A NEW VORTEX EROSION TEST METHODOLOGY FOR EVALUATING EROSION RESISTANCE

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ABSTRACT

Vortices are often generated in industrial slurry flows where flow disturbances exist. These can include bolt heads, weld beads, temperature sensors and other similar flow disturbances. The vortex flow generated typically leads to changed particle impact angles and velocities creating increased localized erosion. Recent work at CSIRO's Fluids Engineering Laboratory has built on previous fundamental erosion studies to develop a standardized methodology for evaluating the erosion performance of different classes of materials under vortex erosion conditions. The fundamental design is a flat plate sample with a cylindrical obstacle protruding from it to provide the vortex generation at the junction of the sample and the cylinder. These samples are then mounted in the large-scale CSIRO slurry erosion test rig and exposed to a sand-water slurry flowing at 3.6 m/s, typical of industrial slurry applications. The erosion on each sample is measured using a coordinate measurement machine (CMM). The relative erosion of mild and alloy steels, a white iron, ceramic materials and polyurethane under vortex erosion conditions was tested using this methodology. The erosion results were then compared with ceramics showing significant resistance to vortex erosion and polyurethane the least erosion of all the materials tested. These results are discussed in terms of the erosion test methodology and improved slurry flow designs to mitigate erosion.

Keywords: Slurry erosion, vortices, fluid dynamics.

INTRODUCTION

Severe erosion attack can occur in mineral processing plants where complex fluid dynamics occurs. Vortex flows are one example of a common flow situation where erosion can be severe and have been discussed in the literature by [1] in the context of a blanked tee in pipe work and [2] who examined the flow around obstacles and the consequent erosion caused by vortices trailing from the obstacle and influencing the flow on the surface adjacent to the obstacle. A summary of the details of vortex flows caused by obstacles is given by [3] as further background on this class of flows.

Erosion testing is commonly undertaken to examine the performance of materials of construction given that selection of appropriate materials is a large part of providing erosion resistant equipment for mineral processing applications. A recent review of slurry erosion test methods is given in [4]. They point out that erosion testing can have two aspects: i) developing fundamental understanding and material rankings or ii) development of erosion models for use in erosion predictions. Test systems reviewed include slurry pots, jet erosion, Coriolis testers and closed loop pipe tests.

In devising a new test methodology it is desirable that the conditions of the test corresponds as closely as possible to the erosion situation of interest. Given the prevalence of vortex erosion in mineral processing applications, it was desired that a vortex flow system be developed with the following characteristics:

- Consistent vortex action
- Simple geometry – to allow easy sample manufacture
- Able to be readily integrated into a slurry handling system
- Operated at velocities consistent with full scale slurry systems
- Useful for ranking the performance of materials under slurry vortex erosion conditions.

A vortex system which meets these requirements is the horseshoe vortex, well known as a fluid dynamic phenomenon. The horseshoe vortex is generated by an obstacle rising from a surface and the interaction of the oncoming flow with the obstacle. The basic concept of the horseshoe vortex is described in [5]. Fundamentally, the name is due to the shape of the vortex which forms as the obstacle causes the separation of boundary layer which then rolls up to form a vortex upstream of the obstacle. The ends of the vortex system flow either side of the obstacle giving it the characteristic shape. The horseshoe vortex has been studied as a fundamental fluid dynamics example up to recent times, both experimentally and computationally, such as by [6].

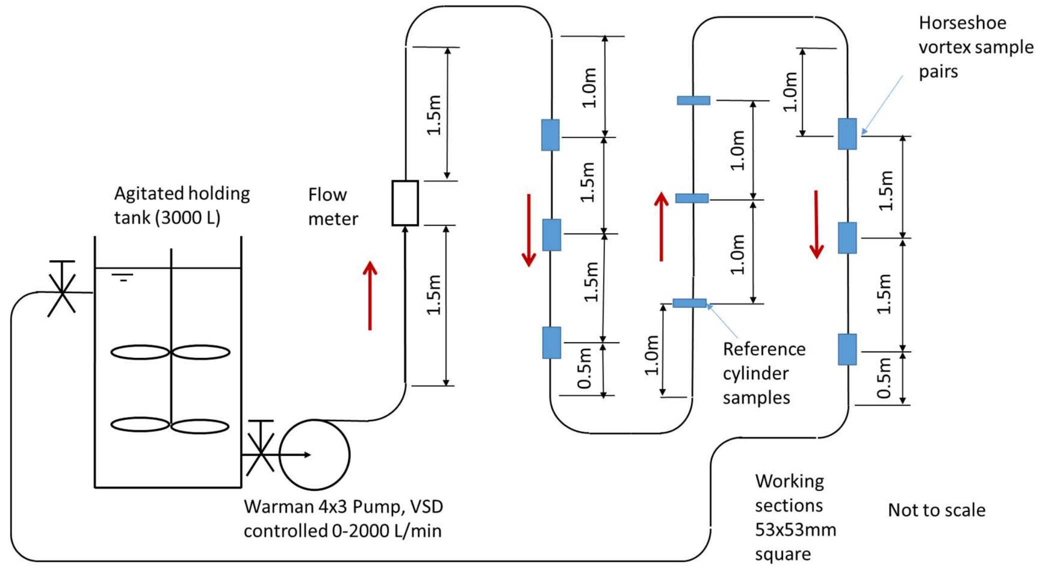
The horseshoe vortex has a real-world presence in slurry systems where obstacles are present. These obstacles can include butterfly valve shafts, bolt heads, weld beads, sensors and similar obstacles. Other applications where erosion due to a horseshoe vortex occurs are in the erosion of sediment around bridge piers as described in [7]. The horseshoe vortex is thus considered to be a realistic flow which can be used as a test system for erosion resistance evaluation.

Recently CSIRO and Alcoa have developed a test procedure to use when ranking materials for service in cases where vortex erosion might be expected to occur in slurry flows. The philosophy of the test is to test the materials under a consistent vortex flow with solid particles providing the erodent. This procedure provides a flow similar to the expected service conditions, thus the ranking of material performance should be realistic. The horseshoe vortex as described above is generated in the test rig at CSIRO in such a way that the erosion is applied to flat material samples. The present paper describes the details of the horseshoe vortex test and presents example results of erosion tests of materials of interest in slurry handling.

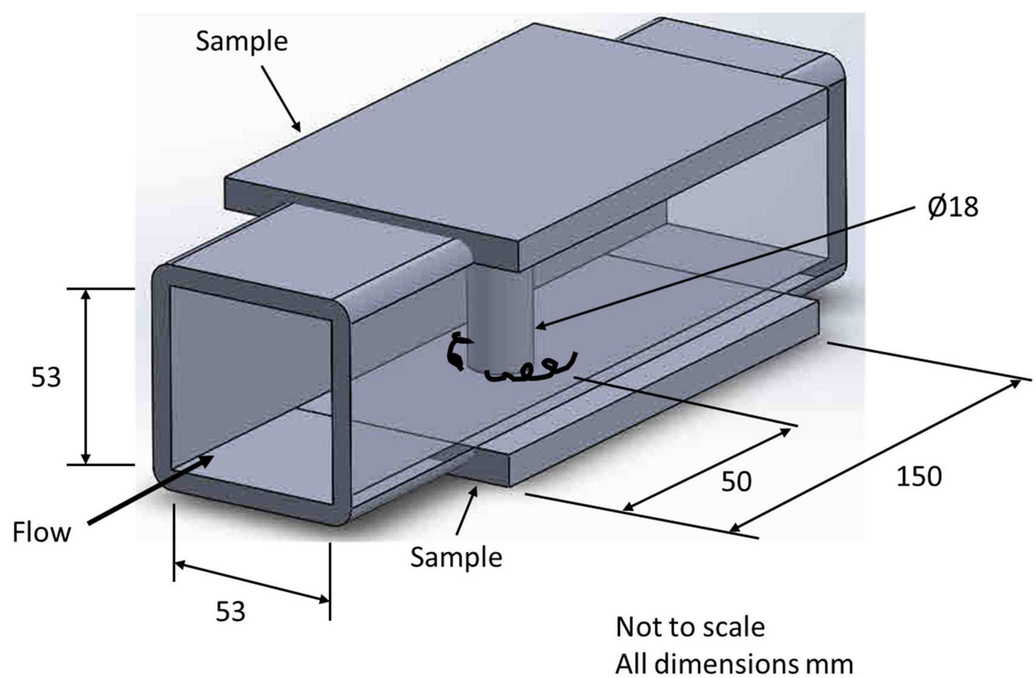
EXPERIMENTAL FACILITY

A slurry flow loop test facility was developed at the CSIRO Fluids Engineering Laboratory to perform the test program (Figure 1 a). The rig consisted of a 3000L agitated holding tank together with a Warman 4x3 centrifugal pump to provide the flow. The pump was controlled by a Danfoss Variable Frequency Drive. A Rosemount magnetic flow meter was installed in the flow loop to monitor the slurry flow rate. The tank was fitted with cooling coils connected to a chilled water system so that extended runs could be made without the slurry overheating.

Pairs of the vortex erosion samples were installed in square test sections of 53 mm by 53 mm internal dimensions. The square cross-section test sections were 1.89 m in length. Flat material samples were used in these tests with the obstacle being provided by a ceramic covered pin, generating a horseshoe vortex as discussed in the introduction and shown in Figure 1 b. A total of up to12 flat samples can be tested in the rig simultaneously together with up to three cylindrical samples if required [8]. The sample holders are installed vertically in the rig to avoid the effects of stratification of the solids concentration profile.



(a)



(b)

Figure 1 Erosion Test Rig Set-up schematic. (a) Test rig schematic, (b) test section for vortex erosion samples.

All erosion measurements were made using a Sheffield Discovery II Coordinate Measurement Machine (CMM) as shown in Figure 2. The CMM consists of a computer-controlled touch probe which is used to scan the surface of the object of interest. The repeatability of measurements made using the CMM was of the order of 3 µm as tested by repeat measurements of uneroded samples. The design of the obstacle included a step to leave an uneroded surface in the immediate vicinity of the mounting hole. This feature removed the need to take a CMM scan before the test as the uneroded surface was able to be used as the reference surface with erosion measurements being taken relative to this surface. This procedure removes one level of uncertainty in the erosion measurements as the erosion measurement is a single measurement rather than two separate measurements taken on separate occasions.

Figure 2. Sheffield Discovery II Coordinate Measurement Machine (CMM) at CSIRO Fluids Engineering laboratory

The slurry used for the test program comprised sand and tap water with sand at a concentration of 12% by volume. All tests used Sibelco Incast 70 sand with a d_{80} of 260 micron as the erodent. The parameters of the test run are given in Table 1. Figure 3 shows a Scanning Electron Microscope micrograph of the particles.

Table 1. CSIRO 2" Slurry Erosion Loop Facility Parameters

Pump description	4x3AH Weir Minerals
Test section pipe ID	53mm
Pipe loop length	~20m
Holding tank volume	~2500 L
Solids concentration	12 %v/v
Particle size d80	~260µm
Flow rate	600 L/min
Velocity	~3.6 m/s

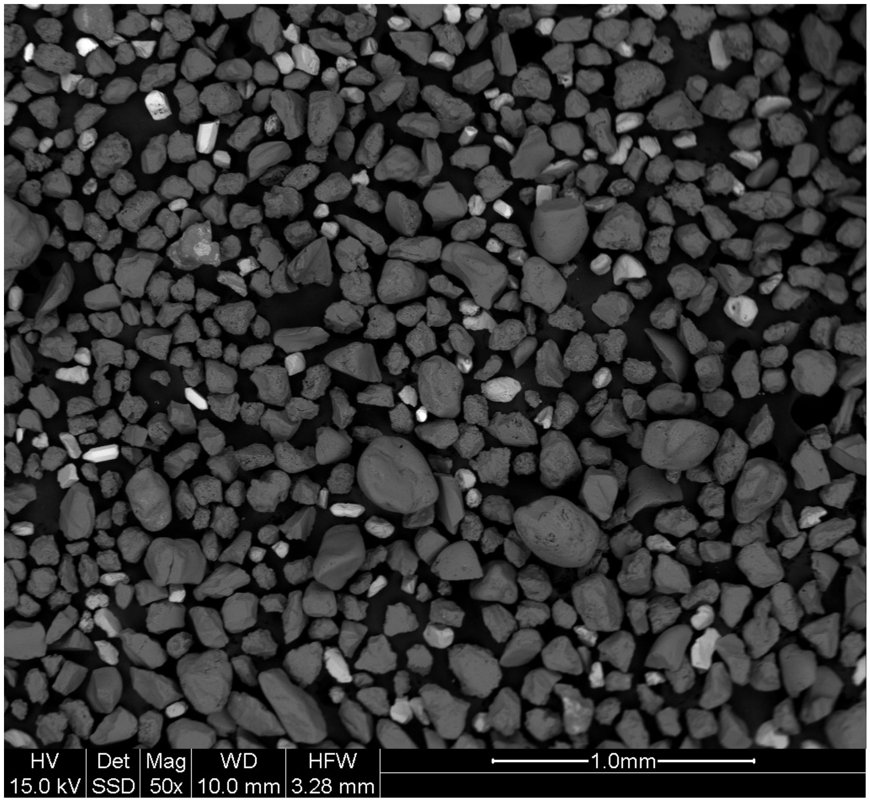


Figure 3. Scanning electron microscope micrograph of Sibelco Incast 70 sand particles.

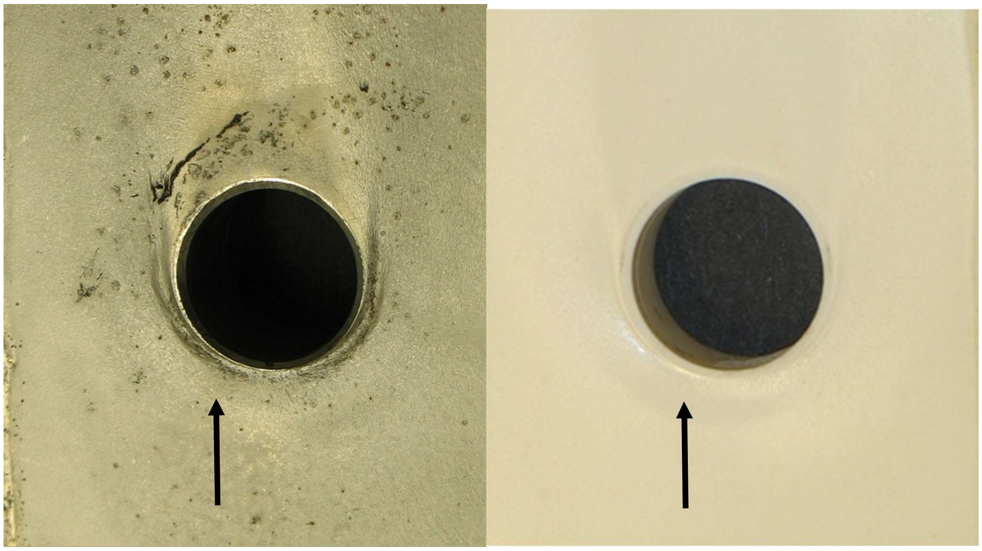
RESULTS

The experimental duration for the test run reported here was 244 hours after which the samples were removed from the test rig and measured using the CMM. The normalized maximum erosion results relative to the mild steel sample are given in Table 1 for each sample. The highest erosion measured was from the mild steel sample. The polyurethane showed the least erosion of the vortex erosion samples from this series of tests.

Table 2. Erosion test results, after 244 hours of operation, normalized with respect to the mild steel. Test velocity 3.6m/s.

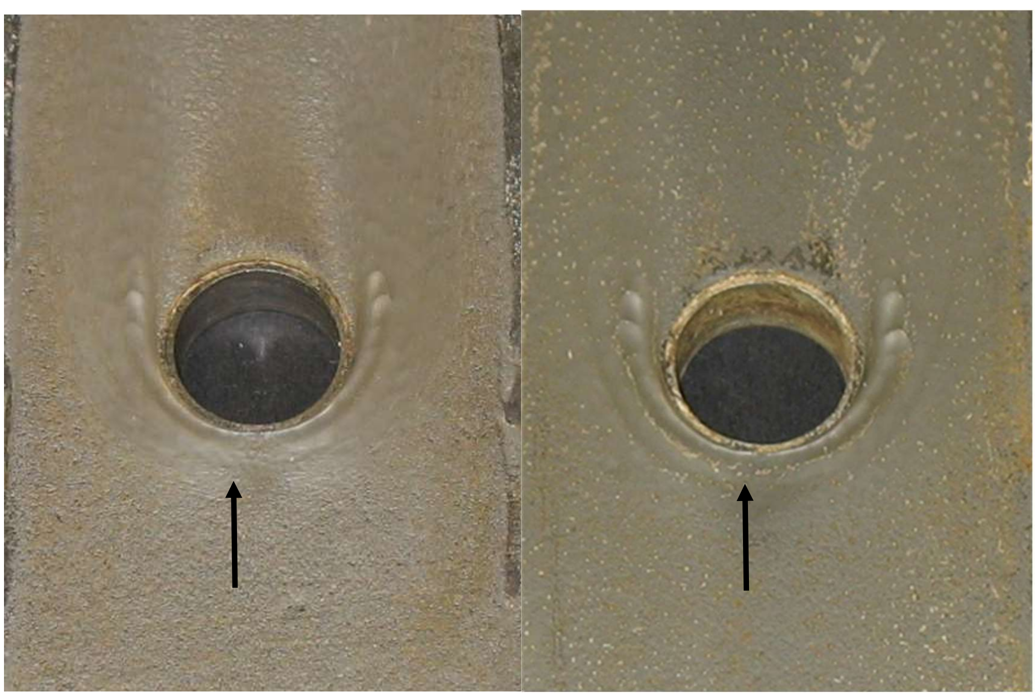
Sample	Normalized Maximum erosion
Mild steel	1.000
Bisalloy	0.754
White iron	0.270
Alumina 99.6%	0.107
Silicon carbide sintered	0.039
Polyurethane	0.013

Photographs of the erosion samples after the test are shown in Figure 4 to Figure 6. The characteristic erosion scar due to the erosion generated by the horseshoe vortex is readily identifiable, at least on the white iron and steel samples. It is less obvious on the ceramic and polyurethane samples where the erosion is much less, although the shape of the vortex and its trailing ends is clear on the sintered silicon carbide sample. Evidence of vortex driven erosion is also visible on the alumina sample.



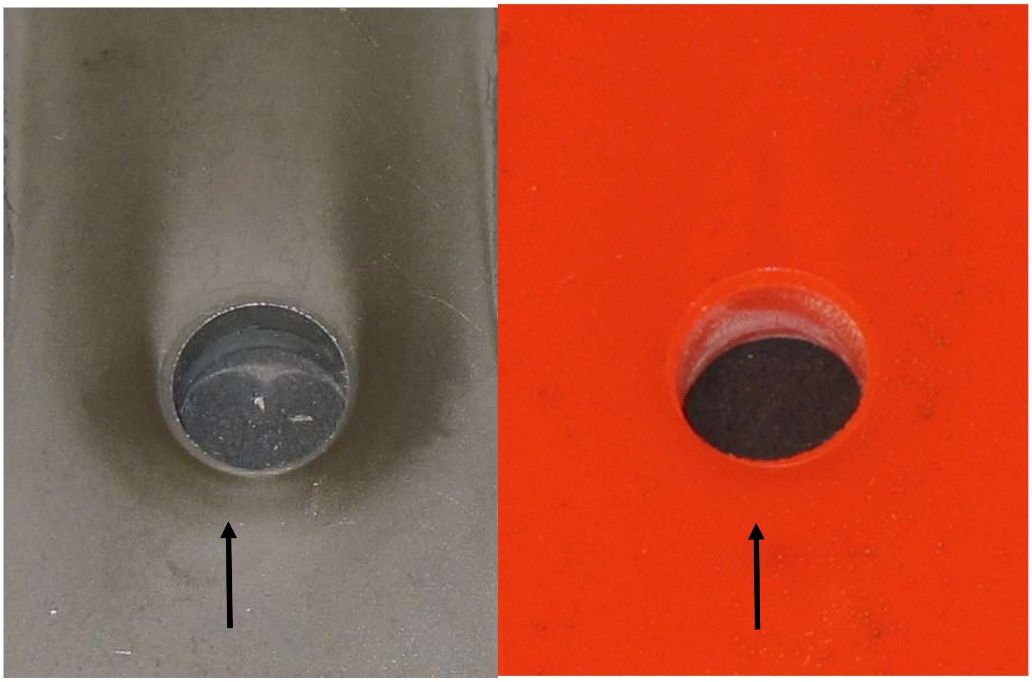
(a) (b)

Figure 4. (a) White iron and (b) 99.6% Alumina after vortex erosion test, 244 hours.



(a) (b)

Figure 5. (a) Bisalloy and (b) Mild steel after vortex erosion test, 244 hours.



(a) (b)

Figure 6. (a) Sintered Silicon carbide and (b) Polyurethane after vortex erosion test, 244 hours.

RELEVANCE TO MINERAL PROCESSING INDUSTRY

Erosion of mineral processing equipment relevant to the alumina industry has been discussed in [9] including heat exchangers, and a positive displacement pump discharge accumulator, both of which showed vortex erosion damage. Other work by some of the present authors, [10], examined vortex erosion known to occur on the blanked leg of slurry pipeline tee-junctions, building on previous work by [1]. Similar equipment is common in many hydrometallurgical applications with similar erosion issues. Changes to the flow geometry to reduce erosion have been discussed in [9] and is one available approach to reduce erosion severity. Otherwise, the effects of vortex erosion on materials as discussed in the present work can inform material selection in areas vulnerable to vortex erosion.

There is potential in the method described in this paper to explore other aspects of vortex erosion such as the effects on target materials due to changes in:

- Particle size
- Particle shape
- Particle concentration.

It is known that these parameters are of significance to erosion but the effects under vortex conditions are not yet clear. For instance, smaller particles may follow vortices in a different way to larger particles thus leading to different erosion behavior which is not necessarily intuitive. Particle shape can also depend on whether the eroding material is milled and to what degree. Further test work is desirable to explore these issues and their effects on erosion so that full scale erosion can be better modelled and mitigated.

The authors also suggest that equipment vendors consider providing material erosion test data under vortex erosion conditions to potential customers in the mineral processing industry. Given the prevalence of vortex erosion in hydrometallurgical plants, such data would be valuable to allow for the optimal selection of materials for erosion service.

CONCLUSIONS

An experimental test program was undertaken at the CSIRO Fluids Engineering to measure the vortex erosion on a variety of samples. A new test rig and procedure was developed to provide a vortex flow thus providing a realistic vortex erosion scenario. Sand particles (Sibelco Incast 70) were used as eroding materials. The present tests were 244 hours duration.

For the materials used in the present tests the polyurethane showed the least erosion of the vortex samples with the mild steel sample showing the most erosion.

Erosion due to the presence of vortex generating obstacles in a slurry flow is a relevant and common issue for mineral processing plants. Understanding the response of materials to these conditions can assist in mitigating the effects of erosion especially if used in conjunction with fluid dynamics design changes which can also reduce the severity of the erosion. A standardized test to cover the vortex erosion case such as that described here would be useful for equipment vendors and clients alike to assist the selection process for the most appropriate materials for these erosion conditions. Such a test could be used in addition to the conventional erosion test data already available.

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