Wear 271 (2011) 1264–1272

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Abrasive wear behaviour of conventional and large-particle tungsten carbide-based cermet coatings as a function of abrasive size and type

Z. Kamdi [a,c,*], P.H. Shipway [a], K.T. Voisey [a], A.J. Sturgeon [b]

[a] Division of Materials, Mechanics and Structures, Faculty of Engineering, The University of Nottingham, University Park, Nottingham NG7 2RD, UK
[b] Genesis Oil and Gas Consultants Ltd. London, UK
[c] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 1 September 2010
Received in revised form
15 December 2010
Accepted 15 December 2010

Keywords:
Hardmetal
Dry sand-rubber wheel
Micro-scale abrasion
WC-Co
ASTM G65

ABSTRACT

Abrasive wear behaviour of materials can be assessed using a wide variety of testing methods, and the relative performance of materials will tend to depend upon the testing procedure employed. In this work, two cermet type coatings have been examined, namely (i) a conventional tungsten carbide-cobalt thermally sprayed coating with a carbide size of between ~0.3–5 μm and (ii) a tungsten carbide-nickel alloy weld overlay with large spherical carbides of the order of ~50–140 μm in diameter (DuraStell). The wear behaviour of these two materials has been examined by the use of two abrasion tests, namely the micro-scale abrasion test using both silica and alumina abrasives (typically 2-10 μm in size), and the dry sand-rubber wheel test (ASTM G65), again with both silica and alumina abrasives (typically 180–300 μm in size). It was found that when the abrasive particles were of the same scale or larger than the mean free path between the hard phase particles, then the matrix phase was well protected by the hard phases. Testing (in both test types) with alumina abrasives resulted in wear of both the hard carbide phases and the matrix phases in both the thermally sprayed coating and the weld overlay, with the thermally sprayed coating exhibiting lower wear rates. The wear behaviour of the materials with the more industrially relevant silica abrasive was more complex; the thermally sprayed coating exhibited a lower wear rate than the weld overlay with the fine abrasive in the micro-scale abrasion test due to effective shielding of the matrix from abrasive action due to the fine reinforcement particle size. In contrast, with the coarser silica abrasive in the dry sand-rubber wheel test, the weld overlay with the large carbides was able to provide matrix protection with low rates of wear, whereas the thermally sprayed coating wore by fracture of the more brittle microstructure. These findings demonstrate the importance of selection of appropriate laboratory test procedures and abrasives to simulate behaviour of materials in service environments.

1. Introduction

Material removal caused by hard particles in lateral motion across a surface is known as abrasive wear [1]. According to Eyre [2], 50% of wear in industry is caused by abrasion, and as such, much laboratory work has been carried out to understand wear behaviour in wide range of materials with wear tests such as the dry sand-rubber wheel test, the micro-scale abrasion test and the pin-on-drum sliding abrasion test. Hutchings [3] described two broad mechanisms of abrasive wear, dominated by plastic deformation and brittle fracture respectively. *Two-body* and *three-body* are distinct terms used in describing the mode of abrasive wear; in two-body abrasion, abrasive particles move across the surface but are constrained not to rotate whereas in three-body abrasion, the abrasive particles are free to rotate. Three-body abrasion is generally encountered when the abrasive moves freely between two opposed surfaces in relative motion [1,3]. In wear tests with loose abrasive particles, the abrasive is normally a third body between two surfaces (one of these being the testpiece) but the particles can either groove across the testpiece (being temporarily embedded in the counterbody) or roll across the surface, depending upon the conditions of the test and the materials being abraded [4,5]. Thus, as suggested by Trezona et al. [6], the terms "grooving" and "rolling" will be used to describe abrasive motion.

Micro-scale abrasion is a technique that is gaining wide acceptance for the wear testing of coatings and surface engineered materials [7]. This test allows the abrasion behaviour of a small sample to be examined, and allows the controlled use of fine abrasive particles in a slurry [8]. In addition, it also allows the wear behaviour of thin coatings and layers to be studied independently of the influence of the underlying material [9]. Much previous work has studied the effect of test parameters including ball type

* Corresponding author. Tel.: +44 115 8466407; fax: +44 115 951 3764.
E-mail address: emxzk@nottingham.ac.uk (Z. Kamdi).

0043-1648/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2010.12.060

[10], slurry concentration [11–13], abrasive angularity [14], load [13,15] and abrasive type [13,16,17]. The test is commonly used with abrasives in the size range 2 μm to 10 μm, but larger abrasives (~250-300 μm) have also been used [18]. However, three-body abrasion testing with abrasives in this larger size range is more commonly conducted with the dry sand-rubber wheel (DSRW) test. The DSRW test simulates low stress three-body wear which typically occurs in a range of industrial applications such as linkages, pivot pins and wire ropes in the mining industry. Both the micro-scale abrasion test and the DSRW test are thus used in this study to understand the effect of test type (and particularly abrasive size and type) on wear behaviour.

Much work on characterizing the wear properties of hardmetal and cermet coatings has been conducted. The main parameters influencing the properties of such coatings are carbide grain size, carbide volume fraction and binder mean free path [19,20]. The abrasive wear rate is found to increase with increasing carbide grain size when examined with abrasive that is slightly larger than the carbide itself [21–24]. A study on the addition of WC to a nickel-based coating demonstrated that increasing the carbide content resulted in a decrease in the wear rate as the carbide prevented abrasive penetration into the surface [25]. Van Acker et al. [26] conducted abrasion tests on a nickel alloy reinforced with much larger carbides (between 30 μm to 150 μm) and observed preferential wear of the nickel alloy surrounding the WC particles, but with no significant dependence of wear rate on the carbide particle size. Neville et al. [27] studied the erosion-corrosion performance of a 65wt% carbide reinforced nickel-self fluxing alloy with four different carbide sizes ranging from 45 μm to 180 μm. As binder extrusion dominated the erosion behaviour, the material with the larger carbide exhibited the highest erosion-corrosion rate since this material exhibited the highest binder mean free path.

In the current work, the wear behaviour of two carbide-reinforced materials with very different microstructural scales was examined. The materials were a WC-Co thermally sprayed coating (carbide size ~0.3–5 μm) and a weld overlay coating with much larger carbide size (~50 - 140 μm). The abrasion behaviour of these materials was examined using abrasive particles also with very different scales (180 - 300 μm in the DSRW test and 2–10 μm in the micro-scale abrasion test), with two abrasive types with very different levels of hardness (alumina and silica).

2. Experimental procedure

2.1. Materials properties

The wear behaviour of two types of WC-based coatings has been examined using both the micro-scale abrasion test and the DSRW abrasion test; in addition, mild steel has been included in the testing programme as a reference material. The compositions of the coating feedstock are WC-17wt% Co and W_xC-35wt% Ni alloy. Both coatings were prepared and supplied by external vendors; the thermally sprayed WC-Co coating (hereafter termed *TSWC*) was deposited by high velocity oxy-fuel (HVOF) spraying, and the W_xC-35wt% Ni alloy was weld deposited, being marketed under the name DuraStell (Deloro Stellite, UK). The coatings have been characterised using a Philips XL30 scanning electron microscope (SEM) and a Siemens D500 X-ray diffractometer (XRD). Vickers hardness tests were carried out using a Mitutoyo microhardness tester (with a 300 gf load). For each sample type, ten indentations were made from which the average hardness was calculated. All indentation tests were performed on samples which had been ground and finally polished with 1 μm diamond abrasive. The volume fraction of the carbide in each of the deposits has been determined using quantitative analysis of backscattered electron images produced via SEM at magnifications which allowed the carbide particles to be readily measured.

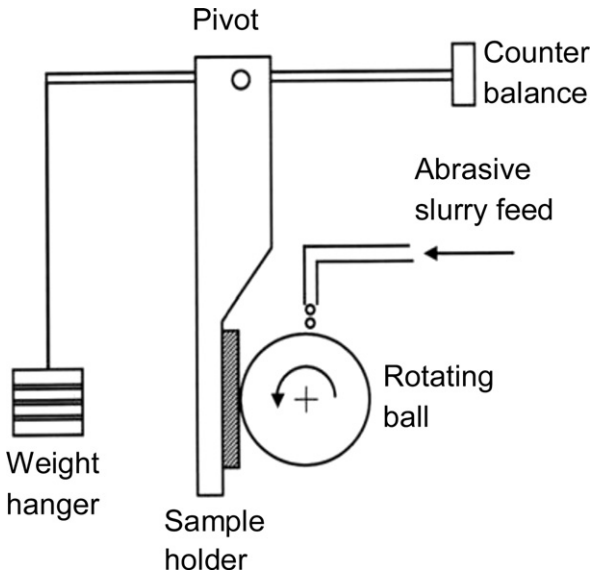

Fig. 1. Schematic diagram of the micro-scale abrasion apparatus.

2.2. Wear testing

2.2.1. Micro-scale abrasion test

Micro-scale abrasion testing was performed using a block-on-ball geometry with a commercially available apparatus, the TE66 Micro-scale Abrasion Tester (Phoenix Tribology Ltd., UK). A schematic diagram of the apparatus is shown in Fig. 1. In this test, the sample is loaded against the ball (using a dead-weight); the ball is rotated about a horizontal axis parallel to the plane of the specimen surface whilst abrasive slurry is dripped onto the ball and specimen resulting in wear of the specimen. Specimen wear results in an indentation, which generally takes the form of a spherical cap with geometry similar to that of the ball. The samples were tested at a range of sliding distances up to 80 m with a constant load of 0.2 N. In order to ensure reproducibility, tests at each sliding distance were performed three times. Following a wear test, the sample was removed from the apparatus and the wear crater dimensions measured using a Talysurf CLI 1000 profilometer (Taylor Hobson Ltd., UK). The scars were traversed using a contact probe with spacing of data points of 1 μm in the scan direction and with a 10 μm spacing between adjacent traverses. Mountains Software (Digital Surf, France) was used to analyse the data, from which the wear crater volume was deduced.

Micro-scale abrasion tests were conducted with slurries of two abrasive types suspended in distilled water: (i) alumina (White bauxilite micropowder, F1200, USF Abrasive Developments Ltd., UK) and (ii) silica (Sibelco UK Ltd.), with nominal sizes ranging from 2 to 10 μm. SEM micrographs showing the abrasive morphologies are shown in Fig. 2. In each test, the slurry was kept agitated with a magnetic stirrer. Different solids volume fractions are used in the two slurries, namely 17.2 vol% and 30 vol% for alumina and silica respectively. The solids fraction in the alumina slurry was in line with that used in previous work [16]; however, it was found that if the same solids fraction was used for the silica slurry, then a slurry of very low viscosity was produced which resulted in ridge formation in the wear scars (the presence of such ridges is known to invalidate the tests) [13]. As such, the solids volume fraction in the silica slurry was increased to equalise their dynamic viscosities (0.02 ± 0.001 Pa s measured over a 2 minute period with a Bohlin