Improved Performance in a Stirred Mill: The Hidden Trade Off

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In a processing plant, new ideas are often born out of necessity, such as a need to reduce maintenance downtime. Downtime typically inspires the development of new components for most major equipment in a processing plant. In the case of stirred mills innovative developments have included new wear compounds (PU, Ceramics, and different types of rubber) and internal designs (discs, rotors, pins, etc.). Whilst such modifications facilitate an improvement in the overall availability of equipment at face value, what is typically less communicated is the influence on efficiency these changes contribute to a process. Using the IsaMill™ as a case study, this paper demonstrates how material selection may not only reduce mill downtime, but also influences the overall specific energy for grinding, why it is important to understand materials of construction in testwork, and the processes involved in evaluating new materials and designs prior to market release.

1.0 Introduction

In industrial processing plants, new ideas are often born out of a primary necessity, such as a need to reduce maintenance downtime. Quite often, when new components or materials are trialled, the need to reduce downtime comes at the expense of energy efficiency. However, since most of this type of testwork is conducted within brownfield installations, very rarely, in the author's opinion, do implications of specific energy and grinding efficiency get considered.

When this paper was initially conceived, the aim was to show how material selection can influence specific energy. However, after recently seeing the results from a poorly run component trial, it was felt that the paper could be expanded to provide guidance on running trials in any stirred mill (using the IsaMill™ as a case study).

2.0 Material Selection and Impact on Specific Energy

Material selection of internal components has always impacted the specific energy of the stirred mill. This logically makes sense when you consider the mechanism of kinetic energy transfer between ceramic media and the rotating discs. A hard surface such as steel will transfer energy through shearing the bed of ceramic media in comparison to softer rubber or rubber lined components which accelerate the media via shearing and friction.

One of the best examples of this impact of material selection behaviour is Figure 1, where an attempt was made to develop an optimum stress energy curve by grinding silica. Testing various process parameters was repeated under two different material combinations for the grinding chamber and stirrer. A difference in the specific energy between the PU-PU (upper curve) and ceramic-ceramic (lower curve) combination became apparent very quickly, resulting in two optimum curves (Sterling, et al 2024) highlighting that material selection has significant influence on performance.

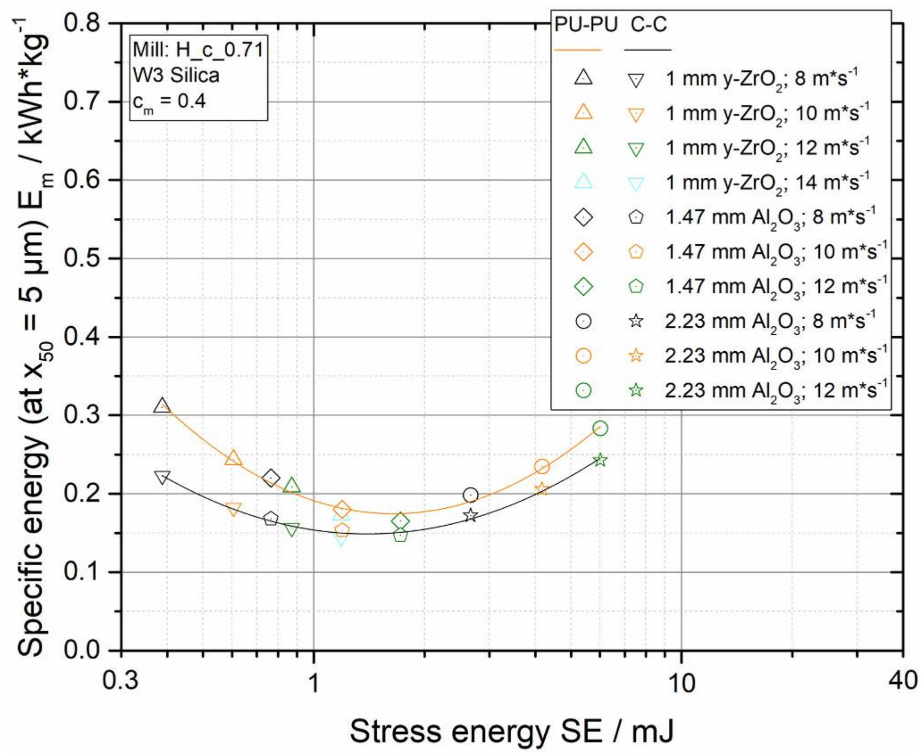

Figure 1 - Stress Energy Optimum Curve - D50 - 5 micron (Sterling et al, 2024)

On a side note, and from an unfortunate lesson, when using ceramics for material trials, it's always important to know their hardness. A ceramic grinding chamber liner with a lower hardness than the ceramic media will fail rapidly.

Historically, some of the IsaMill™'s stirred mill competitors have utilised steel components. Steel components in the IsaMill™ were historically never commercially used due to a combination of high parts wear, and the severe detrimental impact on process efficiency.

The harder ceramic media caused accelerated wear leading to steel disc failure, with lower process performance being attributed to poor energy transfer from the rotating discs to the media. Rather than the faces of the discs allowing friction to accelerate and/or maintain momentum of moving media, the media tends to slide off the steel disc. Thus, the only mixing came from shearing the media bed via the edges of kidney holes, the disc face contributing only minor energy transfer. This results in a significant drop in efficiency.

This influence of materials is not IsaMill™-specific either as other mill examples include Paz et al, 2021 where it was found the Operating Work Index on a HIG mill decreased by 10% using rubber rotors (rubber lined to manage wear) when comparing it to the HIG 5 testwork on steel discs. This highlights the importance when conducting material trials, that it is important to carry those materials through to the testwork phase if the full-scale mill utilises those materials/compounds.

2.1 How Materials Are Trialled in an IsaMill™

The M4 IsaMill™ Signature Plot test is widely accepted as the industry standard for specific energy determination which is performed by accredited laboratories worldwide. It is known for the highly accurate 1:1 scale-up, with numerous (Ernest Henry, Anglo Platinum, MacArthur River Mining etc) previously published examples (Gurnett et al, 2022).

Pilot scale testing to replicate results obtained within the M4 or for testing alternate internals on continuous streams under plant conditions can be done with an M20 or M100 pilot IsaMill™.

Comparative material components testing can also be undertaken with full-scale mills, with Glencore Technology regularly undertaking material tests to evaluate both wear and process performance.

2.2 Material Evaluation in a Laboratory

If a material change is being considered within a full-scale mill, ideally the mill operator should run representative testwork in a laboratory. In the case of the IsaMill™, a signature plot is conducted.

The aim of running the signature plot is to evaluate what influence the proposed changes will have on specific energy. If it reduces the efficiency of the process, there would likely be an increase in the media load within the full-scale mill or a coarsening of the grind size. Figure 3 demonstrates this concept when PU, Duro 40 and Duro 60 discs were tested to evaluate the overall effect on specific energy. It should be noted that the test operator is accredited in the procedure to ensure that their results scale up 1:1 with a full-scale mill.

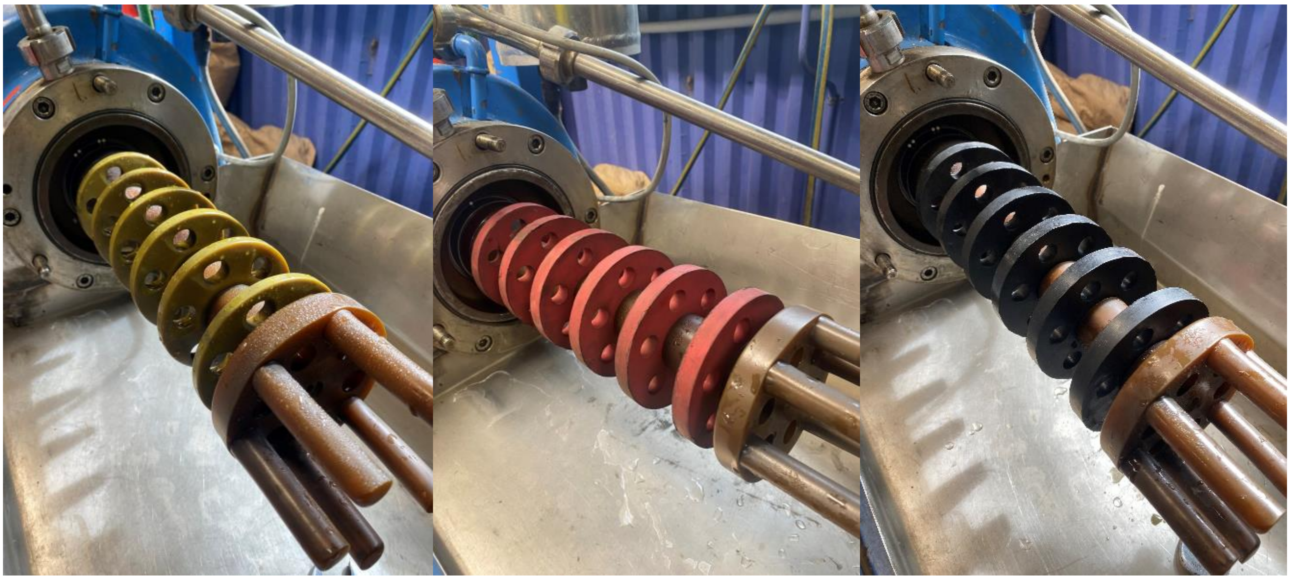

Figure 3 - In order of appearance, PU, Duro 40 and Duro 60 discs tested on an M4

Table 1 shows the trials' results. As a baseline, it is expected that if there is a greater than 10 % difference in Specific Grinding Energy (SGE) it is likely to have a noticeable effect on a full scale mill. In the example listed, the Duro 40 disc relative to the PU and Duro 60 would likely require a larger volume of media to maintain the same grind size.

Table 1 Specific energy for three material types and percent error difference relative to the PU disc

Grinding Energy (kWh/t)				
Particle size (µm)	30	25	20	17
PU	12.2	18.6	31.3	45.6
Duro 40	14.4	21.5	35.2	50.3
%Difference	17.9%	15.4%	12.5%	10.4%
Duro 60	12.2	19.4	34.5	52.5
%Difference	0.0%	4.3%	10.4%	15.1%

As the IsaMill™ typically operates close to 70% media loading, it is possible to increase the media load up to 90% to compensate for any deterioration in efficiency due to material selection. However, this will likely increase media consumption and need to be considered when conducting the economic model for the mill, as the cost of the media may outweigh the cost of parts replacement.

2.1 Full Scale Installation Testing in an IsaMill™

As there are thousands of different materials that can be tested, how does Glencore Technology evaluate what is worth considering? Glencore Technology tests materials within full-scale IsaMill™'s to determine their wear characteristics through pizza flange testwork (Figure 2). This is installed in an operating IsaMill™ on the Non-Drive End Flange (next to the feed inlet where most of the media interacts with the liner). The Non- Drive End Flange is selected as the internal classification mechanism (rotor) keeps the media up the feed end of the mill and is likely to ensure that it is exposed to the harshest grinding environment in the IsaMill™. It is normally best to install the pizza flange into a mill that is currently treating an abrasive material, e.g. platinum or magnetite.

Test pieces are stored next to control pieces to determine how the wear components perform relative to the existing preferred material selections. To ensure the best performance is seen trials can run from around 6000 to 10000 hours with longer duration eliciting the most accurate results. More than a hundred trial slices have been tested over the year and materials have ranged from PU, Tungsten Carbide, Ceramics, Duro40, Duro50, Duro60 and Duro70 Rubbers.

Figure 2: Pizza Slice Modelling (Gurnett et al, 2021)

Interestingly, from experience, it has been found that some rubber compounds, like Duro40 rubbers, can wear very differently between suppliers as they are designed for different applications. Hence, there is a need to test them prior to converting components to them. An example of how wear rates look relative to controls can be seen in Figure 3 below; as evidenced, none of the test pieces have wear rates less than the control samples.

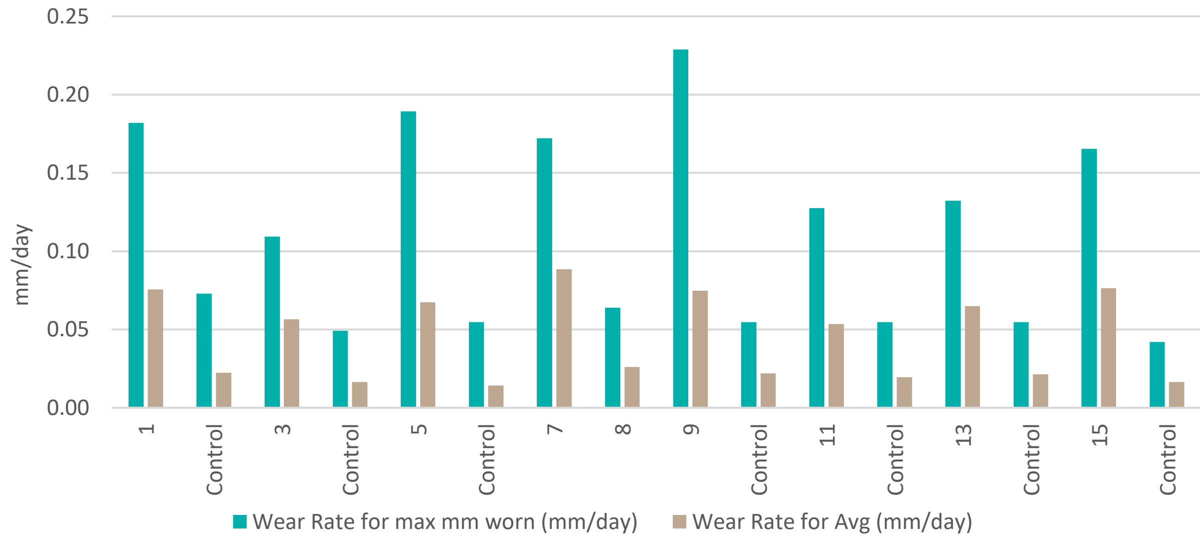

Figure 3: Example of Pizza Flange Wear Rate Comparisons

This approach has allowed Glencore Technology to develop components such as Duro 60 (improved thermal resistance properties; harder) rubber discs, which have fed into developments such as the dual compound discs.

3.0 How do I Test Variations to Mill Geometries

Component testing is significantly more complicated than material selection for a fixed component. Materials directly correlate with wear, while disc shapes have a significant impact on flow behaviour within the mill. Changing the flow dynamics can result in significant wear characteristics. Therefore, if you are changing the flow behaviour in the mill, it is always recommended to talk to the Original Equipment Manufacturer (OEM) first.

Glencore Technology utilises a cost-effective solution to evaluate many different designs via Polyurethane (PU) discs for a pilot mill (M20 - Figure 5 below) to demonstrate the concept, negating the need for complex process modelling.

Figure 4: M20 Pilot Mill

3.1 Pilot Component Trials – Shapes – M20 Scale

The following example is of recent alternate disc component trials for a coarse grinding application in a lead zinc concentrator in Australia. As feed conditions can fluctuate greatly in many plants, it can be challenging to get a consistent feed. One simplified method to evaluate disc designs with real plant conditions is to look at the upgrade (reduction ratio) for a fixed media load (the same theoretical power application). It is key to evaluate both variance in drawn power, as well as multiple media loading conditions, to provide a more accurate evaluation of the potential for new disc geometries. While a disc may be able to draw more power this does not necessarily equate to improved energy efficiency, as shown in Figure 5.

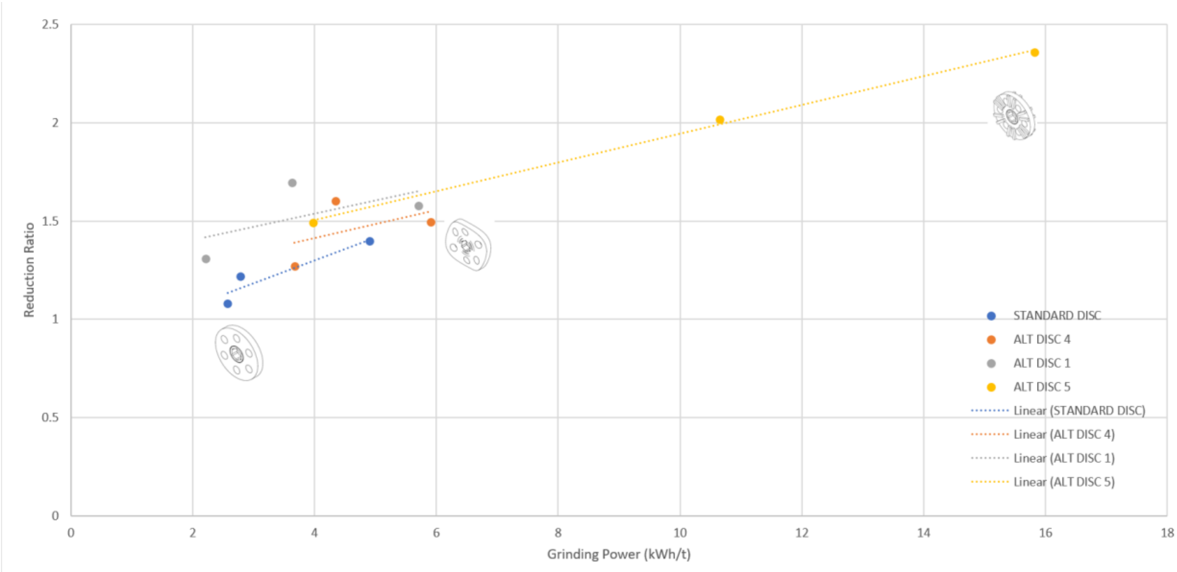

Figure 5: Reduction Ratio vs Grinding Power – 35Hz

In Figure 5 there is a low, approximate linear correlation between the reduction ratio and grind power for the discs. When comparing all discs together there was no apparent statistically significant change in their grind efficiency (when considering a generalised slope of the linear relationships).

Significantly more operating points would assist in more accurately quantifying the differential performance; however it should be stressed that pilot work for proof of concept should be undertaken with that in mind. Evaluating a generalised performance to identify outliers allowed more rigor to be applied to the appropriate designs in further stages.

In coarse grinding applications, the IsaMill™ needs to reduce the tip speed to manage the wear characteristics, hence why the results in Figure 5 are operating at 35 Hz. As tip speed correlates almost directly with wear. Since the success criteria deemed this trial successful and there were no fatal flaws with the trials, all discs were carried forward for testing in larger pilot mills.

When looking at the castellated disc (Figure 6), there did not seem to be any evidence at a pilot level that performance had improved relative to standard flat discs (just a higher power draw). However, due to the claims of the castellation improving efficiency (it was continued forward for another trial to evaluate these claims.

Figure 6: Worn Castellated Disc and M100 Trial Disc

Less quantifiable are other valuable outcomes (such as wear profiles) from comparative plant trials.

For example, certain disc shapes during this trial had to be limited with lower tips speeds, with the change in fluid behaviour from these geometries promoting media distribution into the discharge arrangement of the mill. This behaviour is consistent with anecdotal performance of alternative geometries which have resulted in high discharge component wear within IsaMills.

3.2 Component Trials – Guidelines for Setting up a Component Trial Design

Once a component has been developed it is necessary to evaluate the performance in a fair and consistent manner. The first step of any trial is reviewing the process data (a minimum of a month's worth of data at 5-minute intervals) and optimising the mill to run at the best condition possible prior to the trial. Otherwise, claims of performance can be grossly exaggerated, which, in the author's opinion, happens too frequently. Therefore, it is recommended that the set-up of the trial should consist of:

1. Define what success looks like. For example, does it need to improve the life of the existing part, draw more power, or improve efficiency?
2. Optimise the mill circuit to ensure that it is running as efficiently as possible. For the IsaMill™, it is recommended that you follow the guidelines outlined by Swann et al., 2023 to optimise the mill prior to a trial.
3. Ensure that the base case set-up is comparable. For example, as identified in this paper, if a new disc is made of PU, it should be compared to a standard PU disc since the material type will affect the mill's overall performance.
4. The same volume and type of media charge should be consistent between the trials.

Once the trial base case has been set up, it is always recommended to increase the media loading to see the effect of the component. This allows you to develop a signature plot if the feed is consistent or look at the upgrade ratios. Surprisingly, some discs can work better in compressive environments versus a more free-flowing, fluidised environment.

When the trial is run, it is recommended to survey the following streams, they are graphically represented in Figure 7:

- **Cyclone Feed**
- **Cyclone Overflow**
- **IsaMill™ circuit fresh feed (Cyclone Underflow)**. If IsaMill™ feed comes from pre-cyclones, cyclone feed, underflow and overflow must all be sampled for a complete mass balance to calculate the fresh feed tonnage.
- **IsaMill™ Feed**
- **IsaMill™ Discharge**
- **(Optional) IsaMill™ Circuit Discharge** – Combined pre-cyclone overflow and IsaMill™ discharge.

Because of the recycle around the IsaMill™, mill fresh feed (not mill feed) needs to be used when calculating specific energy (compared to the power in the mill per tonne of fresh feed treated). It is also important to ensure that viscosity is monitored via the Marsh funnel.

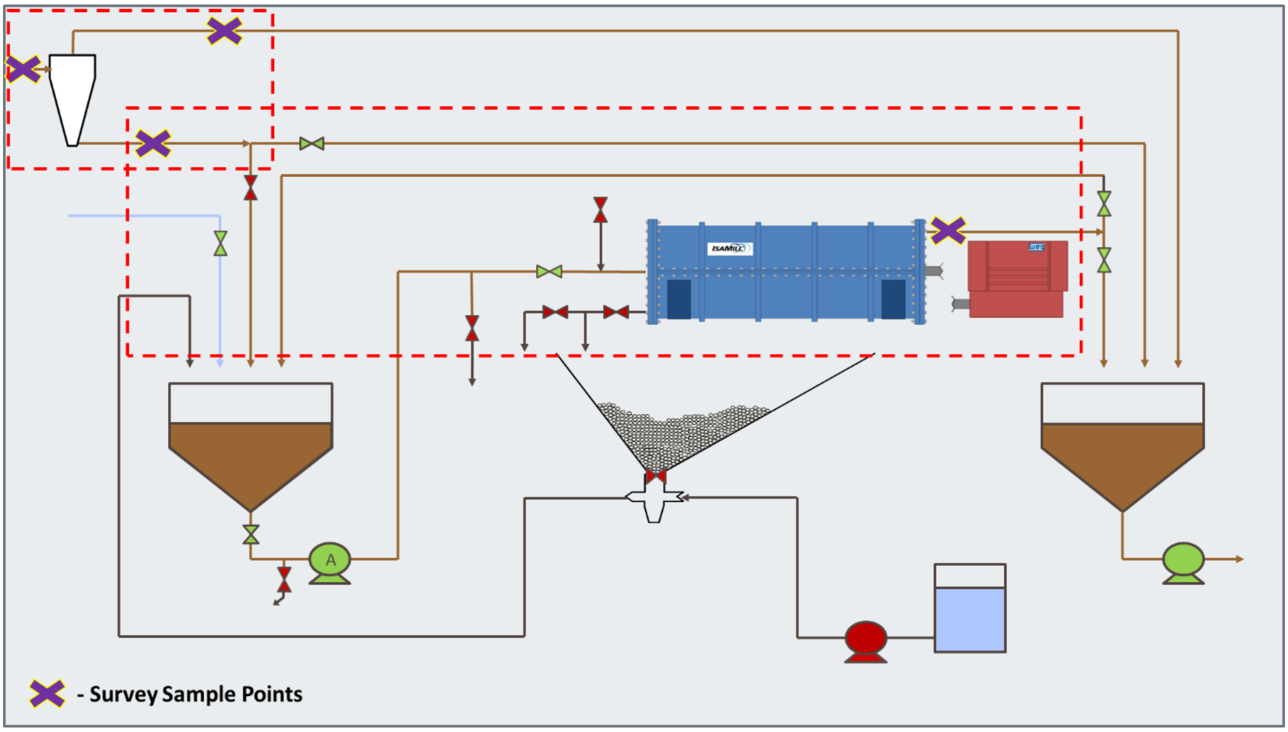

Figure 7: Survey Sample Points for an IsaMill™

Cyclones are surveyed because most issues reported with regrind circuits are typically associated with poorly maintained or operated cyclones. Many "sliming events" can be attributed to a bimodal product from the cyclone overflow being vastly different from the mill discharge in open circuit designs (Swann et al., 2023).

Conclusion

This paper aims to detail how materials are tested and processes for evaluating different components. The authors hope that this paper acts as a benchmark for setting up trials and evaluating components to get the best performance out of your stirred mill.

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