

Measurement Note

Stepwise Erosion To Determine The Mechanisms Of Wear In Gas Borne Particulate Erosion

Summary

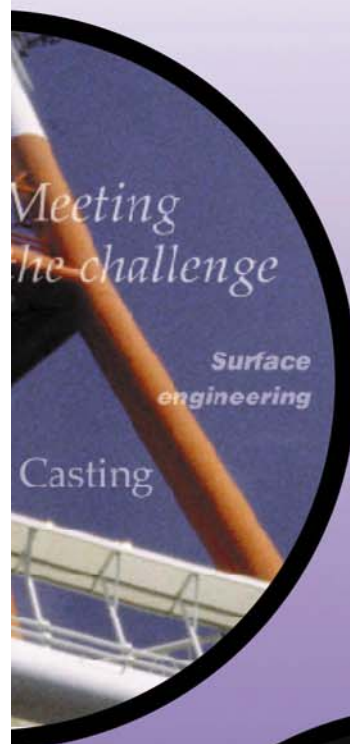
In erosion and abrasion, the detailed processes that cause material removal are still poorly understood. This means that with a few notable exceptions, good models for the prediction of materials behaviour are still not readily available. Stepwise testing is a new approach that has been recently developed as a way of providing information on the build up of damage in erosion.

The technique uses a combination of exposing a test specimen to repeated very low duration abrasion or erosion followed by accurate relocation in the SEM. This enables the real wear processes within a material to be followed in considerable detail, giving an excellent basis for developing new and improved models.

In this preliminary study, the technique has been applied to the gas borne particulate erosion wear of a WC/Co hardmetal. It was observed that in the initial stage of wear although gross damage to the structure of the material occurred over the localised area corresponding to the impact area of a particle, some damage occurred over a much wider area. This was thought to be due to immediate fragmentation of impacting particles followed by scouring of the surface near the impact site by fragments. Further damage was caused by a combination of further removal of the binder phase, build up of plastic deformation in single WC grains followed by fracture, fragmentation and removal, and intergranular fracture of the WC skeleton. Multi-grain cracking was not observed, suggesting that models based on indentation cracking are not realistic.

M G Gee, and I McNaught

September 2002



Introduction

WC based hardmetals and high speed tools are widely used in applications where erosion and abrasion resistance are important. Because of this, there has been considerable interest in measuring the wear performance of these materials in the laboratory, and developing an understanding of the mechanisms of wear that occur in abrasion and erosion [1-24]. These studies have often used tests that have been standardised so that comparisons in results between laboratories can be facilitated [25-27]. Often these studies have been combined with an evaluation of the microstructure and mechanical performance of the materials, so that information on how the wear resistance alters with changes in material make-up can be gathered. Attempts have also been made to model the wear so that equations linking the wear to materials properties such as hardness, toughness and grain size can be developed [28-30, 12, 13]. Despite this, the understanding of the wear mechanisms in abrasion and erosion is by no means complete.

This paper describes a new method that can be used to determine the detailed wear mechanisms that take place in erosion and abrasion. This uses stepwise erosion or abrasion combined with relocation scanning electron microscopy. The aim of this type of approach is that more knowledge about the wear mechanisms can be used to guide the development of new materials, and also to provide better ways of selecting materials for particular applications.

This preliminary report describes work that was carried out on gas borne particulate erosion. In this type of experiment, a stream of erodent particles borne in a gas flow impinges on a sample giving linear increases of wear for WC/Co hardmetals and high speed steels (Figure 1).

Experimental Method

The essence of the method is to incrementally expose a sample to erosion from small quantities of erodent, and then be able to accurately relocate the test sample in the scanning electron microscope to enable the same area to be examined at high magnification, allowing for the development in damage to be followed at specific points on the sample surface.

Materials

In this preliminary investigation a WC/Co hardmetal was examined. This had 11 % of Co as binder, a 5.16 μm mean linear intercept grain size, and a hardness of 912 HV30. The samples were 40 mm x 20 mm x 5 mm. One of the 40 x 20 mm faces of each sample was polished by standard metallographic techniques.

Before testing the polished face of the sample was cleaned by washing in detergent solution, rinsing in very hot water, and then blow drying with compressed air. After every exposure this cleaning procedure was repeated before examination in the SEM.

Erosion Test System

The erosion test system that was used was a conventional gas borne particulate erosion system (Figure 2). The nozzle bore size was 5mm and the nozzle length was 250 mm. Erodent is drawn into the gas stream through a venturi from a rotating table that controls the feed rate of erodent.

The test conditions that were employed were:

- erodent of rounded quartz 220 μm in size
- particle velocity of 75 ms^{-1}
- stand-off distance between end of nozzle and sample of 20 mm
- angle of impingement 90°

The samples were exposed to aliquots of erodent at these conditions. In early experiments, estimates of the size of aliquot were calculated on the basis that the probability of contact of any point on the surface should be 50% for a single exposure, but it was found that the damage from a single exposure with this size of aliquot was too large. Instead an empirical approach was used with a very small initial aliquot that was increased in weight as the experiment proceeded.

Table 1 gives the aliquots that were used on the two samples. At the start of the experiment, the samples were carefully placed in the erosion test system so that the area chosen for the repeated erosion was at the centre of the expected wear scar. The position of the sample was carefully marked so that the sample could be replaced in the same position in the erosion system. The sample was then exposed to the first aliquot of erodent. It was then taken from the test system, cleaned as described earlier, and examined in the SEM. After the appropriate images had been

taken, the sample was exposed to a further aliquot of erodent.

Table 1, Weight of aliquots used for stepwise erosion studies.

Aliquot Number	WC/Co	
	Aliquot Weight, gm	Cumulative Weight, gm
1	0.05	0.05
2	0.05	0.10
3	0.06	0.16
4	0.15	0.32
5	0.21	0.53
6	0.23	0.76
7	0.20	0.95
8	0.21	1.16
9	0.40	1.56
10	0.80	2.36
11	1.60	3.96
12	1.20	5.16
13	1.60	6.76
14	1.60	8.36
15	1.60	9.96
16	1.60	11.56
17	2.00	13.56
18	2.00	15.56

Relocation Scanning Electron Microscopy

The relocation relied on marking the samples so that the same area on the sample could be found repeatedly. This was carried out by marking the samples with lines of Vickers indentations made with a 30 kg load as shown in Figure 3. A number of areas for the mechanistic study were chosen close to a specific marker indentation. Care was taken when inserting the sample in the scanning electron microscope to ensure that the orientation of the sample was the same after every exposure to erodent. As a secondary measure, the digital stage of the SEM was zeroed on a specific indentation and the position of the chosen areas measured with a nominal resolution of 1 μm relative to the zero position.

A high resolution, high brightness field emission scanning electron microscope was used for the

imaging. A careful strategy was employed to enable the same area to be identified. Thus micrographs of the general area were taken at 500 x, 1000 x, and a montage of the working area was taken at 2000x. It was originally planned to use the digital framestore associated with the field emission SEM to acquire large pixel size images of the area of interest, but unfortunately the framestore proved inadequate to the task so that a return to the use of film proved essential.

Results

A series of montages that resulted from the stepwise erosion experiments on the WC/Co sample is shown in Figure 4. On the first exposure, considerable damage to the surface in the form of removal of much of the cobalt binder phase on the surface has already occurred. As exposure proceeds, cracking around individual WC grains occurs until the grains become unsupported. Removal of individual grains occurs as the exposure continues with a concomitant roughening of the sample surface.

Examination of the exposed surfaces at higher magnification reveals more details of the wear mechanisms that are occurring (Figure 5) In Figure 5b considerable evidence of plastic deformation through the presence of slip lines on the large triangular grain can be seen. On the same Figure some of the larger WC grains can be seen to be cracked, with some cracks also occurring between grains. Fragmentation of a narrow sliver of WC grain has taken place towards the bottom right of the image, and grooving has occurred to the Co binder phase to the bottom of the image. Between Figure 5d and 5e the large triangular grain has been removed, and it is perhaps significant that internal cracking can be seen at the base of this grain in Figure 5d. In Figure 5e material is smeared across some of the underlying WC grains, and a grain at the base of the image is fragmented. In Figure 5f the large grain at the top of the image has a large internal crack; this grain was removed on the next exposure.

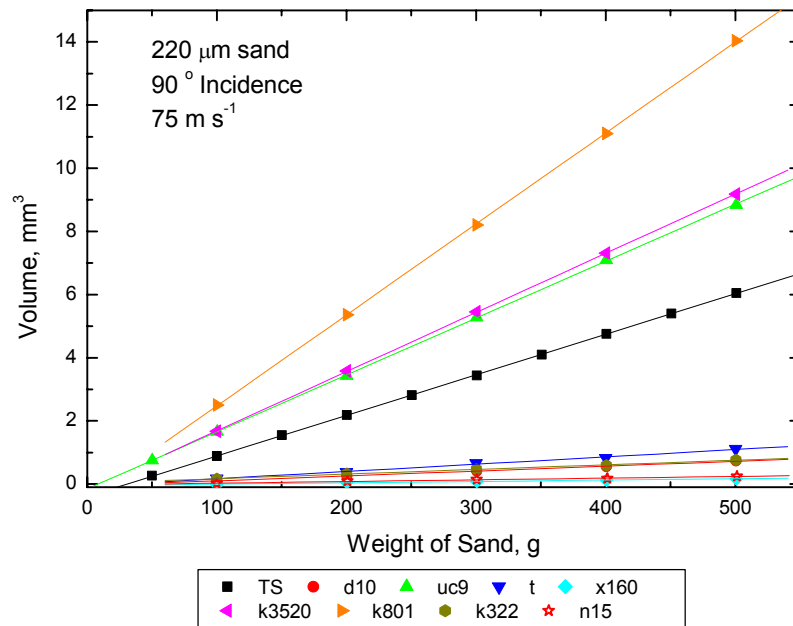


Figure 1, Typical erosion results for tool steels and hardmetals.

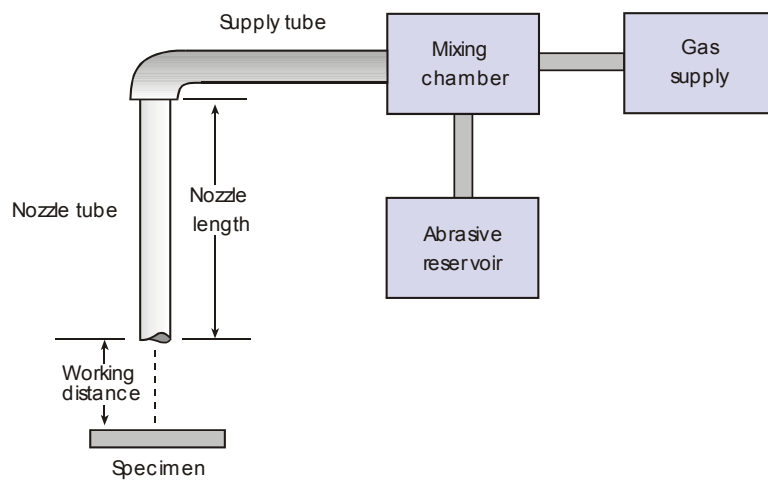


Figure 2, Gas borne particulate erosion test system [27]

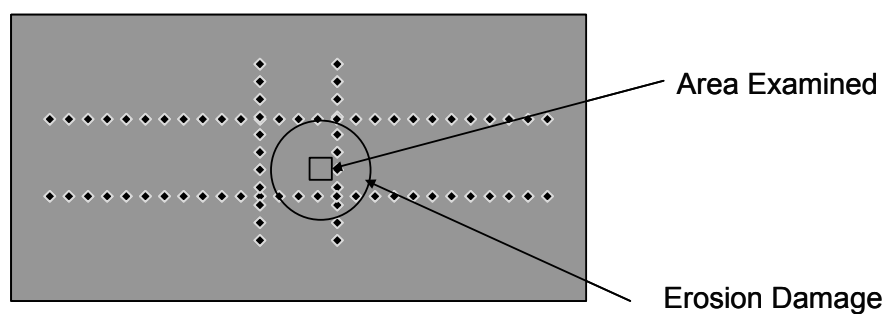


Figure 3, Sample marking technique

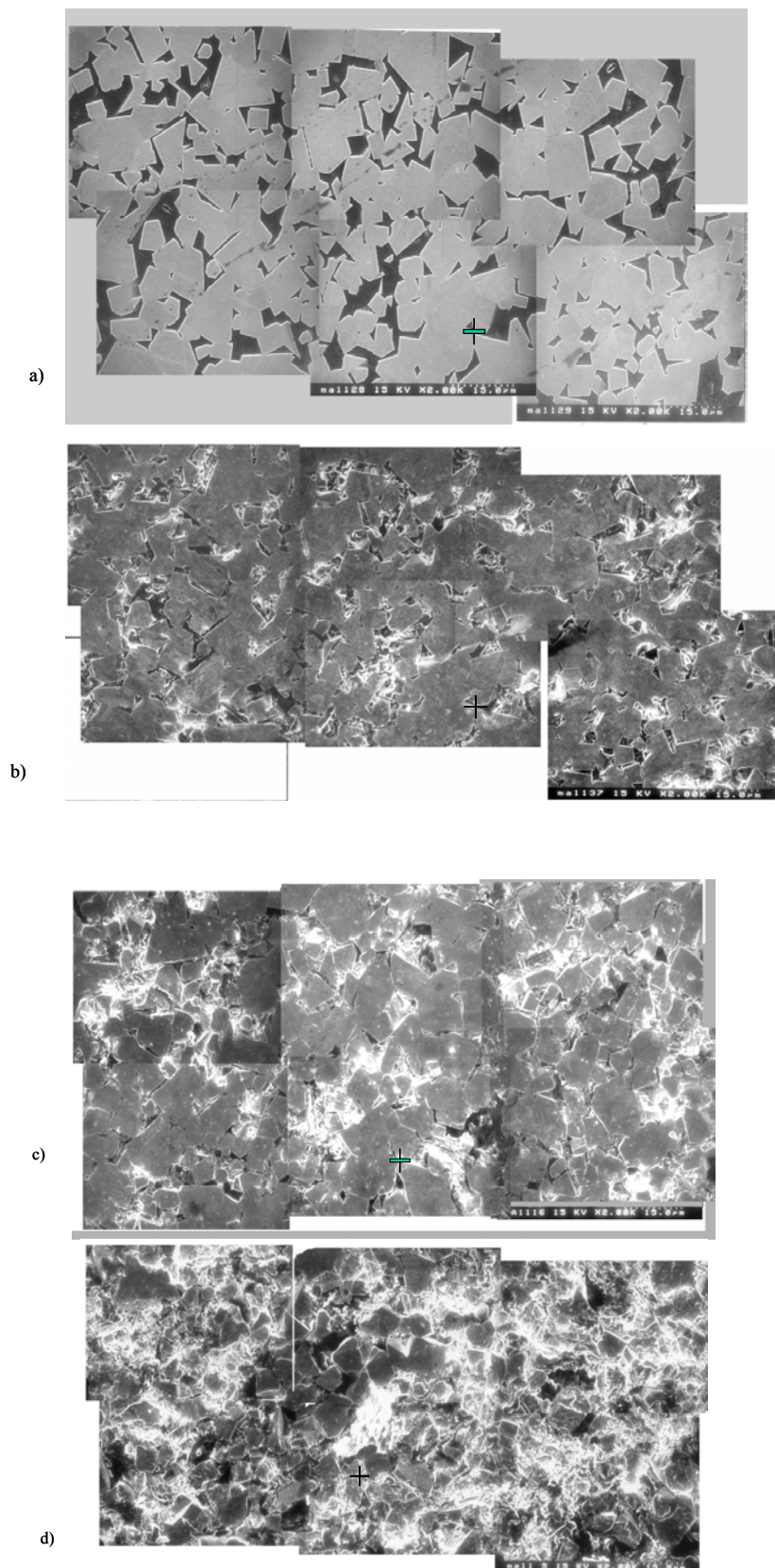
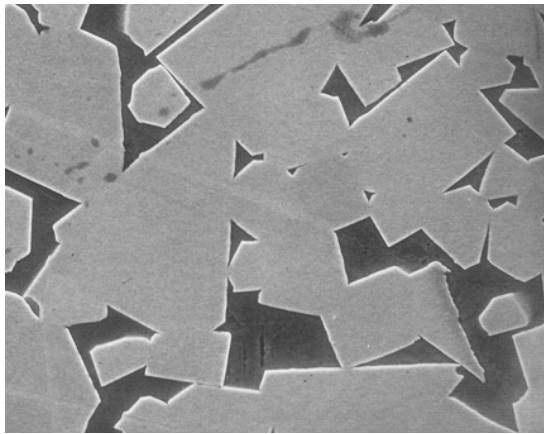
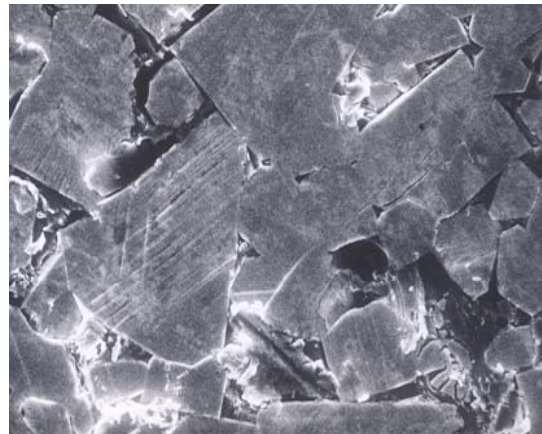


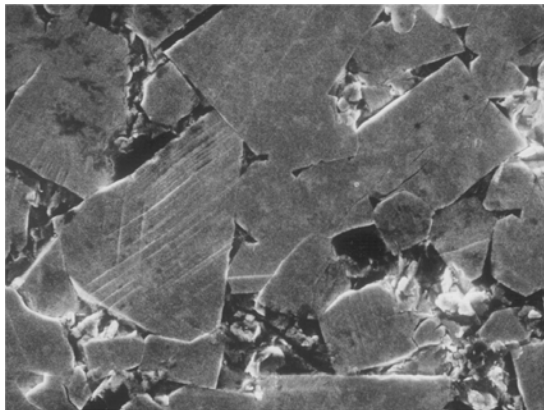
Figure 4, Maps of relocated area on WC/Co sample. Cross marks same point on each image, a) unexposed sample, 0.05 gm cumulative exposure, b) 0.53 gm cumulative exposure, c) 2.36 gm cumulative exposure, d) 15.56 gm cumulative exposure



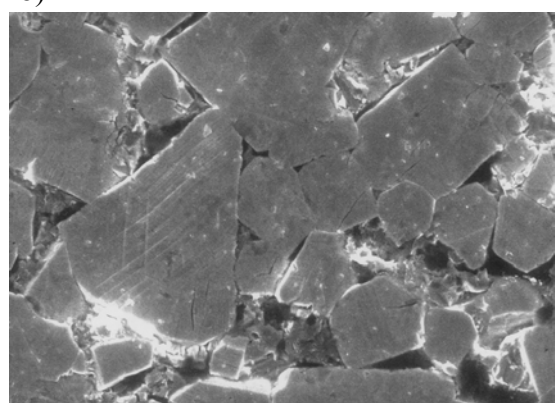
a)



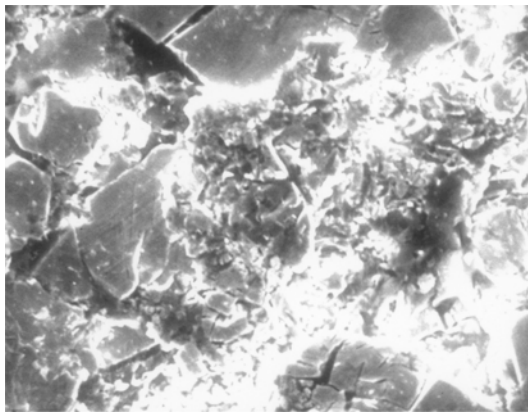
b)



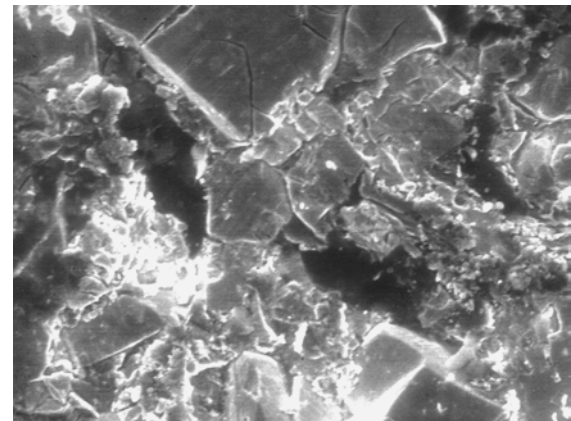
c)



d)



e)



f)

Figure 5, Area A in Figure 4a, a) unexposed sample, b) 0.05 gm exposure, c) 0.53 gm exposure, d) 2.36 gm exposure, e) 3.96 gm exposure, f) 5.16 gm exposure.

Conclusions

The stepwise erosion technique has proved to be an effective tool to investigate the mechanisms of wear that occur in WC/Co hardmetals and high speed steel. The preliminary results for the coarse grained hardmetal that was examined show that wear occurs by progressive damage process that involves:

- Surface binder phase removal almost instantly
- Build up of considerable plastic deformation in WC grains
- When further plastic deformation cannot be accommodated, or when local impact forces are too high, individual grains fracture and fragment
- Growth of cracking between individual grains in the WC skeleton of the material
- Final breakaway of single WC grains

No evidence for large scale lateral cracking was found.

Acknowledgements

The authors would like to acknowledge the support of the materials measurement programme of DTI for the work reported here.

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For further information contact M Gee, Centre for Materials Measurement and Technology.

National Physical Laboratory
Queens Road
Teddington
Middlesex
TW11 0LW

Telephone: 020 8977 3222 (*switchboard*)
Direct Line: 020 8943 6374
Fax: 020 8943 2989
E-mail: Mark.Gee@npl.co.uk

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