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Influence of particle shape on slurry wear of white iron

C.I. Walker [*,1], M. Hambe

Weir Minerals Australia Ltd., 1 Marden Street, Artarmon, NSW, Australia

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ABSTRACT

Slurry particle shape is an important variable in determining equipment life in mineral processing operations, especially in the grinding circuit. Slurry particles here are generally coarse, sharp and at high concentrations. Little information is available to guide practitioners in measuring particle shape or understanding the impact of particle shape on the wear rate of the hard white irons that are commonly used in processing equipment.

The first part of the current work has explored the differences between 2 methods of measuring particle shape – Circularity Factor (CF) a ratio of the perimeter to projected area of the particles and spike parameter (SPQ) which is an analytical method of fitting triangles to the prominent features of the particle outline. Calculating the CF and SPQ for a wide range of particle shapes (from angular to round) found a close linear correlation between the two. This was surprising given that the more complex SPQ methodology was developed to improve particle shape characterisation.

The second part of the work used a large scale Coriolis tester to determine the effect of particles of different shape on the wear rate of white cast iron. To simulate the type of wear experienced in grinding circuits a range of different particle shapes with similar CF to those observed in field applications were tested. Coarse silicon carbide, alumina and silica sand particles were individually run through the Coriolis tester. By recirculating the particles in the rig, the shape became more rounded (with CF eventually spanning the range seen in field applications) without dramatically impacting particle size. An inverse power law relationship was found between the CF and the erosion rate for white iron. This correlation should be able to be used to determine the impact of changes in CF on equipment wear life.

A third element of the work was a microscopic investigation of the worn sample surface from the Coriolis tester to identify changes in wear mechanisms with particle hardness and shape. In addition a comparison was made with worn slurry pump parts to ensure that the mechanisms of wear from the Coriolis test were representative of those seen in equipment in the field.

1. Introduction

The wear of mineral processing equipment such as slurry pumps, hydrocyclones, screens and pipes in grinding circuits is quite severe. Wear in this equipment is mostly hard particle slurry erosion. A typical worn slurry pump impeller made from high chrome white iron is shown in Fig. 1 and erosion wear rates of up to 2 mm/day are not uncommon [1].

Mineral particles in the grinding circuit are relatively sharp and quite coarse as they are crushed by balls or rods in the mill and undergo further attrition due to the high concentrations and velocities (viz. particle–particle collisions) required for transporting and classification. While the size of the particle is important to wear rate, the "sharpness" is also a significant factor. There is very little data available on mineral particle shape in grinding circuits and no data specifically looking at the effect of particle shape on wear of hard white iron.

The objective of the current research is to establish a measure of typical particle shape and particle size in grinding circuits and then measure the wear rate of different particles in a representative test to establish what impact shape has on wear of white irons.

2. Literature review

There has not been a lot of prior research on the impact of particle shape on wear of materials and the little there is has focused on wear of ductile materials, not hard white iron. In addition, none of the wear test methods reported (dry-sand rubber wheel and ball on plate abrasion test and air jet, slurry jet and slurry pot erosion test) accurately simulate the type of

* Corresponding author. Tel.:+61 4 10661522.
E-mail address: craig.walker@weirminerals.com (C.I. Walker).
[1] Consultant.

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Fig. 1. Typical worn slurry pump impeller.

wear seen in slurry handling equipment, particularly pumps [2]. The following summarises the relevant literature on particle shape measurement and wear.

There are a variety of methods that have been used to characterise particle shape in wear situations. The simplest and probably most common of these methods is the Circularity Factor (CF) developed by Riley in 1941 [3] where

$$CF = 4\pi A/P^2 \quad (1)$$

For Eq. (1) A is the projected area and P the particle perimeter. In this approach a particle's CF conveniently approaches 1 as its shape approaches a perfect circle. Much of the wear literature uses this approach because of its simplicity.

Levy and Chik [4] used a variety of erodents of different hardness and shape in an air jet test rig with velocity of 80 m/s to look at the wear rate of steel specimens. Sharp particles of steel grit eroded the specimen at 4 × the rate of steel shot (spherical shape) all other parameters held constant. They concluded that sharp particles are more erosive than rounded particles.

Bahadur and Badruddin [5] used silicon carbide, alumina and quartz particles in an air jet erosion test rig. Particles were small (10–500 μm) and jet velocity high (40–65 m/s). CF was measured at 0.70–0.97 but accuracy is questionable given the relatively low image resolution of the camera and the small particle size. Whilst the CF values may be skewed they found the erosion rate had a power law relationship with the CF. The authors concluded that the impact of shape was equal to if not more important than particle size under the test conditions.

Desale et al. [6] also used the CF to characterise 3 different particle types for wear testing. Quartz sand, alumina and silicon carbide with CF of 0.70, 0.34 and 0.44 (respectively) were used in a slurry pot tester at 3 m/s against mild steel and stainless steel specimens. (Note – because of the spread in measured CF the average results were corrected to $CF_{modified}=(CF_{avg}CF_{max}CF_{min})^{0.33}$. This resulted in the modified values being 3–8% lower than the measured average values.) Particle size was sieved to the range 500–600 μm. The results for the erosion rate as a function of modified CF are shown in Fig. 2. Results from the prior research of Levy and Chik are also plotted. Erosion was seen to decrease linearly with increasing CF. Density and particle shape were seen as the more dominant factors at shallow impact angles.

Woldman et al. [7] used the CF to measure the shape of sand particles (0.56–0.65) over a size range of 80–500 μm with the wear measured by a dry sand rubber wheel test. Size effects were not isolated, and comparing CF with wear rate yielded no definitive correlation. Details of the shape readings were not provided however the particle size of the bulk of the particles and the boundary photos of the thresholded images bring into question the accuracy of the perimeter measurement.

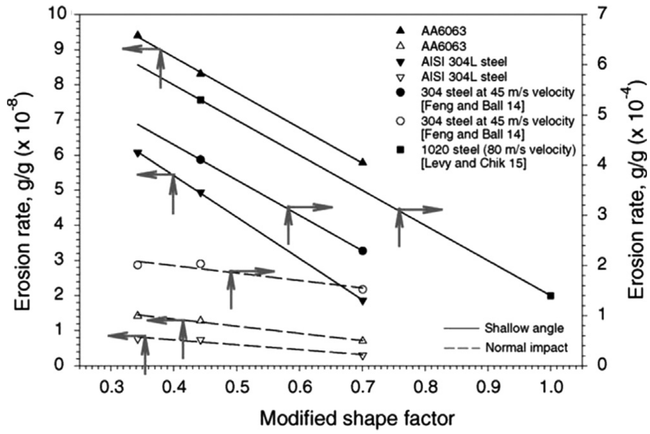

Fig. 2. Slurry pot tester erosion rate for various particle shape factor CF [7].

Vite-Torres et al. [8] used 400–420 μm silicon carbide and compared the wear rate with similar sized steel shot in an air jet tester at 24 m/s with AISI 420 stainless steel samples. The particle shape was not measured, but a quick calculation from the photographs in the paper gave the CF as approximately 0.6 for the SiC and 0.9 for the steel shot. The wear rate of the SiC particles was approximately double that of the steel shot.

A more sophisticated alternative for particle shape measurement in wear scenarios has been proposed by Stachowiak [9,10] and is called the "spike parameter – quadratic fit". This is a complex method requiring proprietary software to ascertain particle features, or "spikes" that protrude outside a circle centred on the particle centroid of average radius. The reasoning here is that only significant features that are likely to come into contact with an opposing surface are considered in calculating the shape parameter. Two different abrasion tests and an air jet erosion test were used to correlate with the SPQ calculation for a range of particles including glass beads, silicon carbide, alumina, quartz, silica sand and garnet of diameter between 250 and 300 μm . While there appeared to be reasonable linear relationship between wear and SPQ for the abrasion tests, there was no clear relationship for the erosion test [10].

To better understand the relationship between Circularity Factor and SPQ, comparison has been made by calculating CF from known SPQ values in published material [9–11] with the results shown in Fig. 3.

In an earlier study, Walker [11] used a slurry jet erosion test with alumina and sand slurries of 500 and 1000 μm size, respectively, to look at the effect of particle shape using SPQ to characterise the particles. Two different impingement angles (α=30° and 90°) were examined with 27% chrome white iron samples. The results have been replotted using the above relationship to calculate the CF values and are shown with power law trend lines fitted in Fig. 4. The results are similar to those found by Desale et al. [6]. The 90° impact angle has a lower wear rate than the 30° impact angle.

3. Experimental details

3.1. Erodent particle CF measurement

Given the close correlation between the SPQ and CF methods, the work here will use the CF approach to shape measurement because of its simplicity and no proprietary software being required.