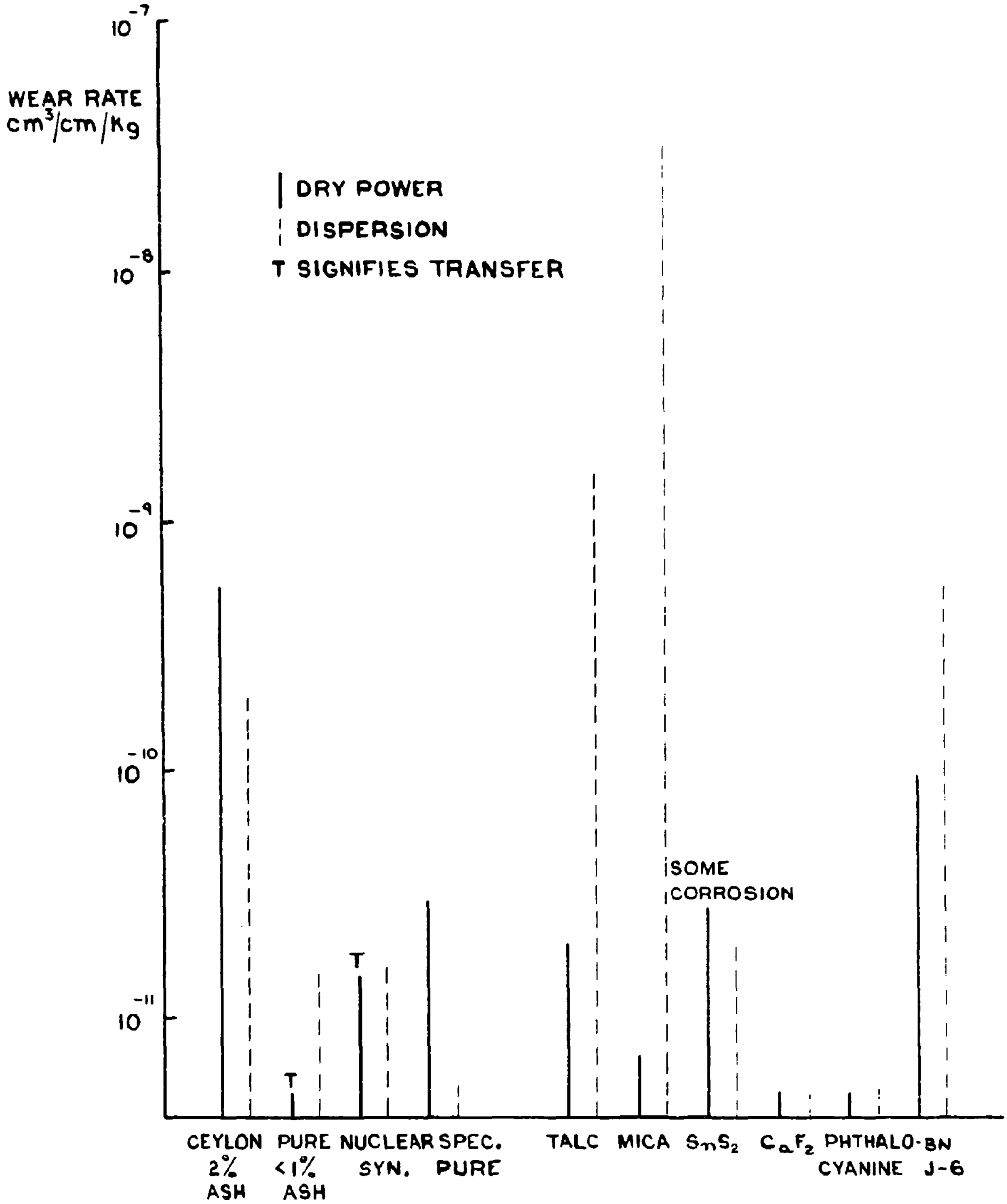


FIG.12. ABRASION BY GRAPHITES AND OTHER LAMELLAR SOLIDS

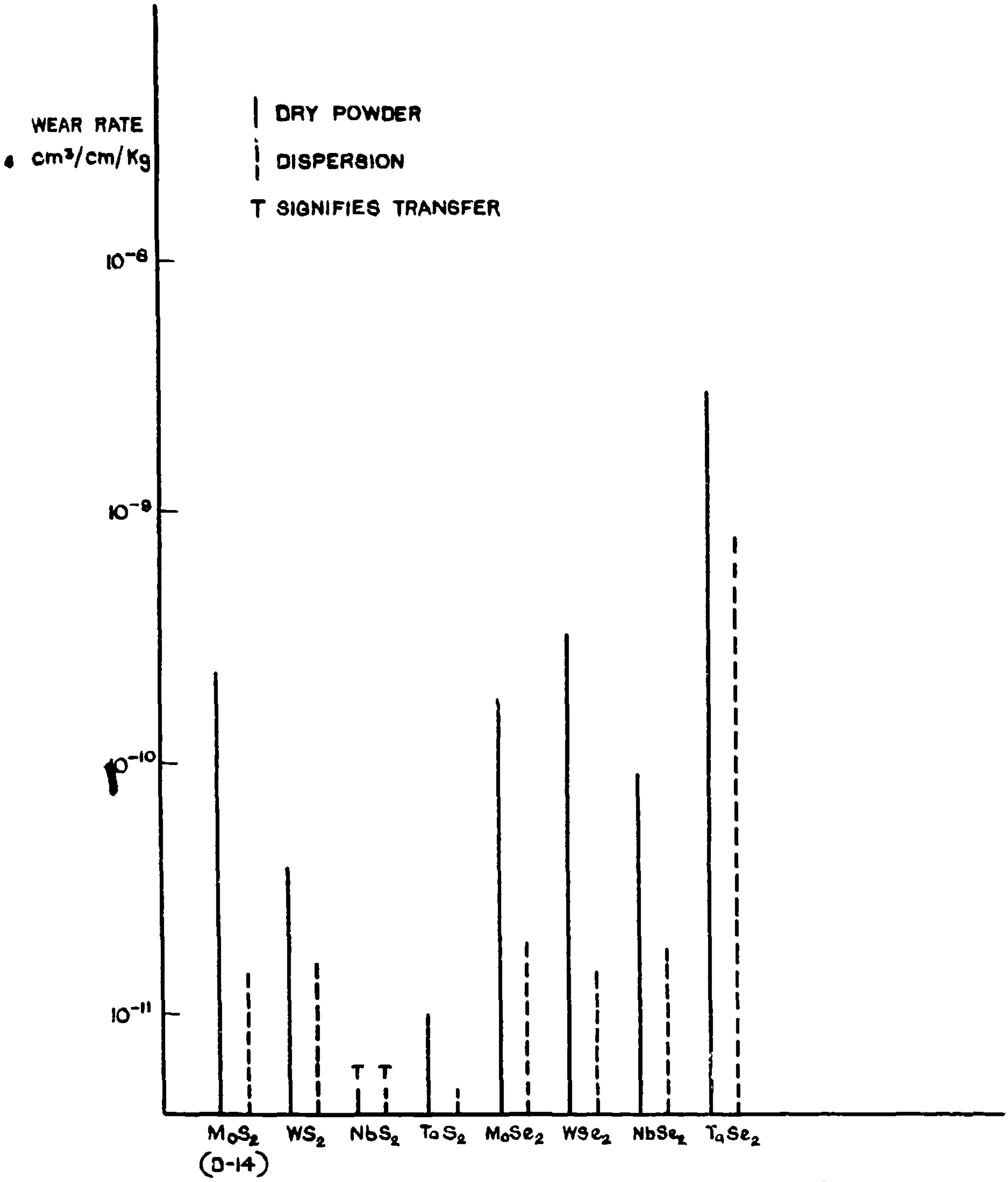


FIG. 13 ABRASION BY CHALCOGENIDES OF Mo, W, Nb, & Ta

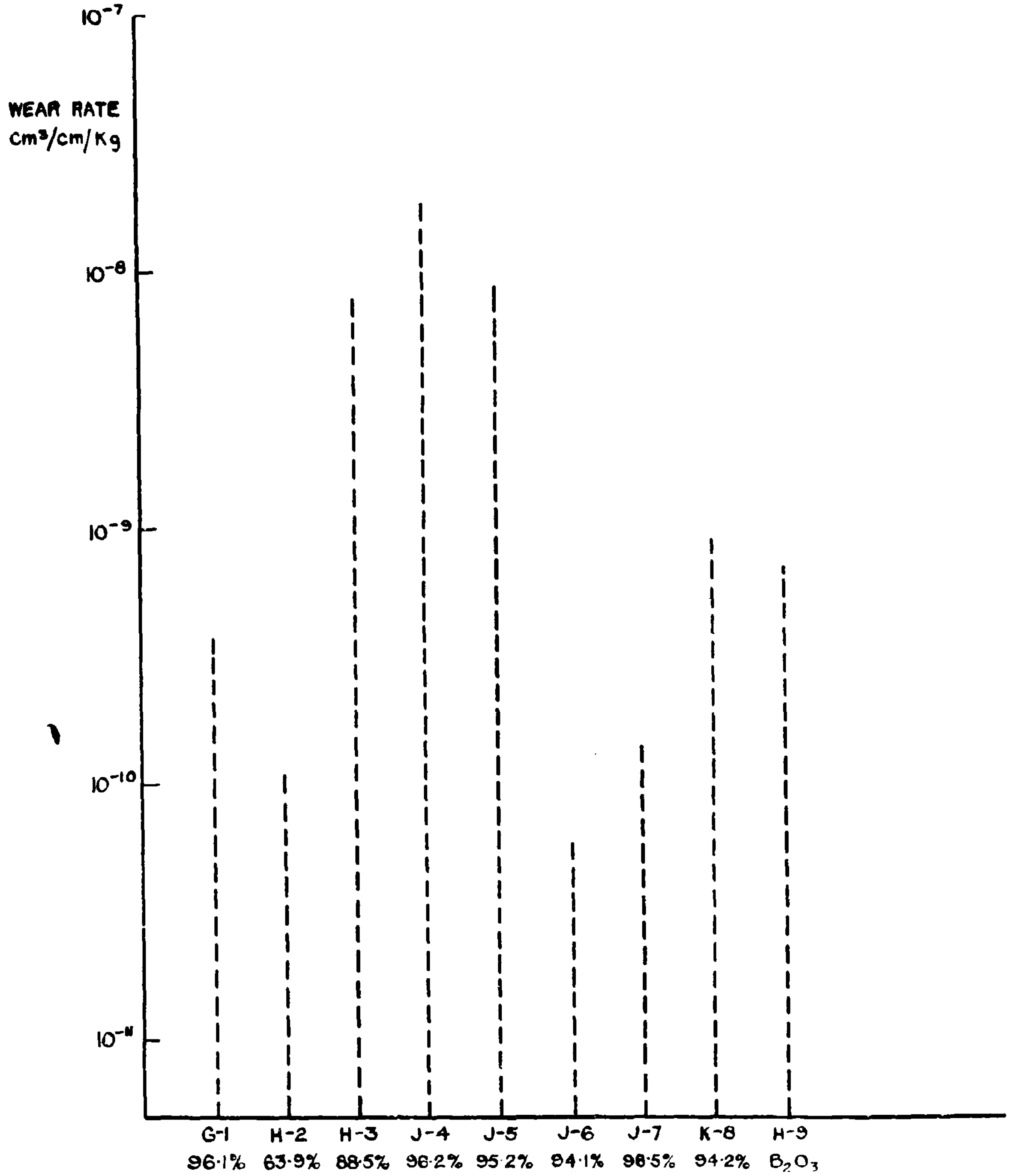


FIG. 14 ABRASION BY BORON-NITRIDE. 10% WT. DISPERSIONS IN 20 c/s SILICONE FLUID

Neg. No. C1536

Fig.15

A. SYNTHETIC × 60000.

B. NATURAL (D-14) × 60000.

Fig.15 ELECTRON MICROGAPHS OF MoS_2

T.R. 66012

DETACHABLE ABSTRACT CARDS

Lancaster, J.K.
Grattan, Patricia A.

ABRASION BY LAMELLAR SOLID LUBRICANTS

Royal Aircraft Establishment Technical Report 66012

539.576 :
539.216 :
621.892.9 :
539.22 :
546.774.2 :
669.35.6.779

January 1966

The extent to which lamellar solid lubricants (graphite, MoS_2, BN, etc) are abrasive has been determined by measuring the rate of wear of phosphor-bronze sliding against PTFE in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder in order to avoid complicating effects due to transfer of the solid lubricant to the sliding surfaces. There are significant differences in the abrasiveness of samples of MoS_2 conforming to standard specifications and it is suggested that the major factor responsible is the degree of perfection of the crystal

/over

Lancaster, J.K.
Grattan, Patricia A.

ABRASION BY LAMELLAR SOLID LUBRICANTS

Royal Aircraft Establishment Technical Report 66012

539.576 :
539.216 :
621.892.9 :
539.22 :
546.774.2 :
669.35.779

January 1966

The extent to which lamellar solid lubricants (graphite, MoS_2, BN, etc) are abrasive has been determined by measuring the rate of wear of phosphor-bronze sliding against PTFE in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder in order to avoid complicating effects due to transfer of the solid lubricant to the sliding surfaces. There are significant differences in the abrasiveness of samples of MoS_2 conforming to standard specifications and it is suggested that the major factor responsible is the degree of perfection of the crystal

/over

Lancaster, J.K.
Grattan, Patricia A.

ABRASION BY LAMELLAR SOLID LUBRICANTS

Royal Aircraft Establishment Technical Report 66012

539.576 :
539.216 :
621.892.9 :
539.22 :
546.774.2:
669.35.6.779

January 1966

The extent to which lamellar solid lubricants (graphite, MoS_2, BN, etc) are abrasive has been determined by measuring the rate of wear of phosphor-bronze sliding against PTFE in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder in order to avoid complicating effects due to transfer of the solid lubricant to the sliding surfaces. There are significant differences in the abrasiveness of samples of MoS_2 conforming to standard specifications and it is suggested that the major factor responsible is the degree of perfection of the crystal

/over

Lancaster, J.K.
Grattan, Patricia A.

ABRASION BY LAMELLAR SOLID LUBRICANTS

Royal Aircraft Establishment Technical Report 66012

539.576 :
539.216 :
621.892.9 :
539.22 :
546.774.2 :
669.35.6.779

January 1966

The extent to which lamellar solid lubricants (graphite, MoS_2, BN, etc) are abrasive has been determined by measuring the rate of wear of phosphor-bronze sliding against PTFE in the presence of the powdered solid. Dispersions in silicone fluid are preferable to dry powder in order to avoid complicating effects due to transfer of the solid lubricant to the sliding surfaces. There are significant differences in the abrasiveness of samples of MoS_2 conforming to standard specifications and it is suggested that the major factor responsible is the degree of perfection of the crystal

/over

structure. This aspect is particularly important for boron nitride and may largely account for its inability to function as an effective solid lubricant.

structure. This aspect is particularly important for boron nitride and may largely account for its inability to function as an effective solid lubricant.

structure. This aspect is particularly important for boron nitride and may largely account for its inability to function as an effective solid lubricant.

structure. This aspect is particularly important for boron nitride and may largely account for its inability to function as an effective solid lubricant.