THREE-BODY ABRASIVE WEAR IN A BALL-CRATERING TEST WITH LARGE ABRASIVE PARTICLES

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Three-body abrasive wear resistance of mild steel, low alloy steel (Bisalloy) and 27%Cr white cast iron was investigated using a ball-cratering test. Glass beads, silica sand, quartz and alumina abrasive particles with sizes larger than 100μm were used to make slurries. It was found that the wear rates of all three materials tested increased with time when angular abrasive particles were used and were rather constant when round particles were used. This increase in wear rates was mainly due to the gradual increase in ball surface roughness with testing time. Abrasive particles with higher angularity caused higher ball surface roughness. Mild steel and Bisalloy were more affected by this ball surface roughness changes than the hard white cast iron. Generally, three-body rolling wear dominated. The contribution of two-body grooving wear increased when the ball roughness was significant. More grooves were found when round particles were used or the size of the particles was decreased.

Keywords : Three-body abrasion, Ball-cratering test, Angularity of particles

1. INTRODUCTION

The ball-cratering test is mainly used to measure the thickness and abrasive wear resistance of thin coatings or surface layers [1,2] and commercial tribometers based on this method are available (CSEM Calotest and Calowear and Plint TE-66 micro-scale abrasion tester). For coatings or thin layers testing the abrasive slurries or pastes contain very small abrasive particles of micron, or even sub-micron, size and therefore this test is often referred to as micro-scale abrasion [2]. Micro-scale abrasion test has also been used for testing the abrasive wear resistance of bulk materials such as tool steel [3], plain carbon steel [4], and glass [5], again using fine abrasive particles. Recent research has shown that the ball-cratering test is also suitable for characterizing the abrasive power of various grits [6,7]. In our work the ball-cratering test was applied to study the three-body abrasive wear resistance of bulk materials such as mild steel, low alloy steel and 27%Cr white cast iron. Much larger abrasive grits were used to better simulate true in-service industrial slurries. To accommodate abrasive grits with sizes up to 0.5mm a larger ball of 41mm was used compared to 10-30mm balls used in commercial micro-scale abrasion rigs.

2. EXPERIMENTAL DETAILS

2.1 Wear test rig

The experimental wear tests were carried out using a ball-cratering tribometer, shown in Figure 1. The apparatus consists of a bearing steel ball rotating against a metallic wear plate with slurry passing between the contact point. The steel ball is a standard 41.3mm bearing ball and it is rotated by means of two rubber rings fitted on a drive shaft.

2.2 Test materials

Three commercial materials, mild steel (0.2%C, $130HV_{10}$), low alloy steel (Bisalloy, 0.2%C, $390HV_{10}$) and 27%Cr white cast iron (2.6%C, $720HV_{10}$) were used as wear materials. The hardness of the bearing ball at $860HV_{10}$ was much higher than that of mild steel and Bisalloy and slightly higher than that of white cast iron. The wear samples were square plates with dimensions of 20mm x 20mm x 6mm. The plate surfaces were ground and then diamond polished to a surface roughness of R_a=0.01-0.02μm. Prior to testing the wear samples were ultrasonically cleaned in acetone and dried in hot air.

2.3 Test conditions

In ball-cratering wear tests a steel ball was rotated against a wear plate with a velocity of 0.2 m s^{-1}. The load exerted by the ball on the plate was 1.4 N. Abrasive slurry was delivered at a rate of 1.3 ml min^{-1}. It was observed that small variations in the flow rate did not affect the wear results. Each test lasted two hours and the wear plates were weighed at thirty minutes intervals with an accuracy of ±0.0001g. After completion of tests the worn surfaces were examined in an SEM and by Talysurf profilometry to determine the dominating wear mechanisms and the extent of wear damage.

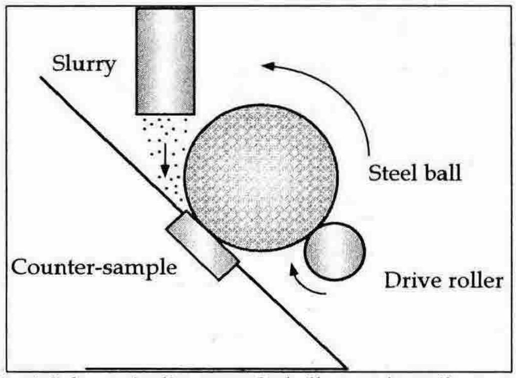

Fig.1 Schematic diagram of a ball-cratering tribometer.

Abrasive particles were sieved for 15 mins into narrow size ranges. In the majority of tests the particles of size 250-300μm were used. The particle angularity parameter SPQ was calculated using specially developed software [8]. At least 100 optical microscope images of particles from each group were used for this calculation. Microhardness of the particles was also measured. The characteristics of abrasive particles are given in Table 1. With the exception of glass beads all the abrasive particles used in testing were harder than the wear samples and the rotating bearing ball. In all tests the slurry contained 10vol% of abrasive particles.

Table 1. Properties of abrasive particles

Abrasives	Hardness $(HV_{0.2})$	SPQ±St. Dev.
Glass beads gb	492±23	0.0359±0.0536
Silica sand ss	1190±54	0.2027±0.0958
Quartz q	1257±126	0.4713±0.1552
Alumina al	1982±130	0.5233±0.1624

3. RESULTS AND DISCUSSION

The relationship between the average three-body abrasive wear of mild steel and 27%Cr white cast iron and the average SPQ values of abrasive particles is shown in Figure 2.

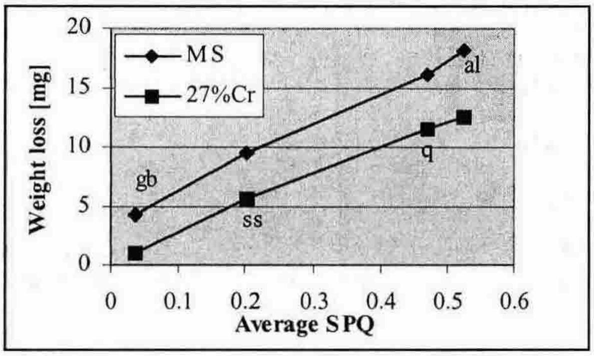

Fig 2. Average weight loss of mild steel and 27%Cr white cast iron versus average SPQ values of abrasive particles.

It can be seen from Figure 2 that there is almost a linear relationship between the average wear loss of both materials and the average SPQ value of abrasive particles. The wear loss of low alloy steel (Bisalloy) was between the wear of mild steel and white cast iron. When the weight loss was plotted against the microhardness of abrasive particles the linear correlation was not observed as can be seen in Figure 3.

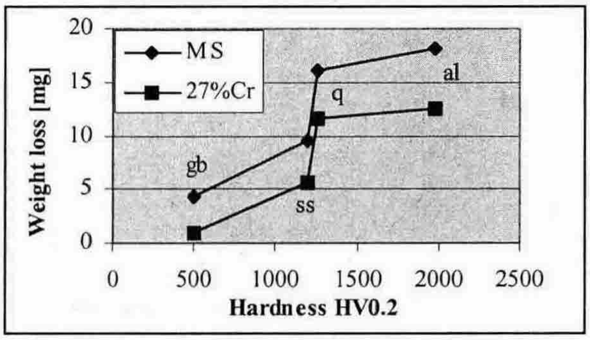

Fig 3. Average weight loss of mild steel and 27%Cr white cast iron versus average microhardness of abrasive particles.

It was found that the wear rates of all three materials tested increased with testing time when angular abrasive particles were used and were rather constant when round particles were used. This increase in wear rates was mainly due to the gradual increase in ball surface roughness with testing time. Abrasive particles with higher angularity caused higher ball surface roughness. Mild steel and Bisalloy were more affected by this ball surface roughness changes than the hard 27%Cr white cast iron.

Two types of wear damage were observed: three-body rolling wear and two-body grooving wear. Some particle embedding was also found. Generally, three-body rolling wear dominated and occasional grooves were mostly located in the middle of the wear scars (Figure 4). The contribution of two-body grooving wear increased when the ball surface roughness increased significantly. More grooves were found when round particles were used or the size of the particles was decreased.

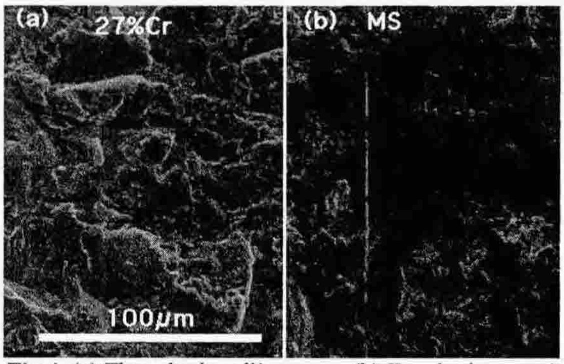

Fig 4. (a) Three-body rolling wear, (b) Two-body grooving wear (vertical grooves).

4. CONCLUSIONS

- There is almost a linear correlation between three-body abrasive wear and particle angularities.
- The surface roughness of the ball significantly affects the wear rates of the metallic plates. More angular particles generate higher ball surface roughness.
- Generally, three-body rolling wear dominates. The contribution of two-body grooving wear increases when the ball roughness is high. More grooves are found when round particles are used or the size of the particles is decreased.

5. REFERENCES

[1] Thomson, V., Hinterman, H.E., and Chollet, L., The determination of composition depth profiles using spherical erosion and scanning Auger electron spectroscopy, Surf. Technol., Vol. 8, pp. 421-428, 1979.

[2] Rutherford, K.L., and Hutchings, I.M., Theory and application of a micro-scale abrasive wear test, J Testing and Evaluation, Vol. 25, pp. 250-260, 1997.

[3] Trezona, R.I., Allsopp, D.N., and Hutchings, I.M., Transition between two-body and three-body abrasive wear: influence of test conditions in the microscale abrasive wear tests, Wear, Vol. 225-229, pp. 205-214, 1999.

[4] Staia, M.H., Enriquez, C.E., Puchi, E.S., Lewis, D.B., and Jeandin, M., Application of ball cratering method to study abrasive wear, Surf. Eng., Vol. 14, pp. 49-54, 1998.

[5] Shipway, P.H., and Hodge, C.J.B., Microabrasion of glass – the critical role of ridge formation, Wear, Vol. 23, pp. 90-97, 2000.

[6] Stachowiak, G.B., and Stachowiak, G.W., The effects of particle characteristics on three-body abrasive wear, Wear, Vol. 249, pp. 201-207, 2001.

[7] Kelly, D.A., and Hutchings, I.M., A new method for measurement of particle abrasivity, Wear, Vol. 250, pp. 76-80, 2001.

[8] Hamblin, M.G., and Stachowiak, G.W., Description of abrasive particle shape and its relation to two-body abrasive wear, Trib. Trans., Vol. 39, pp. 803-810, 1996.