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A Modified Micro-Scale Abrasion for Large Hard Phase Cermet

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Abstract. Various research programmes have been conducted examining cermet coatings in relation to wear, corrosion and the combination of both (erosion-corrosion and abrasion-corrosion). Several methods have been employed to deposit cermet coatings, the most common being thermal spraying or hard facing (weld overlaying).The cermet coatings are carbide-sized ranging from 50 – 150 μm which is larger than abrasive particles which range between 2 to 10 μm. This allows the abrasive particles to interact with the carbide and matrix separately. Understanding the mechanism of this situation is necessary as abrasion maybe caused by a small abrasive. However, carbide sinking caused by this large carbide leads to diverse local carbide distributions and wear rates with a larger standard deviation. Modified micro-scale abrasion tests were performed with a silica abrasive of 2-10 μm particle size distribution and suspended in water. Due to the sinking of carbide particles during the coating process, the ground samples with more carbide on the surface displayed better wear resistance than those with a lower local carbide content. By using a modified micro-scale abrasion wear test, the correlation between local carbide content and wear rate may be determined with a smaller standard deviation. Rolling wear mode was observed due to the lower degree of hardness of the abrasive compared to the hard phase. The wear behaviour is related to the microstructure.

Introduction

Metal-ceramic composites or cermet coatings have become popular due to their enhanced wear and corrosion resistance properties. Cermets consist of ceramic particulates embedded in a metallic binder [1-2]. Metal-ceramic (cermet) materials are typically characterised by the nature of the binder phase, the fractions of the binder phase and ceramic phase, and the nature of the ceramic phase and its size. WC (tungsten carbide) is the most popular carbide used in such materials as it displays high wetability in molten metal, has a low thermal expansion coefficient, and exhibits some toughness [3].

The concept of micro-scale abrasion is an interesting and relatively recent development in the field of tribo-testing methodologies where particles of less than 10 μm are loaded and moved between interacting surfaces. This method is practical due to its direct relationship to the mechanisms of the wear process in bio-tribological applications, ease in conducting tests and the good repeatability of the test results. It has wide ranging applications from space and offshore industries to bio-engineering for artificial joints and implants [4]. Micro-scale abrasion allows a simple and inexpensive rotating sphere apparatus to be used to conduct small scale abrasive wear tests and it is ideally suited to the study of small material samples and surface engineered components [5].

In wear tests of a WC/Ni cladding with carbide size ranging from 30 to 150 μm and lower silicon carbide (SiC) slurry concentrations (18 vol%) resulted in the formation of clearly visible grooves in the soft matrix. However, rolling, still detectable in the overall coating, suggests the transition from a two to three body mechanism [6]. Although considerable work has been done on micro-scale abrasion testing, little emphasis has been placed on the usage of the much softer silica abrasive(750-1200 kgfmm^{-2}) compared to SiC (2100-2600 kgfmm^{-2}).Thus, this study will highlight the modifying of the micro-scale abrasion test for weld-overlay materials with a large carbide size using silica abrasive.

Experimental Procedure

Materials Used. The weld-overlay WxC-35Ni and WxC-65Ni, which will be termed W-35 and W-65 respectively from here on, was used for this study. The specimens were deposited by external vendors and the coatings were characterised using a Philips XL30 scanning electron microscope (SEM) and a Siemens D500 X-ray diffractometer (XRD).

Micro-scale Abrasion: Micro-scale abrasion testing was performed with a commercially available apparatus, the TE66 Micro-scale Abrasion Tester (Phoenix Tribology Ltd., Newbury, UK). A schematic diagram of the apparatus is shown in Fig. 1. The test pieces (ranging in size between 10-25 x 10-15 mm) were ground and polished with diamond abrasive (using 1 μm diamond abrasive in the last stage) before the wear test. The test sample was placed in a holder block which is rotated around its pivot until the sample comes into contact with the ball. The ball is rotated about a horizontal axis parallel to the plane of the specimen surface while 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 distance up to 80 m in a constant 0.2 N load. Due to inhomogeneous carbide distribution in the coatings, micro-scale abrasion was run at the same position. This was done by attaching the sample onto a glass slide using double-sided tape. A metal corner locator is used to ensure the position is maintained (Fig. 2). After the first distance is run, the wear scar is measured using Talysurf CLI 1000 (Leicester, UK). The scars were scanned using a contact probe with spacing of data points of 1 μm in the scan direction and with a 10 μm spacing between adjacent scans. Mountains® sofware was used to analyse the scan from which the wear crater volume was deduced.Then, the sample was returned to its original position with the aid of a metal stopper as an indicator. The test is repeated until the required distance of 80 m is achieved.

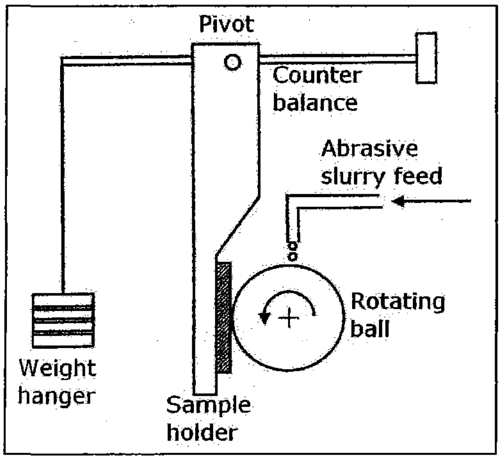

Fig. 1: Micro-scale abrasion apparatus

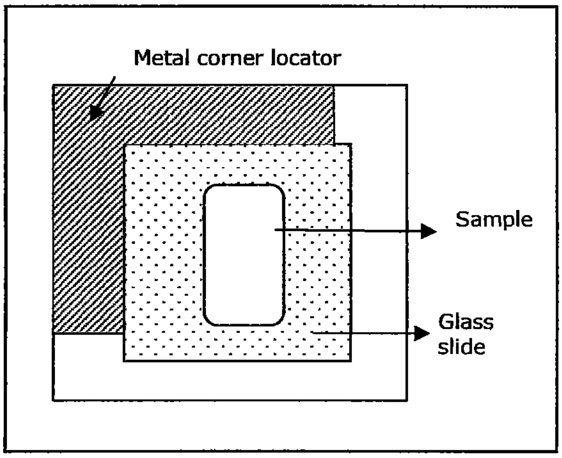

Fig. 2: Schematic diagram of sample position for micro-scale abrasion

Micro-scale abrasion tests were conducted with a slurry containing abrasive silica particles (Sibelco UK Ltd, Cheshire, UK) suspended in distilled water as shown in Fig. 3.The counterface balls employed were made from 52100 bearing steel with a diameter of 25.4 mm and were supplied by Dejay Distribution, Wokingham, UK. Each ball, used for many tests, was turned after each test (to ensure use of a new circumferential track) and the track was run in for 200 revolutions under standard test conditions before being employed in the test to ensure that its surface was reproducible. The track was also roughened to promote abrasive particle entrainment [7]. Examination of the wear scars following testing was done with a SEM employing secondary electron imaging.

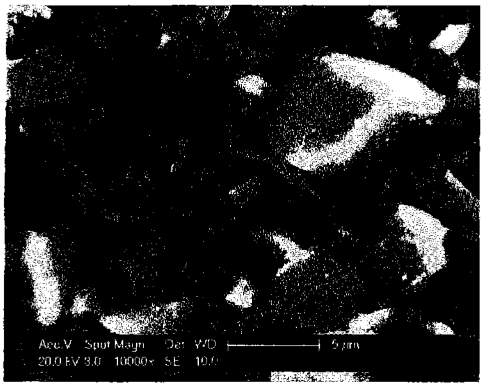

Fig. 3: Morphology of the particle employed; silica

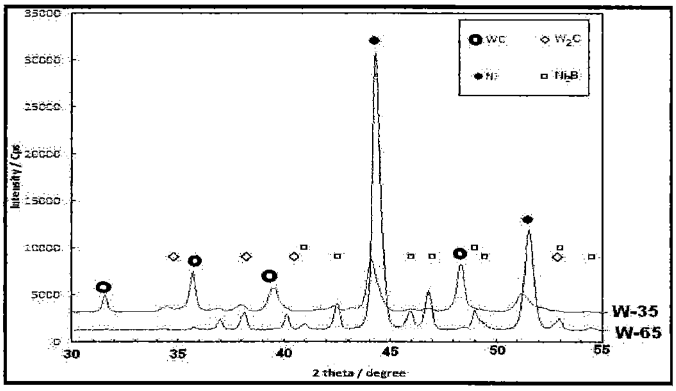

Fig. 4: X-ray diffraction spectra for W-65 and W-35 respectively

Result and Discussion

Fig. 4 shows the x-ray diffraction spectrum for W-65 and W-35. Both coatings have similar phases which are WC, W_2C, Ni and Ni_3B. Figs. 5a and b show cross-sections of W-65 and W-35 respectively. The brighter sphere is the hard carbide and the darker area in between the carbide is the nickel alloy. The term total carbide content refers to overall carbide content during deposition, while local carbide content refers to carbide content at the testing area.

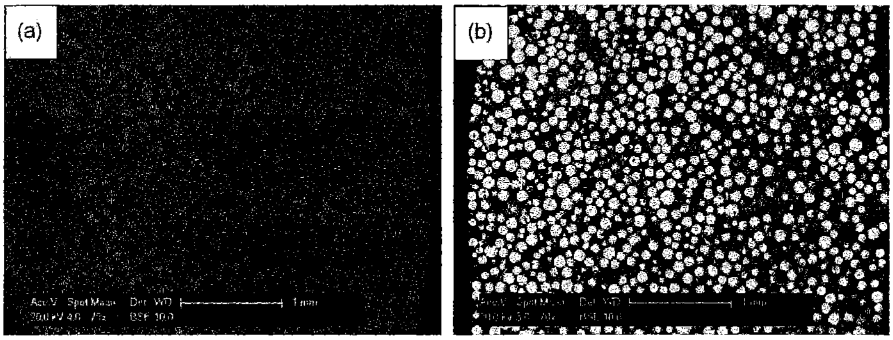

Fig. 5: Cross-section of (a) W-65 and (b) W-35

Correlation between carbide content and wear volume is always a concern. This is due to the nature of the hard phase which provides protection against wear for the softer binder. Large carbide (> 50 μm) with a lower total carbide content as in W-65 (Fig. 5a) leads to inhomogeneous carbide distribution across the coating and on the surface. This is due to the higher density of carbide compared to the binder resulting in the sinking of the carbide during solidification [8]. Lower total carbide content allows the carbide to sink due to the large spaces in between the carbide. With a higher total carbide content W-35 (Fig. 5b) less empty spaces are accessible and this restricts the movement of the carbide.

Fig. 6 shows wear development of a specific area of the surface profile of the W-35 coating. The wear depth increased from 2.5 μm at 20 m to 4 μm at 80 m. Areas with lower local carbide content (as highlighted) experienced higher binder removal or higher wear volume compared to areas with higher local carbide content.

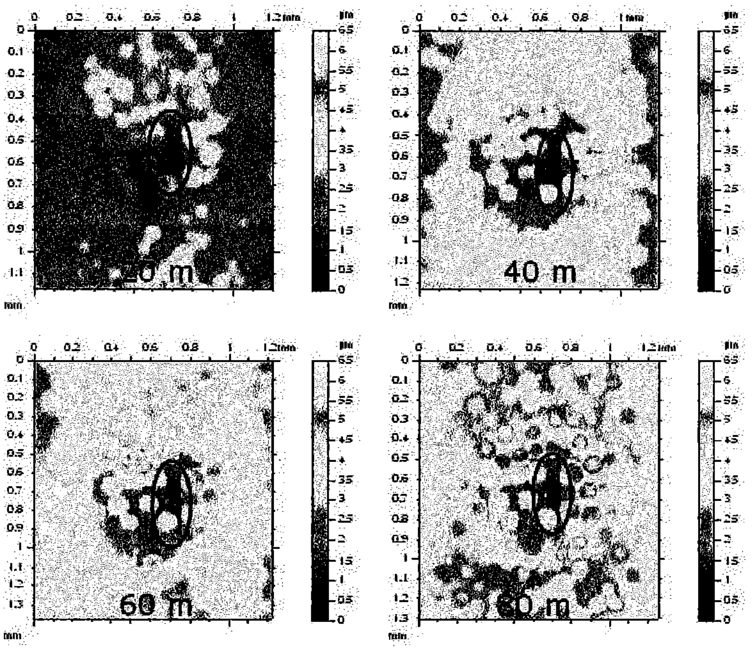

Fig. 6: Wear development at one position with silica abrasive and 0.2 N load

Table 1: The wear rate of W-65 and W-35 at different areas with different local carbide contents

Sample	Local carbide percentage (%)	Wear rate ($\mu m^3 m^{-1}$)
W-65	38	6116
W-65	46	3044
W-35	40	3529
W-35	44	3080

The areas with a lower local carbide content will undergo higher wear volume compared to areas with a higher local carbide content as shown in Fig. 6 and Table 1. Due to inhomogeneous carbide distribution, the wear volume that is measured at different places on the surface with the same total carbide content will exhibit a bigger standard deviation, and lower accuracy and repeatability.Thus, by employing the one position wear test, the wear volume changes at specific distances can be measured, and the wear rate can be calculated by using the gradient of the wear volume versus the distance graph. It is observed that the wear rate of cermets with a similar local carbide content also had a similar wear volume although the cermets concerned had different total carbide contents (Table 1). The wear rate against local carbide content can be determined. It has been demonstrated that one position modified micro-scale abrasion can determine the wear rate of large hard phase cermets and correlate it with the local carbide content.

Conclusion

The weld-overlay Ni based on different total carbide contents has been characterised. The inhomogeneous carbide distribution in W-65 resulted in different wear rates at separate surface areas. The wear volume increased with decreasing local carbide content. Thus, determination of wear rate in relation to total carbide content results is debatable. The modified micro-scale abrasion test is utilised to determine wear volume and correlate it with local carbide content for large hard phases.

Acknowledgements

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