OBSERVATIONS ON EROSION PATTERNS IN BAYER SLURRIES

O.C. Celliers

Alcoa, Cockburn Rd, Naval Base WA 6165, Australia.
Email olaf.celliers@alcoa.com.au

ABSTRACT

Slurry erosion damage in alumina refineries is predominantly caused by vortices and not by direct impingement, yet much of the wear characterisation of materials of construction is only available as slurry jet data, or dry sand rubber wheel abrasion data. Erosion patterns from different slurry streams in alumina refineries can be analysed to provide insight into the relative contribution provided by the different size fractions, and the type of slurry particles such as sand, iron oxide, clay, or hydrate, under different flow conditions such as sliding bed, direct impingement, turbulence and, in particular, vortices. Used in conjunction with CFD, this analysis of observed erosion patterns then provides a basis for the classification of the erosive conditions present at different refinery locations, and the best candidates for materials to be used to combat erosion; it also provides guidelines for materials development. In so doing we need to reconcile traditional measures to rank and characterise wear materials, with actual observed erosion patterns and field ranking of materials.

With the comparatively mild corrosion conditions present in the Bayer process, observations of erosion patterns in alumina refineries can be particularly useful for the development of a fundamental understanding of the effects of the physical attributes of a slurry on erosion, as the confounding corrosion component of the synergistic erosion-corrosion should be relatively small.

INTRODUCTION

Our traditional understanding of slurry erosion has been shaped by three concepts: the effects of the impingement angle and the particle size on the erosion rate, as embodied in figures 1 and 2, and the effect of flow velocity on the erosion rate as given by the equation $E \propto v^n$ with E = erosion rate, v = slurry flow velocity and n ≈2.5

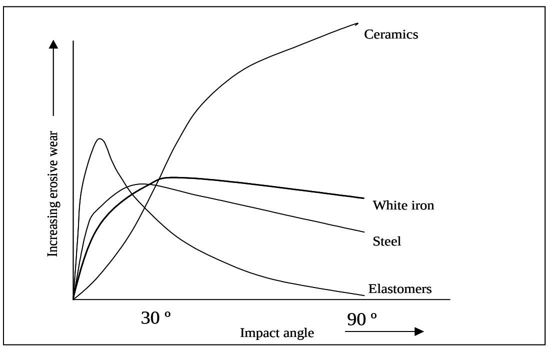

Figure 1. Effect of impingement angle on slurry erosion rate

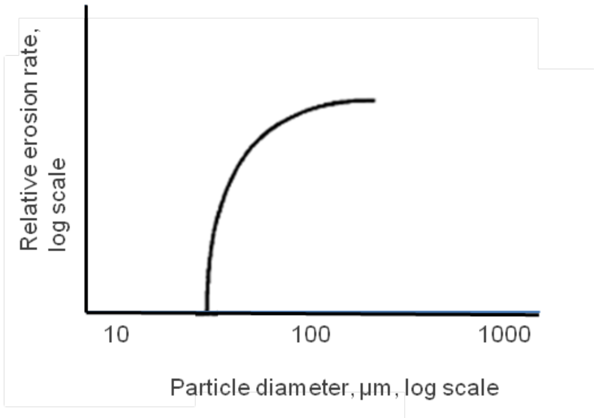

Figure 2. Effect of particle diameter on erosion rate

In long slurry lines, such as those that transport alumina refinery residue consisting of mud and sand from the separation equipment in the refinery to the residue storage area, we do indeed find that these three factors largely describe the erosion regime. In the majority of refinery pipework, though, and in and around flow equipment such as pumps and valves, an inspection of the appearance of the erosion

damage shows that flow modes much more intricate than direct impingement or sliding are involved. Figure 3 shows an impeller from a slurry pump, with clear vortex damage. Figure 4 shows the cover plate on a slurry pump, with erosion ripples. Figure 5 shows another impeller, with ripple damage with the ripples inside vortices, and figure 6 shows erosion ripples inside a vortex gouge in a slurry pump volute. These are not isolated cases, a quick look through a refinery scrap metal bin will show numerous examples of such erosion damage.

Figure 3. Slurry pump impeller with vortex damage

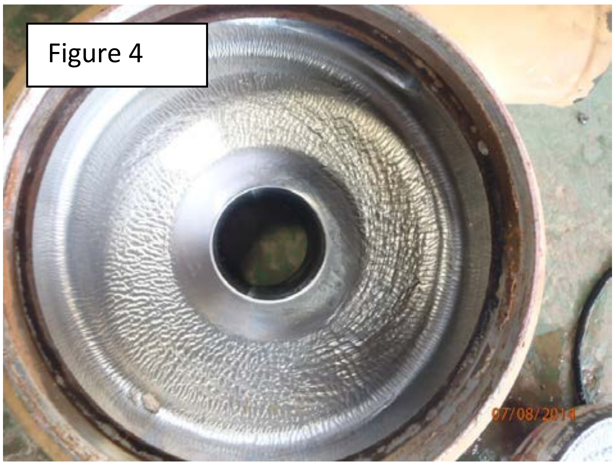

Figure 4. Erosion ripples

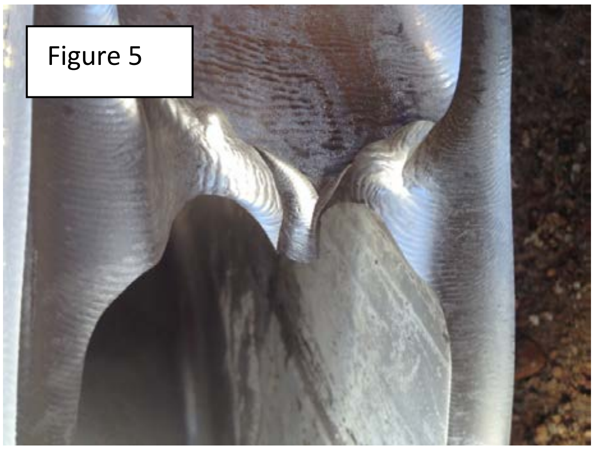

Figure 5. Erosion ripples and vortices

Figure 6. Erosion vortices at the cutwater of a pump volute

This paper attempts to show prominent features of vortex and ripple damage typically found in an alumina refinery. The following section on observations has been divided into three parts: erosion ripples, vortices, and 'localised and persistent eddies in one location'.

OBSERVATIONS: EROSION RIPPLES

Various mechanisms have been put forward to explain the formation of erosion ripples[1], with Walker [2] summarising the theories as "the ripples are thought to be initiated by turbulent eddies in the boundary layer and caused by surface roughness." The existence of ripples has been ignored in industry erosion testing and modeling.

Observation 1: Ripples can co-exist with vortices

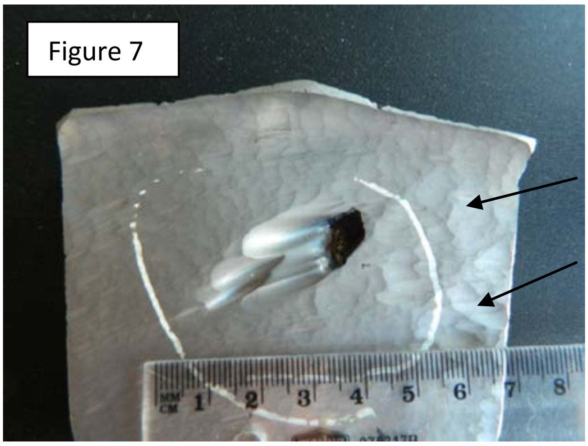

Figure 7. Erosion damage on a slurry pump part

Figure 7 shows a section from a slurry pump throatbush, material 27Cr, with a major casting defect and the associated vortices that formed. Of interest here though is the ripples and vortex gouges that formed away from, and irrespective of, the defect, as indicated by arrows. The ripple lines are roughly perependicular to the direction of flow (the direction of movement of the impeller relative to the throatbush), and appear to have degenerated in some areas into small vortex gouges a few millimetres in size. Similar vortex gouges can be seen in figure 20.

Observation 2: Ripples can occur inside vortex gouges

Figure 8. Elbow from a hydrate line

Figure 9. Other half of elbow from Fig 8

Figures 8 and 9 show an elbow from a hydrate slurry line. The arrows indicate what are assumed to be vortex gouges. Erosion ripples are clearly visible inside these gouges, and it is observed that the ripple lines run roughly parallel to what would have been the direction of swirl in the vortices, ie perpendicular to the vortex axis.

Observation 3: Ripples can exist to an advanced stage of erosion and be several millimetres deep.

Figure 10. Worn impeller from a hydrate pump

Figure 11. Obverse of Fig 10

Figures 10 and 11 show an impeller from a hydrate slurry pump, with massive vortex damage to the front and back shroud (and much less damage to the vanes). Ripples are seen inside the vortex gouges, with the ripple line more or less perpendicular to the vortex axis, and with the ripple peak to valley distance (the ripple depth) ranging from a largely optical effect to more than a millimetre.

Observation 4: A ripple pattern can under some conditions degenerate into chaotic holing.

Figure 12. Slurry pump throatbush

Figure 13. Enlargement of fig 12

Figures 12 and 13 show a throatbush from a mud slurry pump. Ripples are visible, as well as a spiral pattern of small and shallow vortex gouges that degenerate into a chaotic pattern of large holes.

Observation 5: Fine slurry particles give rise to a fine ripple pattern, coarse slurry particles give rise to a larger ripple wavelength.

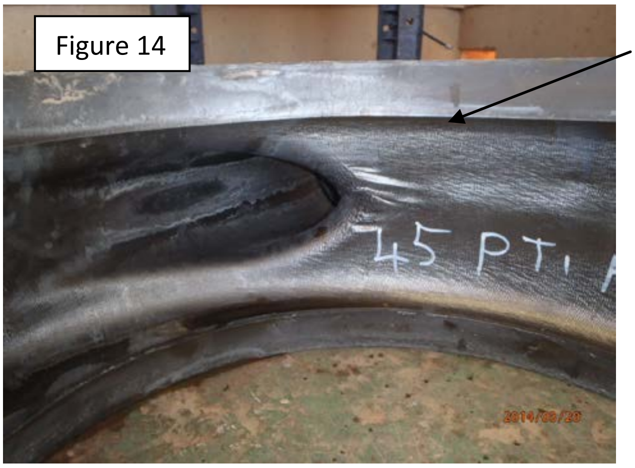

Figure 14. Cutwater of hydrate pump volute

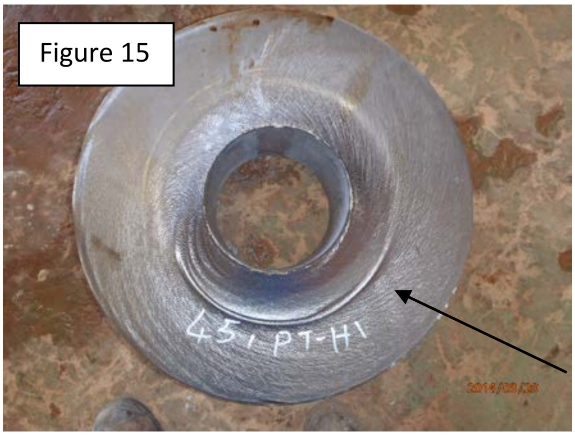

Figure 15. Hydrate pump throatbush

Figures 14 and 15 show the fine ripple on pump parts from a hydrate slurry pump.

Figures 16 and 17 show the much coarser ripple on a bauxite-slurry-to-digestion pump parts.

Figure 16. BSD pump volute

Figure 17. BSD pump throatbush

Mud pumps also show much finer ripples than sand pumps, where in general mud is defined as < 150 micron particles and sand > 150 micron.

OBSERVATIONS: VORTICES

Observation 6: Vortices and vortex erosion damage can be found where flow separation from a surface occurs. In this case the erosion gouge coincides with the long axis of the vortex.

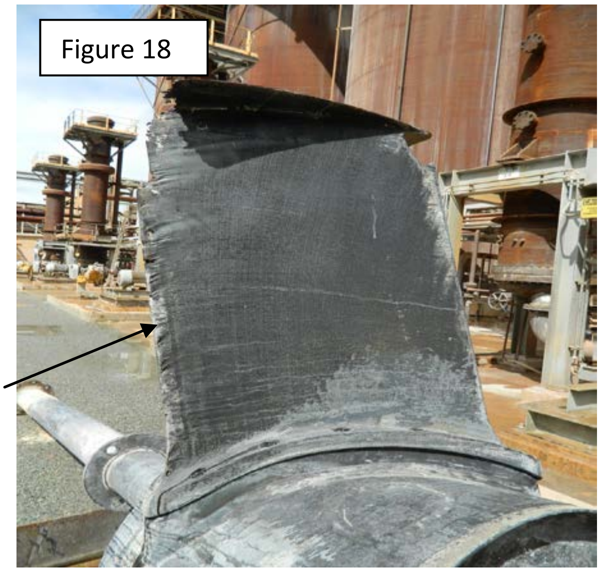

Figure 18. Precipitation tank blade

Figure 18 shows a blade from a precipitation tank mechanical agitator, with vortex erosion damage along the leading edge.

Observation 7: Some swirling flow conditions can give rise to the apex of a vortex drilling into the equipment wall

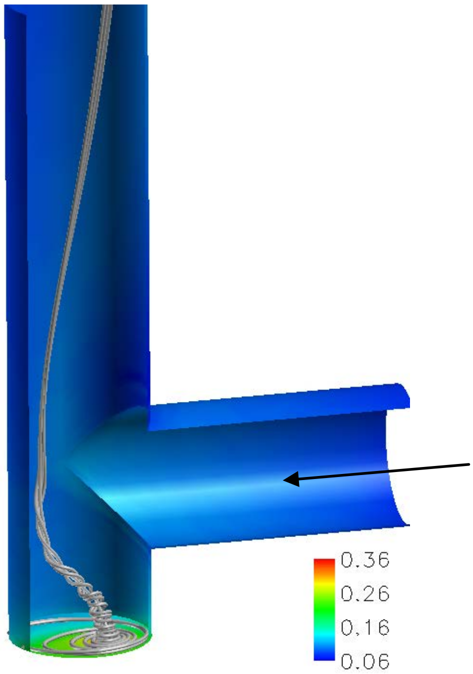

Figure 19. CFD model of vortex in flow

Figure 19 shows a schematic layout of a blind T that has been found to be susceptible to vortex erosion. Notice that the part of the vortex that is in contact with the equipment is the apex.

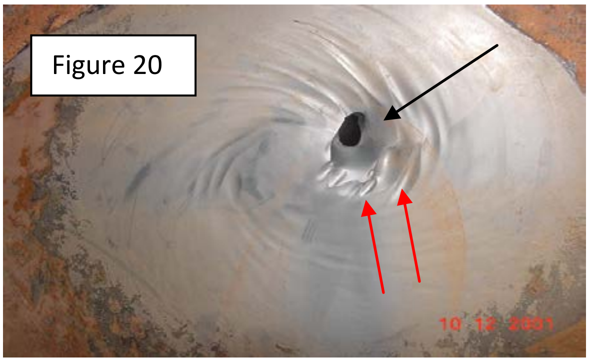

Figure 20. Eroded blank from a blind T

Figure 20 shows an example of vortex erosion observed on a blind T blank, indicated by a black arrow. The vortex apex has drilled a hole through the steel. Notice also the much smaller vortex gouges, indicated by red arrows, that appear to have been formed by vortices with axes more or less in the plane of the blank.

Observation 8: Horseshoe vortices at the cutwater in slurry pump volutes have large diameters if the slurry particles are coarse, and smaller diameters if the particles are fine

Figure 21. Mill product pump volute

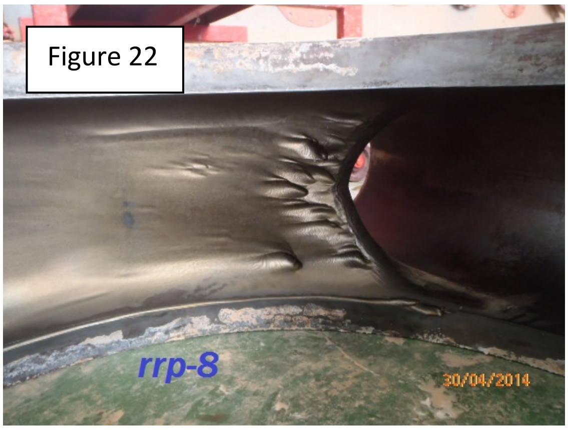

Figure 22. Hydrate pump volute

Figure 21 shows a 'horseshoe vortex' in a mill product pump, where the eroding particles can be mill scats several millimetre in diameter. Figure 22 shows the much finer vortex gouges at the cutwater in the volute of a hydrate pump. Also notice the erosion ripples inside these vortex gouges.

Observation 9: Associated secondary vortices often form some distance away from a main vortex or flow disturbance.

Figure 23. Mud booster pump volute

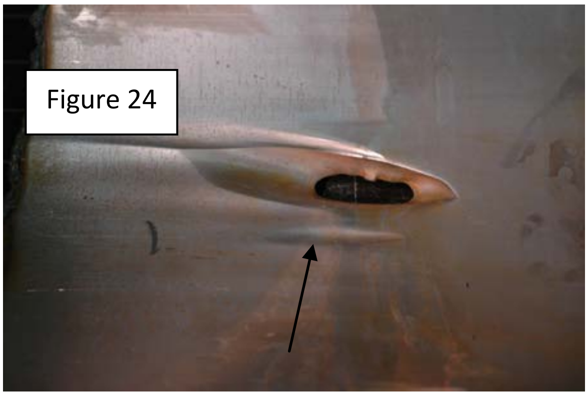

Figure 24. Vortex damage in a slurry line

Figures 23 and 24 show secondary vortices that have formed some distance from the main vortex.

OBSERVATIONS: LOCALISED AND PERSISTENT EDDIES IN ONE LOCATION

Observation 10: Some spherical erosion gouges appear to have been caused by localised and persistent eddies in one location

Figure 25. Worn hardfaced slurry spool

Figure 26. Enlargement of fig 25

Figures 25 and 26 show ball-shaped depressions in the hardfacing on a slurry spool that could have been formed by stationary turbulence, or an eddy that stays in the same location over time. Figures 27 to 32 show similar erosion gouges in different slurry pump parts.

Figure 27. Slurry pump throatbush

Figure 28. Slurry pump impeller

Figuer 29. Slurry pump volute

Figure 30. Slurry pump throatbush

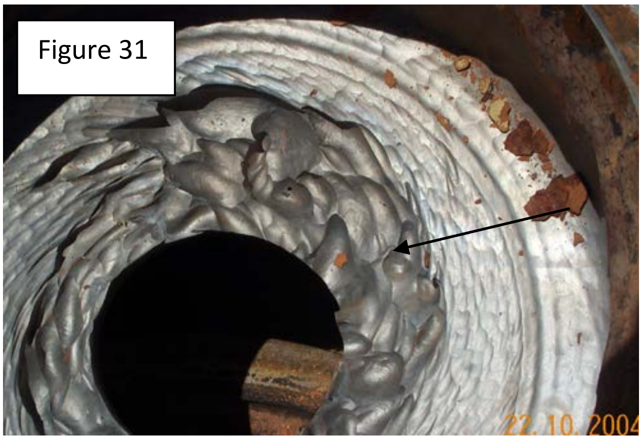

Figure 31. Slurry pump throatbush

Figure 32. Slurry pump throatbush

DISCUSSION

These observed ripple patterns and erosion gouges raise a number of issues.

Impingement angle

If vortices and standing turbulence are involved, the notion of impingement angle becomes a gross oversimplification. At the apex of a vortex acting perpendicular to a surface, such as in Figure 19, the impingement angle should be zero, but along the sides of a vortex such as a horseshoe vortex at the cutwater of a slurry pump volute, the impingement angle will change with the depth of the gouge. It looks likely that a range of impact angles are involved as erosion gouges develop.

The effect of particle size

Larger particles will not be able to follow the fluid path in a vortex as well as smaller particles, so that smaller particles should be relatively more important in this type of erosion. This is the opposite of the usual view of the role of particle size in erosion, where smaller particles follow the fluid and curve away before hitting the sample or equipment surface whereas the larger particles are less coupled to the fluid and therefore hit the wall. Smaller particles in the traditional view have lower collision efficiency than larger particles.

If this is correct, then erosion involving vortices will involve smaller particles more, and the erosion mechanism will likely involve washing out of the matrix in between hard secondary particles more than fracturing of hard secondary particles in the case of the white irons.

The effect of flow velocity

In vortex erosion the damage is caused by the much larger number of impacts between the particles in the vortex and the equipment surface, rather than one impact by each particle in the traditional once-through mechanism, so the 'vorticity', or the propensity of the flow to form vortices, will have a larger effect than the actual flow velocity.

OVERALL OBSERVATIONS

1. Vortices and localised and persistent eddies in one location cause a large part of the erosion damage in alumina refineries, compared with direct impingement and sliding.

2. Erosion ripples appear to be linked to the formation of vortices, but the link at this stage is not clear.

ACKNOWLEDGEMENTS

Some of the photos of worn slurry pump parts were taken by Alcoa's Pinjarra Alumina Refinery Central Maintenance Team Pump Crew under the guidance of Jim Hair. Figure 19 is from work by Gary Brown.

REFERENCES

1. Karimi, A., Schmid RK, 1992. Ripple formation in solid-liquid erosion. Wear, 156, 33 – 47
2. Walker, CI. Wear in Centrifugal Slurry Pumps, published by Weir Minerals Australia