A CRITICAL REVIEW OF GRINDING DESIGN PROCEDURES FOR THE 21st CENTURY

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Introduction

There are four main aspects of SAG mill design that will be discussed in this paper. The first and most important is the samples that are taken upon which the design is to be based. The second is the testwork that is done on these samples to determine the energy requirements. The third is the interpretations of test results using sound engineering principles, that allow definitive energy requirements for SAG and Ball Mills to be picked, and fourth, the assignment of mill dimensions required to draw required power.

There have been many ways used to design commercial SAG and AG grinding circuits. The success of each is often related to how much money the client was prepared to spend and what degrees of freedom the designer was given to complete his work. An understanding of hardness variance in the context of a real mining plan is required because any loss in throughput due to an undersized mill will probably cost the client many times the amount of capital saved. Testwork cost and accuracy play key roles.

It is not acceptable to blame the lack of performance in a mineral processing plant on unrepresentative sampling. It is the Consulting Engineer's job to make certain that this does not happen. It is also unacceptable to say that an in-circuit crusher may be required. The choice for using a crusher or not can be successfully made before the plant is built. In cases where the extent of the ore body in not known at the start, the use of forward-looking process selection can be used to the client's advantage.

Discussion of Terms

Since its inception in the mid 1950's autogenous grinding has created a suite of new terms and ideas.

Consider the following commonly accepted guidelines and terms. Comments are added.

- Large pieces of ore are needed in an autogenous mill to make it grind at peak performance. This may be true under certain conditions but it is not true under all conditions.
- Critical size is a term used to describe coarse ore that builds up in a SAG mill. It is hard. But the reason it builds up is that the mill does not have enough power to grind it.
- Autogenous Work Index or AWi is a term used to relate SAG mill Feed and Product sizes to consumed energy, using Bond equations. Its value is determined in the MacPherson Test or as an operating work index by using values from an operating circuit. Its value is only valid at the stated SAG product size.
- Transfer size (T_{80}) is the term used to describe the SAG mill product that is sent to the ball mill. For peak performance and balancing the power available in the SAG mill and ball mill, the transfer size must be measured and controlled.
- The transfer size will be 500 microns using a 12mm opening trommel. This can be true under special conditions of operation when treating fine ore at high mill density, but in general the transfer size for such a trommel will lie in the range of 2 to 6 mm.
- Fine grinding in a SAG mill is less efficient than in a ball mill. This is true with respect to the creation of a finished SAG product (P_{80}) in the order of 75 microns but when the SAG product is in the range of 500 to 2000 microns, the energy required to grind between these sizes is approximately the same whether done in the SAG mill or the ball mill.

Sampling

It is clear from the discussion above that sampling is the key to designing a SAG grinding circuit. That this is true for any SAG design method should be self-evident. The designer should be more concerned with the representative hardness variance profile than with a representative sample, which in most cases the mill will never see and which will be very misleading if it proves to be softer than the median hardness for all of the ore. The criteria for selecting the samples can take several different forms. The most comprehensive form is to explore the entire deposit for hardness variance. Depending on the deposit size this can take hundreds of samples. Sometimes time constraints or lack of money dictates an alternate approach. If a partial analysis is indicated it is imperative to sample the hardest zones. As a minimum, several ore zone intersections should be tested, with sample breaks at geological contacts, and at planned bench heights. It is recommended that the sampling be done to represent ore units that can be delivered to the mill in a given day. The selection of samples also needs to be focused on the first several years of ore in the mine plan.

Hardness Tests

Commonly used hardness tests are listed below.

- Bond Rod Mill Work Index Test
- Bond Ball Mill Work Index Test
- Bond Abrasion Test (High speed vanes)
- MacPherson Autogenous Wi Test, AWi
- JK Tech Crushing Work Index - Pendulum Test
- Autogenous Abrasion Test
- Bond Crushing Work Index Test
- SAG Power Index (SPI) Test

Design Methods

Common design methods include the following.

1. MacPherson. In house interpretation.
2. JK Tech. Software, JK Simmet (Grinding/Process Simulation Package)
3. Fluor Daniel Wright Ltd. Software, GRINDPOWER for the Sizing and Selection of Grinding Circuits.
4. Minnovex. Software, CEET (Comminution Economic Evaluation Tool)
5. Starkey & Associates, Manual analysis and small scale pilot plant – Public information is now being taught in Canadian Universities.

The most important decision in the design of a grinding circuit is the definition of total installed power required. It must include the allowance for treating hard and soft ores as defined by the profile measurements and include provision for future expansion if warranted, and for known contingencies.

The CEET program does a good job of picking this power value and of sizing suitable mills to provide the required grinding energy. However there are options. SAG design may also be done manually on a lesser number of samples for small deposits where hundreds of samples cannot be done without a new diamond drilling program. In these cases pilot plant confirmation of SPI results will be helpful.

As a direct result of the introduction of the SPI test, the viability of large-scale 50 tonne pilot plant SAG grinding programs has been questioned. Since the cost of obtaining and testing large samples can be prohibitive a choice needs to be made between extensive SPI testing and limited SPI testing followed by a 100 kg / hour pilot plant.

Mill Dimensions

Some existing mill designs are correct and useable and others are not. In certain cases the shell size is adequate to draw the required power but the drive is underpowered. In other cases the motor has the power but the grinding chamber is too small and will not generate the required power under normal operating conditions. In either case, tonnage shortfalls can occur.

There are deliberate choices to be made about how much power to put on the SAG mill and how much on the ball mill. Measurement and control of the Transfer Size are essential for any design to succeed to its maximum potential. When proper control of the Transfer Size is not provided, the performance of the grinding circuit cannot be guaranteed.

Summary and Conclusions

Unlike the technology for sizing most items of mineral processing equipment, SAG mill design has not been taught in our Canadian Universities and the fundamental question of how much grinding energy is needed has not been addressed in a formal authoritative way. We need to teach our students how Engineers protect their client's interest in what can be a multi-billion dollar investment by showing them how to design a viable SAG grinding circuit, using principles of theory, measurement and empirical interpretation.

Considering all of the tests and SAG design methods currently in use, none are so good or so inexpensive that further improvements are not possible. The SAG Power Index (SPI) and Bond Ball Mill Work Index method is in the author's view the most defensible lab procedure technically but we must not stop here in our efforts to find the best answer at the lowest cost, for testing and for equipment purchase.

Small-scale SAG pilot plant testing at 100 kg per hour will save many dollars obtaining samples and in performing the work on those samples, especially if the ore sample can also be used for metallurgical testing. The future of small mining projects depends on these design and cost saving improvements.

Acknowledgements

The energy and clarity of thought that Minnovex contributed in conceiving and developing the CEET software package is hereby acknowledged. Also, acknowledgement is offered to Process Research ORTECH for their support in setting up a 100 kg per hour SAG pilot mill in their facility.