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IMPACT ON MILL DESIGN AND FLOTATION CONTROL OF NEW DISCOVERIES IN THE RELATIONSHIP BETWEEN MACRO AND MICRO GRINDABILITY

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ABSTRACT

Large differences between macro and micro grindability relationships have been discovered for mill design measurements using the patented SAGDesign™ test. Crushing, Rod and Ball Mill Wi tests, and breakage parameter measurements have previously been used to design SAG mills but have not revealed the true magnitude of these differences. A SAGDesign test measures the SAG/Bond Wi Ratio (defined below) for every sample tested and gives a good design result because the F80 of the SAG stage test feed is 19mm and because the test includes a Bond Ball Mill Work Index on SAG ground ore. Good flotation operation demands properly sized grinding mills and steady feed to the flotation circuit.

INTRODUCTION

A previous paper presented in May 2009 at the CIM Annual General Meeting in Toronto May has shown that the SAG/Bond Wi Ratio, that is, the SAG mill hardness (kWh/t to grind the ore from F80 152 mm to T80 1.7 mm) divided by the Bond Ball Mill Work Index (also in kWh/t) for any ore, is a key property that should be used in the design of a SAG/ball mill grinding circuit. The value of this factor can vary from 0.1 to 2.5, the former value representing very soft ore and the latter very hard ore in the SAG mill. This was called a new discovery because the variance of this ratio was far greater than had ever been observed before. The reason for this was that these direct, accurate, empirical measurements on every sample tested, have never been made prior to the introduction of SAGDesign testing. The consistent accurate measurement of SAG hardness, in the range of 1.5 to 34 kWh/t to grind to 1.7 mm, and the calculation of the SAG/Bond Wi Ratio was done over a period of 5 years, on 35 projects. and 232 samples, up to the end of 2008. The importance of using this Ratio to help control the power split between SAG and ball mill at the design stage was the second new discovery.

The impact of these new discoveries on mill design and flotation control is the subject of this paper. This subject represents a new direction in designing an operating plant for recovering minerals from ore. The discussion is based on the writer's test results, observations, and field experience, because there has been insufficient time to fully document the concepts presented here. In the interest of those who wish to develop mining properties for the lowest capital cost and operated at the highest profit level, there are significant issues that need to be considered immediately. These are mentioned at this time because there is so much to learn about what can and should be done at the design stage, and how much can be saved if a plant can operate its flotation circuit at its optimum for the majority of the plant's operating life.

The accuracy and meaningfulness of the various SAG tests has long been a hotly debated issue. Suffice it to say that the original patent for SAGDesign testing was taken out in 2004 and was predicated on the accuracy of the SAGDesign test and its use to design new grinding plants using professionally selected samples. To the writer's knowledge there is no other test that has been supported by a major grinding mill manufacturer to the point of offering a process guarantee for tonnage and grind. The SAGDesign test is a scaled down commercial mill and so produces results that can be directly scaled up to commercial sized mills – from 12 to 44 ft in diameter.

Variability of ore grade from point to point in an ore body is well known from the time the drill core is assayed. Variable hardness is now measurable and transposes to variable tonnage unless the proper SAG mill is provided. Coupled with varying metal grades this makes the job of operating a stable flotation plant to be very difficult. But it can be done if reasonable design procedures are followed. A subsequent paper will deal with the difference between geo-metallurgy and mill design, including getting it right for hardest ores.

HISTORY

In the course of doing plant surveys and benchmark testing in more than 20 operating SAG milling plants in the last 15 years, the author has seen many striking things that are relevant to the topic at hand. Slowly, these problem situations are becoming known and are being corrected. But the balance between operating stability and t/h treated still does not receive the attention that is merited in many flotation plants. If a grinding circuit cannot run steady design tonnage at least 80% of the time, the SAG mill is too small. What we all realize of course is that if extra capacity is available, it will normally be used by pushing the limits of the grinding circuit and all downstream processes, even if lower recoveries and cost efficiencies are the result. This is a problem for flotation control that will not be addressed in this paper.

In projects that today cost upwards of $1 billion dollars, it seems strange that designers will jeopardize the revenue stream by not providing grinding equipment that will produce specified tonnage at specified grind from day one of a project. Somehow we have been told and have come to believe that it will take up to 12 months for a new SAG plant to reach design capacity. What are the things that prevent design tonnage from being reached? If the mine is the problem it is understandable – but the reason should never be that the SAG mill requires post installation modifications to achieve the specified tonnage.

With the introduction of SAG milling, we have come to a point in many plants where variable tonnage is normal because SAG hardness variability is usually very large. Forty years ago tonnage variability was not the problem it is today. Take Kidd Creek for an example. The concentrator was designed in 1965. The rod mills were deliberately designed to be tonnage restricting at design tonnage by Ray Clarke, the first superintendent of the plant. He wanted to have steady tonnage so that the rich base metal ore could be treated by flotation to yield as high a recovery as possible from the flotation circuits. The rod mills treated crushed ore and contributed about 3 kWh/t to the grinding circuit energy input. The crushing plant crushed the ore including any macro competent ore, to about F80 15 mm before being fed to the rod mills. Macro competency was therefore not an issue in that kind of plant. Note that all of Fred Bond's work dealt with rod and ball mill grinding circuits at F80's of 10 and 1.7 mm respectively.

Now that F80 152 mm ore is normally fed to the grinding circuit (SAG mill), the situation has dramatically changed. Instead of 3 kWh/t being required in the first grinding step, up to 20 kWh/t (or more) may now be required in the SAG mill. This makes the circuit vulnerable to tonnage fluctuations, especially when the required SAG mill is not provided to match the 80^{th} percentile of the macro hardness variability power requirement. 80% has been chosen because the hardest 20% of the ore body can be managed – by stockpiling – blending, or leaving it behind in the mine if it is low grade and unprofitable to grind and treat.

Added to this for mill design is the firm conclusion that macro and micro ore hardness (SAG and Bond Wi) are not related, and that a SAG mill cannot be designed using only a Bond Wi measurement. (However for any individual ore body they may be consistent within the same ore zone). This information is demonstrated in the data presented below and proves that accurate mill design can only be done using the measurements on the specific ore body in question. It is also suggested that errors can occur when designing mills by comparing with ores that may have a different SAG/Bond Wi Ratio. This is why we endorse and recommend a measure/calculate procedure for mill design and do not use simulation techniques.

Since the product from a rod mill is normally about P80 1.7 mm, ball milling is quite similar except that in a SAG mill, soft ore is quickly ground and hard ore pieces are not. Hence the Bond work index value from SAG ground ore is about 8 % higher than a crushed Bond BM Wi measurement. The identification of this value in a SAGDesign test further enhances the accuracy of the test and allows for more precise mill sizing without using what some refer to as the "phantom cyclone" to adjust test measurements and calculate power draw.

From this we deduce that the correct identification of SAG pinion energy to grind the ore from F80 152 mm to T80 1.7 mm is a fundamental property required to design a SAG mill and that the ratio of SAG pinion energy to Bond BM Wi is essential to eliminating problems created by the SAG mill being too small because the designer did not realize that the ore was naturally SAG limited (Ratio greater than 1) and so would require additional power on the SAG mill, regardless of what may have been found at some other plant treating another ore with the same macro hardness.

To explain this in more detail the results of 5 years of SAGDesign testing will now be presented. This information was first presented at the CIM, May 2009 in Toronto. Starkey, Samuels [1].

EXPERIMENTAL

During the past 5 years 35 projects have been completed and 232 SAGDesign tests were done. Figure 1 below shows the relationship of macro (SAG pinion energy) to micro (Bond BM Wi) hardness when plotted against each other. As has been seen many times before, there is broad trend to increasing macro hardness with micro hardness (if the Hard Ore project is omitted). This trend is too erratic to use for forecasting SAG hardness from ball mill work index data. But the existence of such a phenomenally different set of data from the hard ore project clearly demonstrates that other data should not be mixed with the project specific data in designing the mills for this project. (This project will be the subject of a paper being prepared for the 2010 CMP in Ottawa).

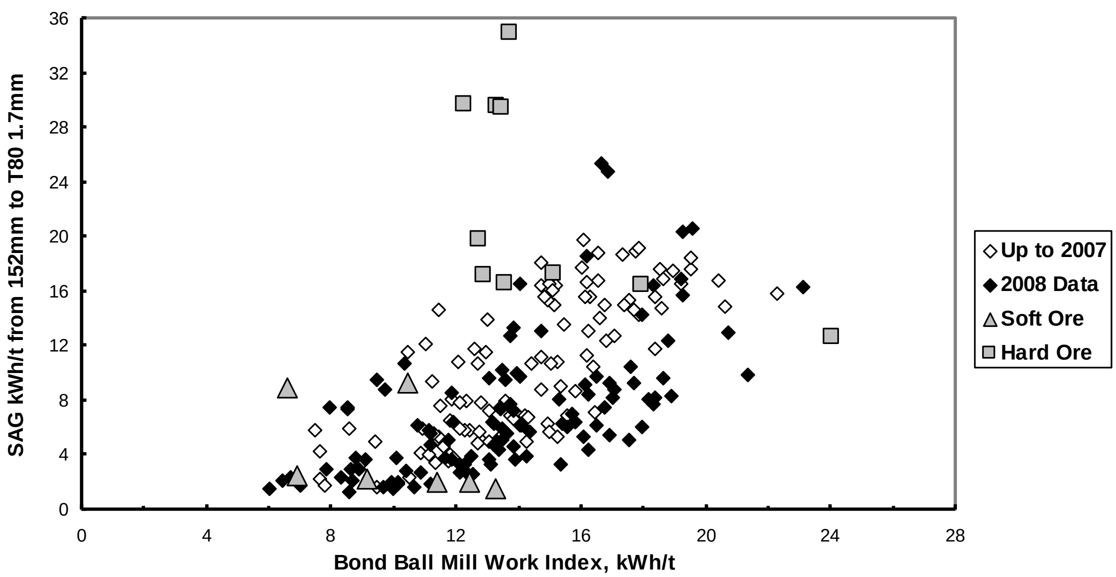

Figure 1 - Database SAG and Bond Data by Year - Including Soft and Hard Ore

The same data is plotted in Figure 2 except the SAG pinion energy is plotted against the SAG/Bond Wi Ratio. This way of presenting the data shows three clearly distinct and different zones. Ore is considered to be soft when it requires less than 10 kWh/t to grind from F80 152 mm in a SAG mill, to a T80 of 1.7 mm. Hard ore requires more than 10 kWh/t of SAG pinion energy and ores with a SAG/Bond Wi Ratio above 1.0 are considered to be SAG limited and require the addition of ways to mitigate the high SAG energy requirements. This can involve the use of an in-circuit pebble crusher and/or pre-crushing all – or part of the feed. For ores in the top left quadrant below, pebble crushing can be helpful and the opportunity to control the power split by adjusting the transfer size T80 increases as the Ratio decreases. But the main point is that whatever the design measurements for an ore might be, the calculation of the required mills is an engineering calculation based on the empirical data.

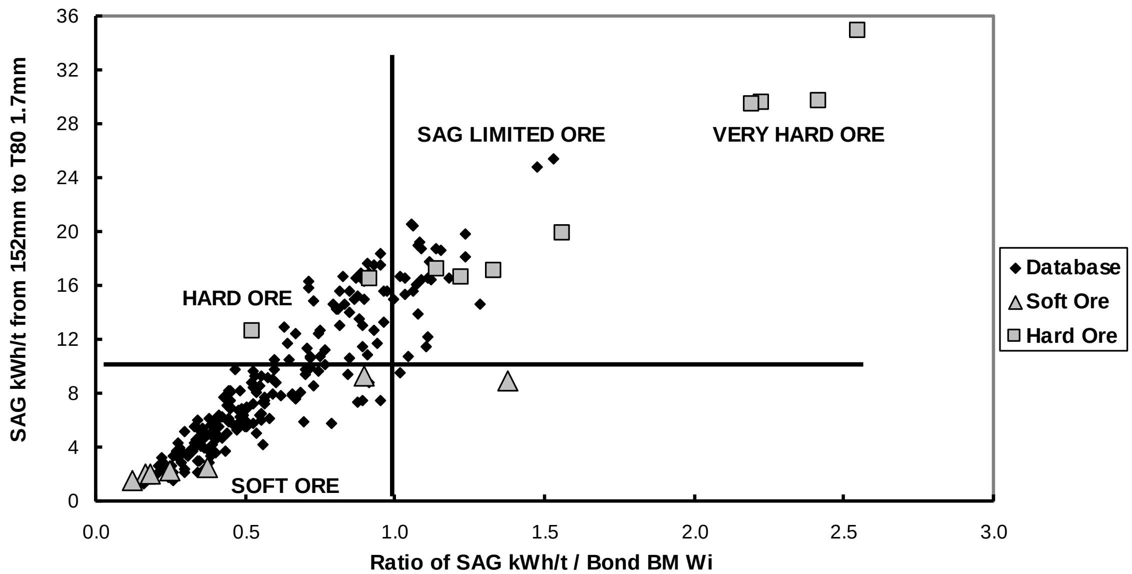

Figure 2 - SAG Pinion Energy Vs Ratio of SAG / Bond BM Wi, including Soft & Hard Ore

DISCUSSION

Many of the projects tested during this five year period were extremely soft as shown by the high density of data points in the bottom left hand quadrant of Figure 2. It can be stated from our knowledge of other testing methods that ores in this quadrant can be successfully tested using other leading methods which give results that are the same as SAGDesign. The paper describing the work on the Tenke project is an example of this. Starkey, Meadows [2].

It is also known that SPI measurements on ores in this quadrant are reasonably accurate as well. The place where SAGDesign tests stand alone for accuracy and mill design purposes are the ores that are harder than 12 kWh/t for SAG pinion energy and where the SAG/Bond Wi Ratio is greater than 1.0.

Other interesting observations can be made from Figures 1 and 2. The soft ore project is really two distinct ore bodies, one extremely soft (5 data points) and the other moderately hard in the SAG mill (2 data points) but quite soft in the ball mill.

The hard ore project is unique in that the SAGDesign test was able to identify SAG hardness up to 34 kWh/t, with 4 of 10 tests recording over 29 kWh/t for SAG pinion energy. An ore similar to this which is moderately soft in the ball mill will require calculations that are relative to this ore alone. An interesting fact was discovered when the three tests at an average of 29.6 kWh/t of SAG pinion energy were tested for the Bond Rod Mill Wi. The result was 19.7

kWh/t. The reason we attribute to this finding is that the ore hardness varied between the test at F80 10 mm (Rod Mill Wi) and 19 mm (SAGDesign). This points out the value of using a test that is relevant to the mill being designed for any unit of grinding equipment.

From the data and discussion above it is clear that a definitive grinding mill design for any ore body is within the grasp of the mill designer. Required, are at least ten samples including the hardest ore in the mine, variability samples from the main and satellite ore zones and accurate composite samples of the first seven years of production, either by production schedule or horizon if the mine plan is not complete. At least 3 such composites is mandatory to be sure that no surprises await. The 80^{th} percentile therefore usually (but not necessarily) falls above the annual composite hardness and ensures that annual production schedule will always be met. On the day to day level it can also be shown that enough power has been provided to run steady tonnage at all times (or at least 80% of the time).

The processing of steady tonnage can only be achieved when the above listed methods (or something more conservative) are used for grinding circuit design. Although no documentation is available at this time, the upside benefit of providing properly sized mills is great. If steady tonnage is provided, optimum flotation recoveries can be achieved as was done at Kidd Creek in the early years. The alternative is to use any apparent "extra" capacity to process more tonnage. We are certain that the economic benefit of providing grinding equipment based on the above mentioned procedures will more than justify the corresponding results that would occur when the SAG mill is not large enough to achieve flotation stability.

It is the spot on accuracy of the SAGDesign test and the use of it as noted above that allows this procedure to be adopted with confidence. Should anyone doubt this, a corresponding parallel test program using classical techniques should be done to compare SAGDesign with the older classical methods. In this way the path to more profitable operations will be quickly built and casualties caused by incorrect design will be eliminated in the author's opinion.

As a footnote, the rapid speed of execution, the worldwide accessibility to local laboratories and overall low cost of using SAGDesign technology places it in a zone where any junior mining company can now afford to get the right grinding design. For larger companies where the cost of grinding equipment can be prohibitive, it is even more important to use SAGDesign testing. It allows for the acceleration of grinding mill orders as was done by Phelps Dodge for the Climax Moly Project (now on hold). Starkey et al [3].

The author has spent the last 20 years in developing the information contained in this paper. It is our pleasure to share it with you. It is also our privilege to explain that new engineers have joined our company to provide continuity of SAGDesign services well into the future and our patent agreement has now been extended for the next 15 years to the end of the patent.

CONCLUSIONS

It is now possible to design SAG grinding circuits with confidence to achieve flotation stability. The benefits of this kind of design are significant and are recommended for all new projects where a SAG mill will be used to feed a flotation plant. This is also applicable to gold leach plants but the need for steady tonnage in this process is not as great.

Measure and calculate methods for mill design (SAGDesign) are preferable to simulation methods because some ores are so unique that they should not be compared to other plants.

Competent ores requiring more than 15 kWh/t for SAG grinding are the ores where SAGDesign testing should always be used. There are so few plants operating at this level of hardness that comparison with operating plants is not always possible.

To the best of our knowledge, the identification of SAG hardness up to 34 kWh/t in SAG pinion energy to achieve a T80 of 1.7 mm is only possible with SAGDesign testing. JK Drop Weight testing may produce a comparable result but since it is not expressed in kWh/t it is difficult to use without the benefit of an operating plant. It is not known if the SMC test can identify ore hardness at his level of competency.

With the successful identification of very hard ores it is now possible to add energy reduction methods to reduce this power cost and make SAG milling competitive even at this extreme hardness level. Conversely, the failure to identify ores of this hardness will be debilitating for those projects where it is not identified before the grinding mill design is complete.

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