Assessment of Mining Wear: Buckets

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Abstract

A system of laboratory wear analysis has been developed in order to investigate wear rates, ore degradation and wear correlation with geographical location. The process will be verified using the example of the wear experienced by the Hitachi EX 3600 buckets used by Pilbara Iron in Tom Price. High stress abrasion and impact test rigs were designed and built to simulate specific mechanisms of wear. The results from these tests will suggest methods of increasing wear resistance economically.

1.0 Introduction

The purpose of this project is to develop a procedure to assess wear in mining equipment. A system will be developed and verified using the Hitachi EX 3600 buckets as an example. Ideally the analysis will optimise the bucket geometry by decreasing its mass and increasing its longevity. In order to implement changes we must first understand the microscopic wear mechanism involved during the process. A high stress abrasion test rig has been developed to simulate bucket wear in controlled conditions. Results from this test, an impact test rig and a rubber wheel test rig will be compared to field tests. Finally scanning electron microscopy (SEM) will be implemented to investigate the microscopic wear behaviour of the wear plate. By implementing a comprehensive testing process significant statements concerning ore degradation, wear rates and correlation with geographical location can be made.

2.0 Background

Wear in the mining industry is an area that has significant financial impact and is rarely addressed in sufficient detail. A fleet of Hitachi EX3600 buckets were brought into operation in 2003/2004. As a major cost of the extraction process is the replacement of wear plate and ground engaging teeth (GET) it is prudent to have a method of assessing the wear. Generally components of accelerated wear are reinforced with more material or replaced with materials that have higher wear resistance. Ideally the microscopic wear mechanism should be determined prior to recommending any changes (Tomlins et al. 1995). This will allow suggestions concerning materials, coating techniques and replacement protocols that maximise the life of a component to be made. Increasing the life of a bucket can substantially decrease the maintenance costs.

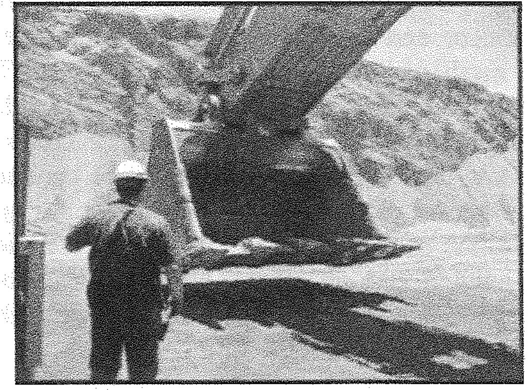

Figure 1: Hitachi EX3600 Bucket

The buckets are currently in operation at a number of locations in the Pilbara region including Tom Price and Paraburdoo. The 22m^3 bucket is outfitted with a mild steel plate that is coated with a layer of abrasion resistant material. The overlay of the material is an austenitic chromium carbide iron. The microstructure of this material consists of primarily M_7C_3 carbides in eutectic matrix of austenite and carbide. (Bradken 2003).

3.0 Theory

A preliminary assessment of the wear mechanisms is necessary to understand the entire process. During excavation we are most likely to observe two body and three body abrasive wear. Three body wear is experienced when the particles are free to roll and slide where as in two body wear the abrasive particles are restrained (Stachowiak 1998). The major mechanisms of wear expected are high stress abrasion and impact gouging (StJohn 1994). The four recognised microscopic mechanisms of abrasive wear are cutting, fracture, fatigue by repeated ploughing and grain pull-out. Grinding and high-stress abrasion refers to the situation where the contact stresses are sufficient to fracture the abrasive particles (Stachowiak, 2001). This is associated with accelerated wear as new sharp, cutting edges are continually generated. Stresses as low as 2MPa can cause high-stress abrasion (Tomlins 1995). Impact gouging wear often causes localised plastic deformation due to the high stresses that are generally involved (Tomlins 1995). Visible grooves are formed during impact wear. Wear test rigs should be designed to isolate the major wear mechanisms.

A detailed understanding of the wear process enables changes to be made that prolong the life of the critical components. Suggested methods of increasing wear resistance include, alternative material, electroplating, diffusion, spraying, hard facing, chill casting and surface hardening (Lipson 1967).

As the wear rate is proportional to the ore properties it is necessary to monitor the ore over time. The three main parameters that determine the abrasive potential of the ore are hardness, size and shape. Spike parameter using quadratic fit (SPQ) is an indicator that has been developed in order to quantify the shape and angularity of particles (Hamblin 1996). The parameter is calculated by first finding any spikes that protrude beyond the average radius of the particle. Two quadratics are fitted between the start of the spike its apex then the apex and the finish. The angle between tangents at the apex is used to describe the angularity of the spike. (Stachowiak 1998)

4.0 Field Testing

Field tests were devised in order to find the wear rates at specific locations on the bucket. Ultrasonic Testing (UT) can measure the thickness of a component and thus determine its wear rate. A wide mesh of points was evaluated using UT in order to identify locations that were low, medium and high wear. The wear rates of the buckets are quite low thus the field tests need to be conducted over a period of months. In order to gain a quick visulisation of the wear pattern areas of the bucket were painted with an enamel prior to a short burst of digging. The wear pattern was then highlighted by the remaining paint.

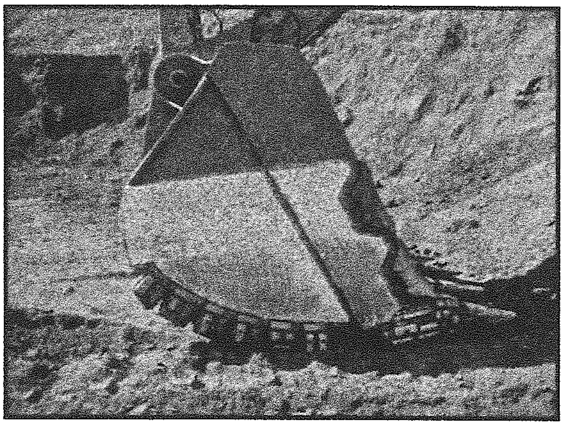

Figure 2: Wear Pattern

Field observations show that heavy earthmoving equipment experience extreme wear conditions (AS/NZS 2576:1996 1998);
High Impact – Impact that causes fracture or plastics deformation
High Loading –The bucket is capable of exerting a digging force of 1050kN (Hitachi, 2000), which is sufficient to cause gross local deformation.
Low Temperature – Ambient temperature ranges between 3.8˚C to 48.2˚C (Bureau of Meteorology 2004)

5.0 Design and Construction of Test Rigs

A series of reproducible tests were required to assess wear in controlled laboratory conditions. The test rigs should simulate the mechanisms of wear experienced in the field. A high-stress abrasion and an impact test rig should be designed in order to simulate the environmental conditions (D. StJohn 1994). The study of impact wear led to the design of a pendulum test rig that directly impacts the wear material (Rabinowicz 1995). Finally a dry-sand rubber-wheel test rig was used to simulate low-stress three-body abrasive wear (Tylczak 1999).

5.1 Paddle Test Rig – High Stress Abrasion

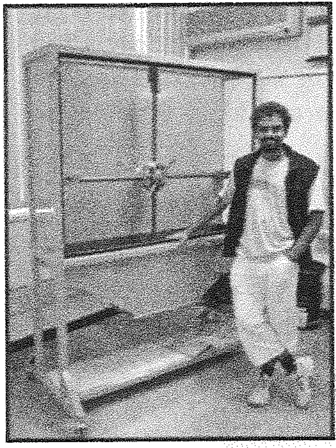
Figure 3: Paddle Test Rig

The high stress abrasion test rig was designed to simulate various wear environments (see Figure 3). The test rig consists of four arms which rotate through a body of abrasive material. Flexibility is provided by allowing the user to alter the speed of the test rig, the orientation of the samples and the abrasive material used. The test rig is equiped with a variable speed drive that allows the samples to rotate between 4 and 10 rpm. This is equivalent to a tip velocity between .3ms^{-1} and .7ms^{-1}. The arms on which the samples are mounted can rotate axially. This allows the user to position the samples normal to the flow or in such as way as to allow the material to flow along the face of the sample. The angle of the backing plate can also be altered to control the angle at which the sample engages the ore. Due to the scale of the test rig and the clearances allowed particles up to 80mm can be used.

5.2 Pendulum Test Rig – Impact Wear

As mining and bucket wear in particular is a high impact environment where chipping and gouging are major contributers to wear, an impact test rig was also developed. The test rig is a simple pendulum with a hardened steel tip which impacts the wear sample. A rotary potentiometer is used to find the forces and velocities involved during impact. This will then allow the user to find the amount of energy absorbed by the material and relate this to the degree of wear experienced.

5.3 Rubber Wheel Test – Low Stress Abrasion

In the final action when the bucket dumps its load into the haul truck it experiences low-stress three-body abrasive wear nearly exclusively. The rubber wheel test rig was developed based on American wear testing standards in order to simulate low stress three-body abrasive wear.

6.0 Experimental Procedure

A number of tests were run on the high stress abrasion test rig. The first test utilised four identical pieces of mild steel in order to confirm that there would be uniform wear across the the arms. Then each ore type, soft, medium and hard, was to be tested with two particle sizes. During each test three samples and one datum was used. The samples were removed every two hours for weight measurements.

The operation of the high stress abrasion rig required careful preparation and cleaning of the samples in order to produce significant results. As wear volume over short periods is minimal the samples were weighed to 0.01g precision.

To prepare the sample it was first welded to a backing plate which would be attached to the test rig. The sample was then sand blasted to remove any weld splutter or other excesss material. Finally the gaps were sealed with a sealant to ensure no dirt or grit contaminated the sample.

Prior to any measurements, the specimens were scrubbed with a bristle brush, ultrasonically cleaned in soapy water, rinsed with water and blown dry with a warm air stream (Tylczak 1999).

The shape and size of the ore utilised greatly affected the amount of wear experienced. The ore in the hopper was graded prior to any testing. Primarily 50 – 80mm particles were used. The second test consisted of particles 16mm and smaller. The average shape parameter of the ore was calculated at two hour intervals in order to monitor the degradation of the ore.

7.0 Discussion of Results

7.1 Field Tests

The field measurements were used to calculate the wear rates, discern the wear pattern and compare to the laboratory results. The average wear rate on the wear plate was found to be **1.5×10^{-4} mm/hr.** By collating the wear rates in a frequency histogram (see **Figure 4**) it is apparent that there are a few points with accelerated wear (above 3.0×10^{-4} mm/hr) that will limit the life of the bucket. The wear rates were then categorised into four degrees of wear; none, low, medium and high, which were diagramatically represented (see Figure 5)

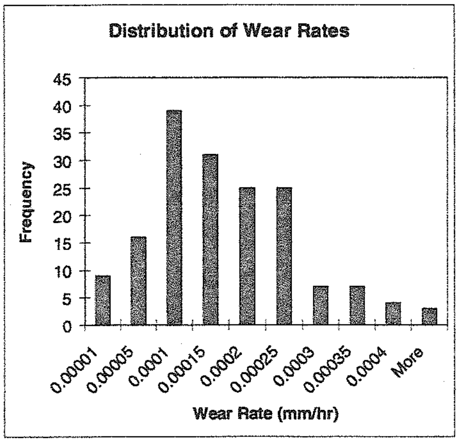

Figure 4: Distribution of Wear Rates

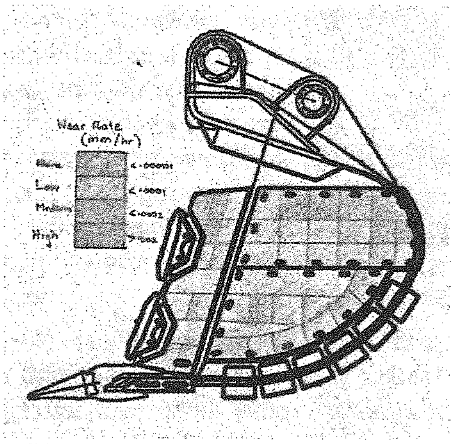

Figure 5: Wear Pattern from field tests

7.2 High Stress Abrasion – Wear rates

The high stress abrasion test rig was used to determine the microscopic wear mechanisms and compare wear rates with field and other laboratory tests. The abrasive material in the first test was soft ore particles 50-80mm in size. Unfortunately due to the angularity of the ore the particles locked up disallowing the wear plates to pass through as intended. Wear data was collected from the soft ore with particle size less than 16mm (see Figure 6). It was found that the model with the best correlation for this data was quadratic. If the ore degradation was linear with respect to time this would explain the quadratic fit as the wear rate would reduce constantly over time.

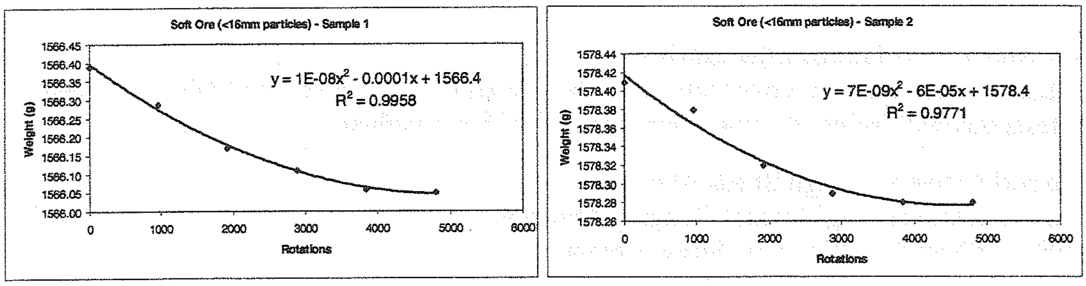

Figure 6: Mass loss vs. Number of rotations

Figure 7: Surface Image of Mild Steel Plate

The microscopic wear mechanisms should be recognisable from the images taken from the scanning electron microscope. Figure 7 shows the microscopic wear on the mild steel plate. It is clear that there is significant cutting and ploughing on the surface that has caused material to be removed. Similar images will be taken of the wear plate. By comparing the microscopic wear on the laboratory test samples to the equivalent wear on field worn wear plate the amount of wear accounted for by high stress abrasion can be quantified.

7.3 Ore Degradation

The ore size and shape was assessed throughout the testing process. A sample of the ore was graded initially and after the test to determine the size distribution of the particles (see Figure 8). There is little degredation in the size composition of the ore over the 10hr testing period. The shape of particles of different sizes was assessed by calculating their spike parameter (SPQ). The averages and standard deviations were plotted to see if there was a correlation between SPQ and size (see Figure 8). As there is a low correlation coefficient it can be assumed that in this case there is little connection between the two.

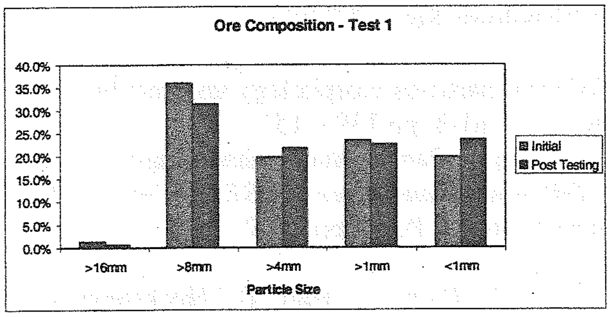

Figure 8: Ore Composition

The next step was to visually inspect the shape degredaion at 2hr intervals (see Figure 10). Images have been taken of 10 particles at each time interval, which will in turn yield the average SPQ at each point. From this a statistical relationship between shape and time can be derived.

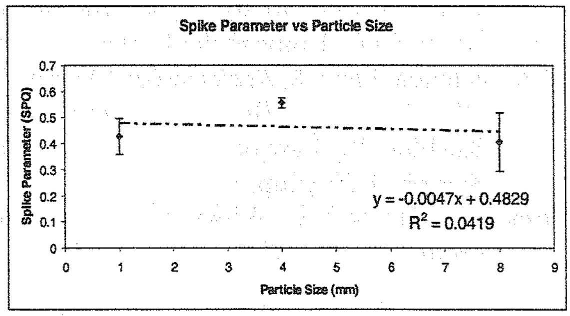

Figure 9: SPQ vs. Shape

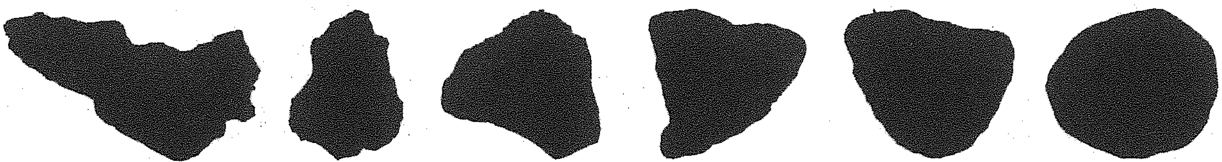

Figure 10: Typical Ore Shape at 2hr Time Intervals (0 - 10hrs)

8.0 Conclusions and Recommendations

An in depth understanding of a wear environment can be gained by using a series of laboratory tests. The laboratory tests that will isolate the major mechanisms of wear include;

- The paddle test rig (High Stress Abrasion)
- The pendulum test rig (Impact/Gouging Abrasion)
- Rubber Wheel Test Rig (Low Stress Abrasion)

The mass of the test samples in the paddle test rig decay quadratically. This is most likely caused by a constant degradation of the ore particles. The degradation of the ore particles will be quantified using their spike parameter. From this a mathematical model for the wear of the samples can be developed. The SEM images will show how much each specific mechanism of wear contributes to the overall wear in the field. The microscopic wear will also give an insight as to how the wear can be controlled.

9.0 References

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