

Study of hard non-ferrous materials for arduous conditions of rolling contact

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AS OUR technological civilization progresses, ever increasing demands are made on rolling mechanisms and on the materials and lubricants necessary for their successful operation. Advances in some fields such as nuclear engineering, aeronautical and space applications, which all involve extreme operating temperatures and environments, can in many instances be achieved only by substantial improvement of the properties of available materials or by the development and use of improved structural materials. Conventional liquid lubricants are generally unsuitable at elevated temperatures and are lost by evaporation in low pressure environments and therefore some rolling mechanisms must operate without lubrication or be lubricated by solid films or by surface treatments. Under conditions of unlubricated rolling contact, conventional ball bearing steels are not satisfactory and hard, wear resistant materials are required.

Owing to the absence of any recognized code of practice, established specifications or evaluating test procedure, the suitability of materials for unlubricated and elevated temperature application can be established reliably only by performance in practice. As such full-scale testing is expensive and time-consuming, NEL has carried out accelerated service simulation tests to screen hard materials potentially suitable for arduous conditions prior to full scale test. The non-ferrous materials tested were principally sintered carbides. Factors influencing the performance of sintered carbides were also investigated.

Wear resistant surface coatings applied to conventional materials and solid film lubricants, which are easily and cheaply applied, are, for economic reasons, commercially more acceptable than expensive newer materials that may require special manufacturing processes. Various non-ferrous surface coatings and solid film lubricants have been compared with sintered carbides under the same test conditions. As En 31 (1.0% C. Cr) steel for ordinary use and high speed tools for special applications have proved successful as lubricated rolling bearing materials, it appeared worthwhile to assess the performance of hard wear resistant materials and surface coatings by comparison with these materials.

SYNOPSIS

In modern engineering some rolling mechanisms are required to operate without lubrication or be lubricated by solid films or by surface treatments. Hard non-ferrous materials and non-ferrous surface treatments potentially suitable for unlubricated and elevated temperature rolling bearings have been compared by accelerated service simulation tests, wear resistance being assessed by loss of weight.

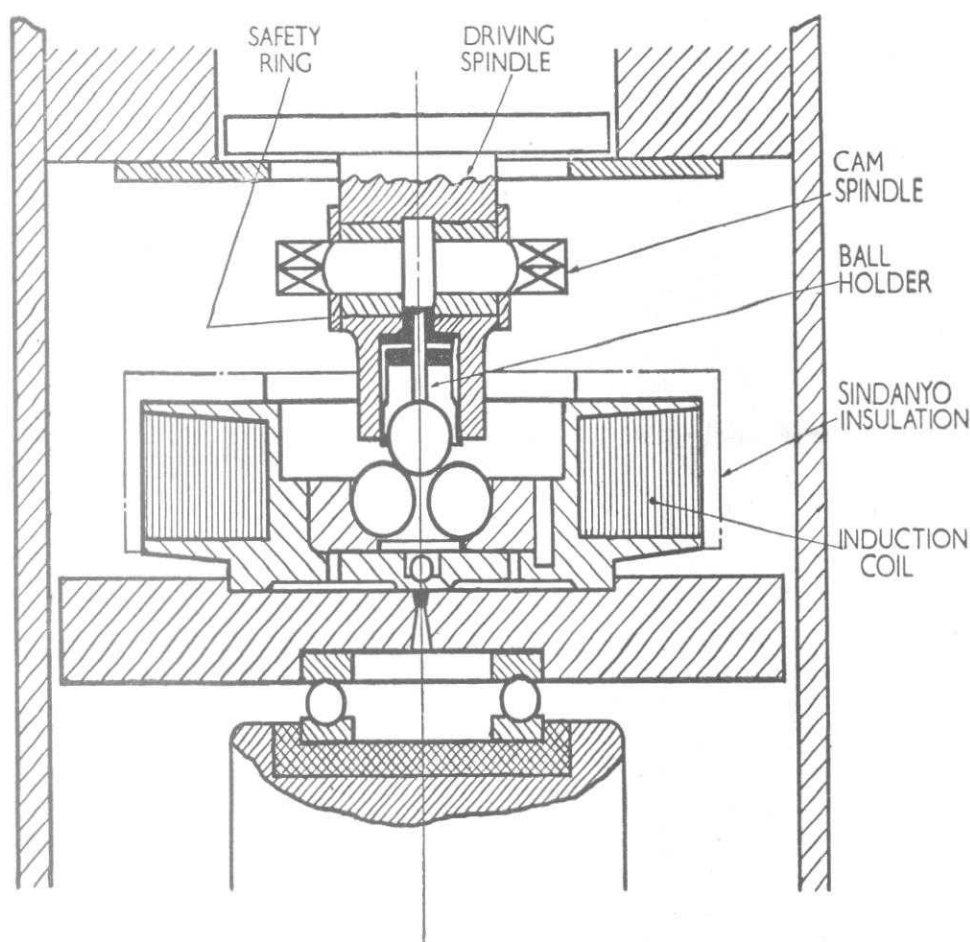
Tungsten carbide was superior to the other materials tested; grain size of the tungsten carbide and the amount of matrix material have a considerable effect on performance. Use of solid lubricants such as MoS₂ can eliminate or reduce wear. Hard facing surface treatments were not effective.

The paper briefly reviews some NEL published work.

Test procedure

The NEL rolling four-ball test consists essentially of a lubricant testing machine in which the upper test ball, held in a chuck, drives three similar balls in a lower race (Fig. 1). It simulates in simple form the rolling and sliding motion experienced in angular contact ball bearings, produces the same type of failure and the results correlate well with those found in practice.¹⁻⁴ For materials not available in ball form, the upper test ball may be replaced by a ball-ended specimen readily manufactured from a small amount of material.⁵ The kinematic arrangement remains essentially unaltered, thus enabling the direct comparison of any material with commercial balls. A simple temperature controlled induction heater permits testing at elevated temperatures.

Under unlubricated rolling contact conditions failure does not occur by the usual surface pitting mechanism, useful life is limited by excessive wear causing vibration and rough, noisy running. Tests are therefore made on a time-basis for thirty minutes; wear being determined by weighing the balls or ball-ended specimens before and after testing. In the present investigation the test conditions were a total axial load of 100 kg at both ambient temperature and at an elevated temperature of 280°C.



1 Diagrammatic arrangement of the rolling four-ball machine

Tests

Some commercially available 12.7 mm ($\frac{1}{2}$ inch) diameter balls were tested. Details of the balls and summarized test results are given in Table I. The mean loss of weight was determined from various numbers of tests up to ten, depending upon availability of test specimens. Dry films of solid lubricants, MoS_2 , WS_2 and PTFE were applied by aerosol spray.

Test at ambient temperature showed that tungsten carbide balls gave the best performance of the commercially available balls tested. Tungsten carbide also gave the best performance at 280°C and was the only material comparatively unaffected by the elevated temperature; all others sustained increased wear. Use of dry film solid lubricant was highly beneficial in preventing or reducing wear. Molybdenum disulphide was the most effective lubricant tried; it eliminated wear of tungsten carbide and high speed tool steel balls and considerably reduced wear of conventional En 31 steel balls. It is of interest to note that WS_2 was not effective with tungsten carbide but was effective with balls of other materials. In practice replenishment of a dry film may be required to ensure adequate life of the rolling elements and may be effected from a specially compounded cage containing the lubricant.⁶

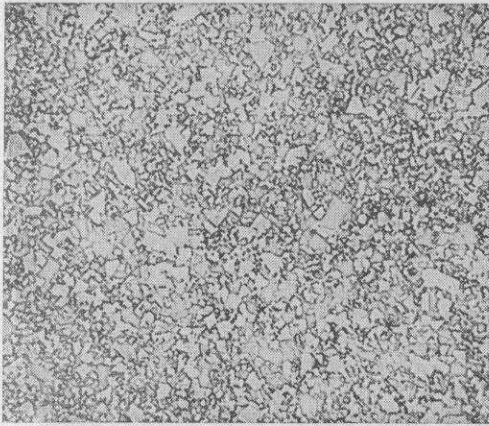
Batches of ball-ended specimens were manufactured in different types of sintered carbide. The specimens,

manufactured slightly oversize, were carefully diamond-polished to a surface finish and dimensional accuracy comparable with commercial grade A balls. To assess the effect of composition and carbide size on the wear, the specimens were tested in comparison with new commercial tungsten carbide balls. Details of composition, carbide size and summarized test results are given in Table I. Photomicrographs of the different types of specimens are shown in Fig. 2. Some comparative electron micrographs are shown in Fig. 3.

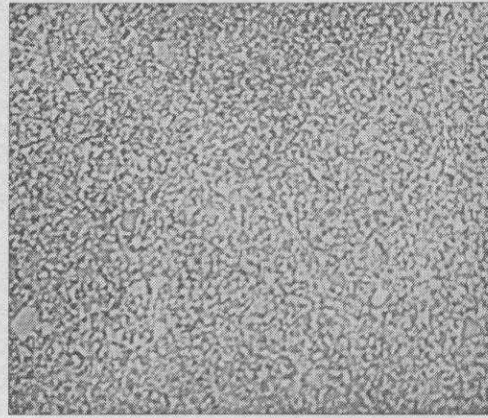
From the results, wear of tungsten carbide appears to increase with the increase of both carbide size and percentage of matrix material.

Very hard wear resisting materials are usually expensive and difficult to manufacture and form. Considerable economy can be effected and manufacturing difficulties alleviated if hard wear resistant materials can be used as surface coatings on components manufactured in conventional materials. Ball-ended specimens in En 31 steel, hard surfaced with various thicknesses of tungsten carbide and molybdenum have been assessed for wear resistance when running against En 31 steel bottom balls. The coated specimens were carefully diamond-polished to a surface finish and dimensional accuracy comparable with those of commercial grade A balls. Summarized test results are given in Table I.

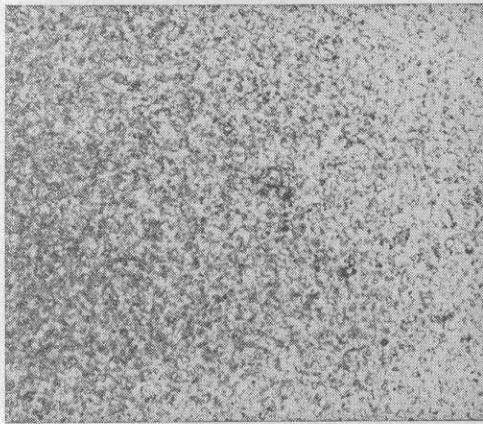
Under the conditions of test the tungsten carbide



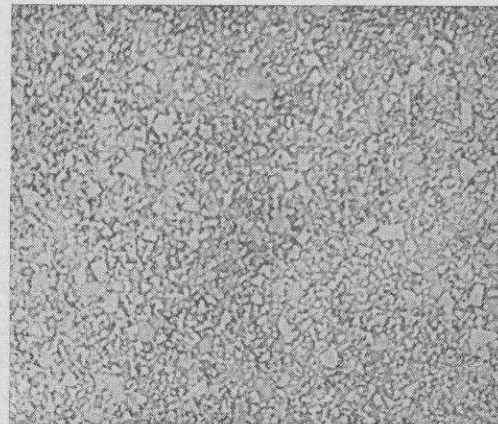
(a) Commercial tungsten carbide ball



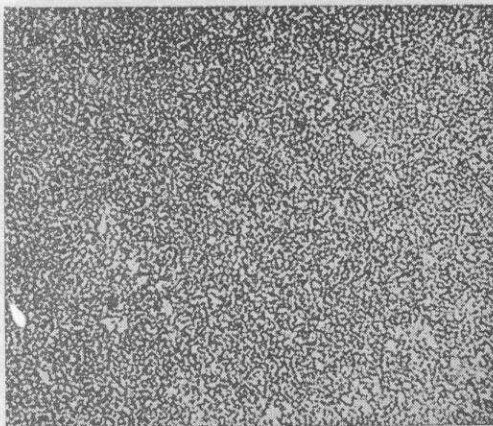
(d) Tungsten carbide, medium grain + 6% Co



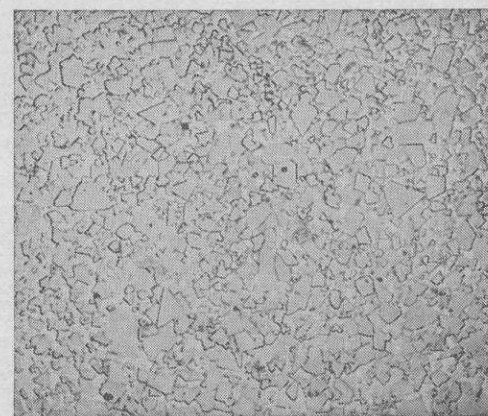
(b) Tungsten carbide, fine grain (1μ) + 11% Co



(e) Tungsten carbide, medium grain + 11% Co



(c) Tungsten carbide, fine grain + 6% Co



(f) Tungsten carbide, coarse grain + 11% Co

2 Structures of cemented carbides etched with Murakami's reagent $\times 680$



(a) WC fine grain (1μ size) + 11% Co



(c) WC coarse grain + 11% Co



(b) WC + TiC + 6% Co

3 Structure of cemented carbides ; electron micrographs of two-stage carbon replicas

× 500

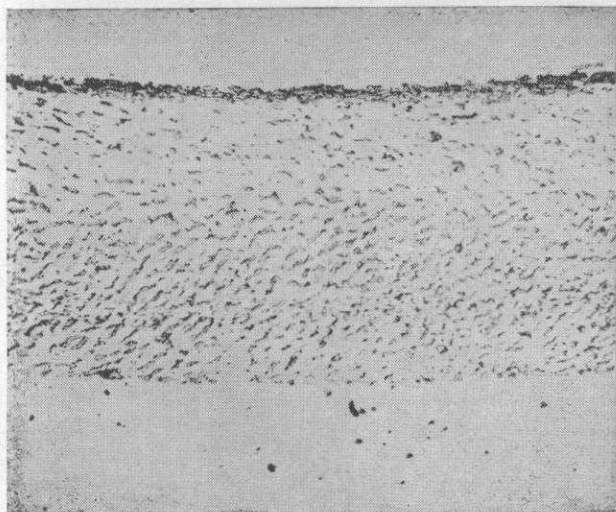
and molybdenum coated En 31 steel compared poorly in wear resistance with sintered tungsten carbide.

Evaporated films of soft non-ferrous metals, gold, silver and nickel were tested as lubricants on various materials. Although of some benefit in reducing wear at ambient temperatures, they were only of slight benefit in reducing wear at 280°C . The nickel film appeared to be the most effective. Under the conditions of test phosphating and sulphurizing treatments were not effective. These treatments tend to roughen the surface of rolling element which appears to facilitate wear initiation. Newer non-ferrous materials such as silicon nitride and boron carbide are included in the

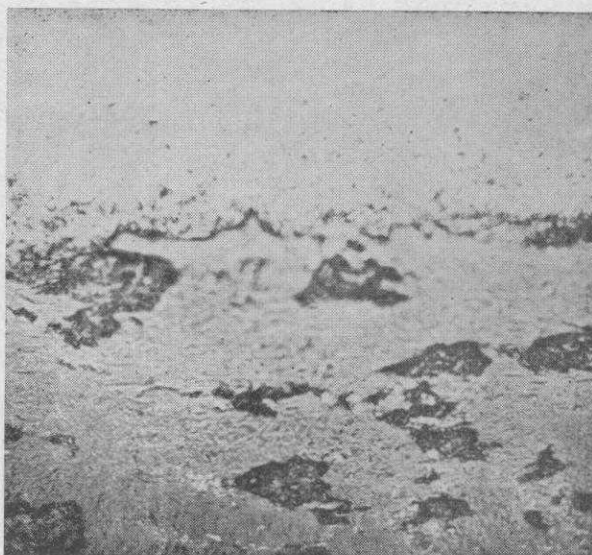
present series of hard materials being assessed as potential unlubricated rolling elements.

Examination of failed specimens

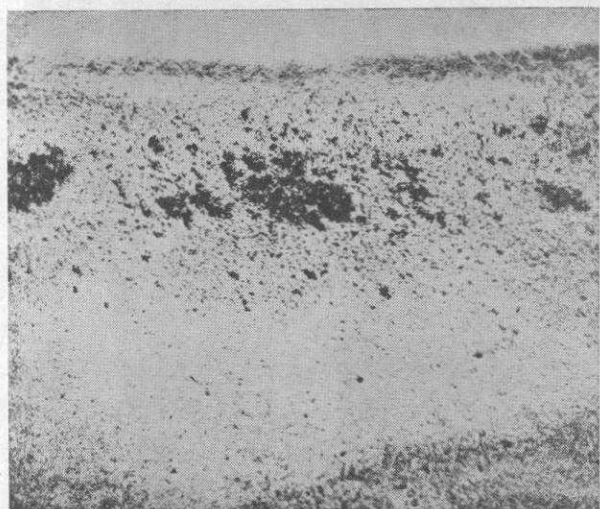
Selected failed test specimens have been investigated metallurgically as an aid to the elucidation of the mechanisms of failure and the controlling factors. Under conditions of unlubricated rolling contact, scuffing and wear of the contacting surfaces take place.⁷ The debris, which may oxidize, appears to be rolled on to the bearing surface. The cumulative effect of these phenomena causes rough noisy running and vibration



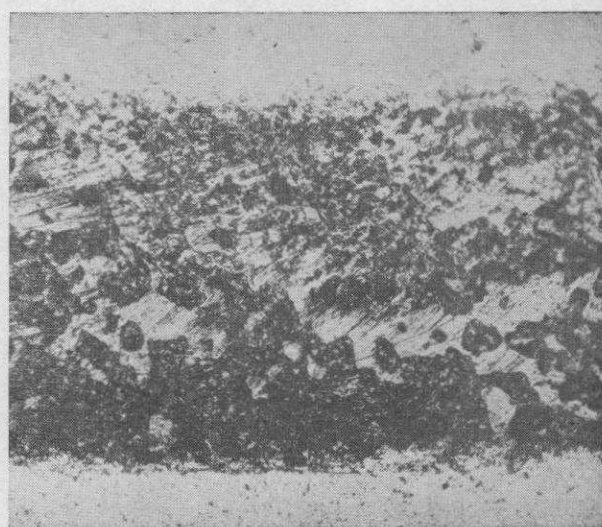
(a) Bearing track of a fine grained WC specimen ; no weight loss at ambient temperature $\times 100$



(c) Wear damage of coarse grained WC specimen $\times 410$



(b) Bearing track of fine grained WC specimen tested at 280°C $\times 100$



(d) Debris on bearing surface of commercial WC ball $\times 110$

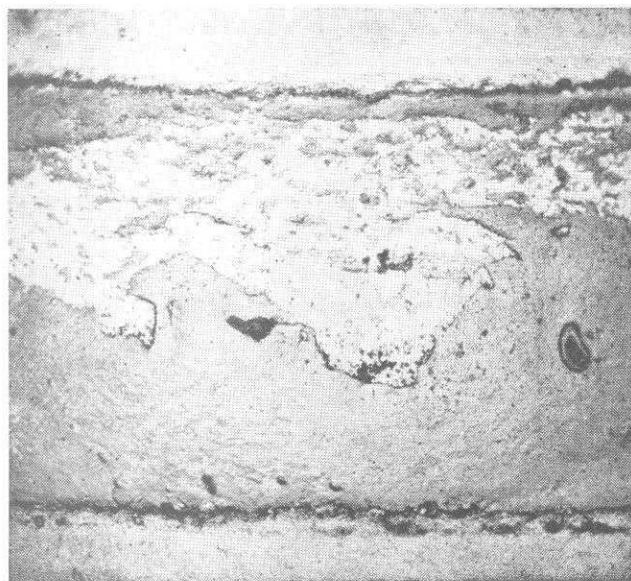
4 Surface damage of tungsten carbide specimen

which terminates the useful bearing life. Deformation and metallographic change of surface material also occur.

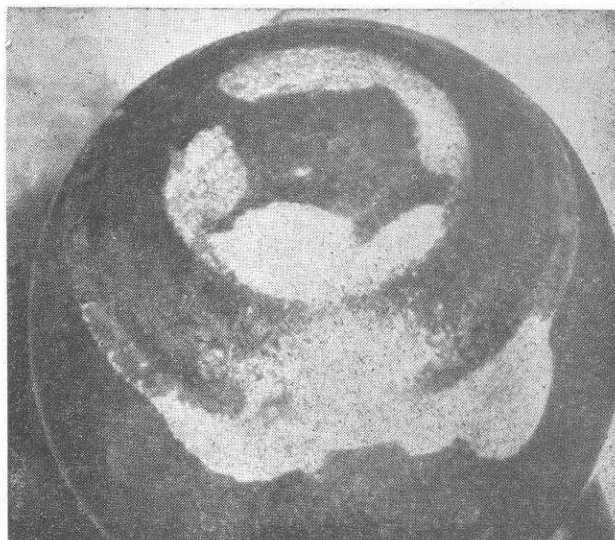
Fig. 4a shows the bearing track of a fine-grained tungsten carbide specimen which had suffered no loss of weight by tests at ambient temperatures. Some fine damage was observed in similar specimens tested at 280°C , Fig. 4b. Wear damage, typical of coarse-grained tungsten carbide is shown in Fig. 4c whilst oxidized

flakes, of debris rolled on to the surface of a commercial tungsten carbide ball, are shown in Fig. 4d. The molybdenum disulphide film which had prevented wear of tungsten carbide is shown in Fig. 5a.

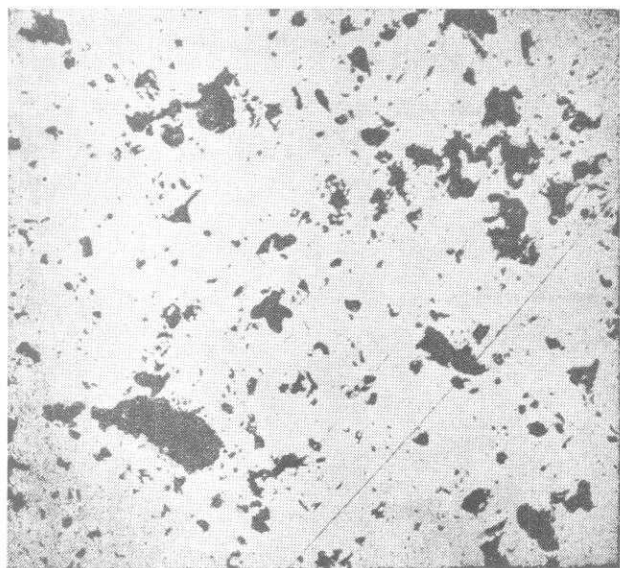
Although hard surface specimens were carefully polished to provide a surface finish comparable with commercial grade A balls, porosity was evident in all coatings (Fig. 5b). Under the conditions of test the coatings generally disintegrated by flaking (Figs. 5c and 5d).



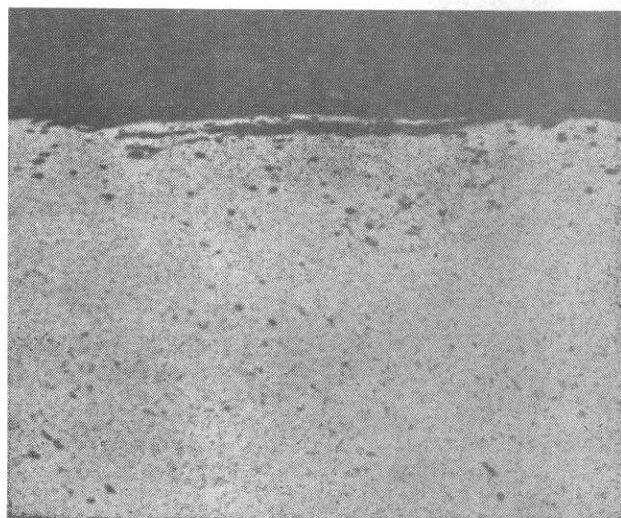
(a) Partially broken film of MoS_2 on the bearing surface of a WC ball after test at 280°C $\times 110$



(c) Disintegration and flaking of a WC coating due to dry running $\times 6$



(b) Surface of a WC coated specimen $\times 200$



(d) Section through WC coating showing flaking of surface material $\times 250$

5 Surface coatings

Discussion and conclusions

Under arduous conditions in the absence of a liquid lubricant, the useful life of rolling elements is limited by wear. Under unlubricated test conditions tungsten carbide balls were superior to other types of commercially available balls tested both at ambient and elevated temperatures. Grain size as well as the amount of

matrix material can have a dominant effect on performance. The trend is for improved wear resistance with reduction of both carbide size and percentage of matrix material. Cheaper substitute hard facings for sintered carbides were not successful due to rapid disintegration by flaking of the hard deposits. The use of a solid film lubricant eliminates or considerably reduces wear and is therefore beneficial.

TABLE I Wear tests on different materials and surface treatments

Specimen		Mean loss of weight of upper test specimen (mg)				
		At ambient temperature	At 280°C	With MoS ₂ at 280°C	With WS ₂ at 280°C	With PTFE at 280°C
Commercially available balls	En 31 (1.0% C Cr) steel	20.3	59.0	0.5	0.1	14.7
	M 10 (8-4-2 Mo Cr V) high speed tool steel	26.1	46.0	Nil	Nil	4.8
	18-4-1 (W Cr V) high speed tool steel	11.7	40.2	Nil	0.2	10.2
	M 50 (4-4-1 Mo Cr V) high speed tool steel	43.8	50.8	Nil	—	—
	Stellite	181.1	455.1	Nil	—	—
	Tungsten carbide	7.0	7.8	Nil	7.0	2.0
Ball-ended specimens	Tungsten carbide, fine grain (1μ)+11% Co	0.3	1.1	Nil	—	—
	Tungsten carbide, fine grain+6% Co	Nil	1.0	Nil	—	—
	Tungsten carbide, medium grain+6% Co	0.8	3.8	Nil	—	—
	Tungsten carbide, medium grain+11% Co	4.4	7.8	Nil	—	—
	Tungsten carbide, coarse grain+11% Co	14.0	15.0	Nil	—	—
	Tungsten carbide+titanium carbide+6% Co	5.6	12.0	Nil	—	—
Ball-ended specimens	Tungsten carbide (0.005 in) coated En 31 steel	70.0	—	—	—	—
	Tungsten carbide (0.015 in) coated En 31 steel	311.0	—	—	—	—
	Molybdenum coated (thick) En 31 steel	478.0	—	—	—	—

— : No test

Acknowledgements

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