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New Discoveries in the Relationship Between Macro and Micro Grindability

ABSTRACT

This paper examines 5 years of SAGDesign testing data with particular emphasis on the grinding test results from two recent projects, the Fortune Minerals Limited NICO project, and the Aurora Energy Resources Inc., Michelin deposits, located in the Northwest Territories and in Labrador respectively. The context is to compare these results with the SAGDesign database. The required SAG mill pinion energy for these two ores showed vast differences, even though both ores had similar average Bond Ball Mill Work Index values - about 13 kWh/t each for the two deposits respectively. Bond Rod Mill Work Index values for NICO ranged up to 19.7 kWh/t for the hardest ore, confirming the harder nature of the coarse material. SAG mill pinion energy to grind the NICO cobalt-gold-bismuth-copper ore from F80 152 mm to T80 1.7mm varied from 16 to 35 kWh/t, while for Michelin uranium ore, it varied from 2 to 9 kWh/t.

NICO ore is harder than any other material encountered to date using SAGDesign testing. SAG pinion energy is more than double the ball mill pinion energy using a transfer size T80 of 1.7mm and a final grind P80 of 74 microns. For NICO, the ore is 'off the charts' for simulation design techniques because there is no comparable operating SAG mill treating ore that is this macro-competent. For Aurora, the relationship between SAG and ball mill pinion energy is reversed in that the SAG mill requires less than half of the ball mill pinion energy using a transfer size T80 of 1.7mm and a final grind P80 of 90µ.

Because these discoveries are so important for grinding mill design, their impact will be dealt with in future papers, at the August METSOC Conference in Sudbury, and at the September SME Workshop in Tucson. It has now been concluded that the ratio of SAG pinion energy to Bond Ball Mill Work Index, is valuable data to use in designing a SAG/ball mill grinding circuit, to help choose the power split needed.

INTRODUCTION

This paper presents all of the SAGDesign^{TM} test data up to the end of 2008, with special emphasis on two projects which have revealed data that is of vital interest to anyone designing comminution circuits using SAG mills. These new discoveries have emerged from the data for the NICO and Aurora projects and a comparative study of the SAGDesign database that has been built up since 2004.

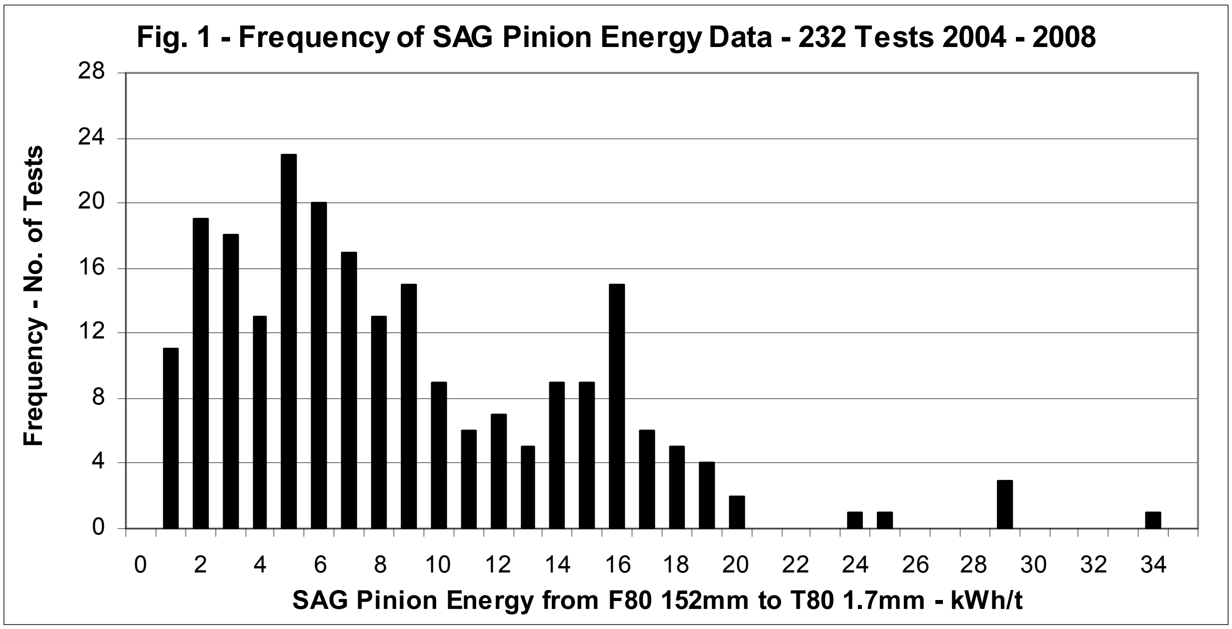
SAGDesign testing was introduced commercially in 2004 using technology invented by J. Starkey and patented by Outotec. The SAGDesign test involves crushing an ore sample to 80% passing 19mm, and grinding it in stages in the 0.5m diameter SAG mill to measure the revolutions of the mill required to achieve a product size of 80% passing 1.7mm. The SAG ground ore is then tested using a standard Bond Ball Mill Work Index test, with a closing screen to match the liberation grind as closely as possible. Both stages constitute one SAGDesign test and the SAG and ball mill results are considered together in any design work. The mill design work is fully disclosed. Mill design is based solely on empirical energy measurements on the client's ore, and basic engineering calculations that determine the required energy. These results are integrated with mill power draw functions that have been used for years to design mills. This procedure permits a client to see results as they develop instead of inserting values into a computer.

During the past five years, 232 SAGDesign tests have been completed on 35 projects in four laboratories. The laboratories are: Dawson Metallugical Laboratories Inc. in Salt Lake City, TOMS Research and Design Institute and IRGIREDMET, both in Irkutsk Russia, and Starkey & Associates Inc. facilities in Canada where we subcontract the work to competent laboratories using our own SAGDesign test mill. This mill is on display in the exhibition hall.

THE DATABASE - 2004 to 2008

The SAGDesign database now contains 232 tests. Previously 63 results were reported in the SAGDesign database (Starkey and Meadows, 2007). The new data is the basis for a master table that includes for each sample, the SAG pinion energy to 1.7mm, and the SAG ground Bond Ball Mill Work Index.

To present the data, we have used graphs to summarize the results and to show significant facts regarding hardness variability. The first method used to study the data is to plot the variability of SAG pinion energy and Bond BM Wi values in the database against frequency. This is done in Figures 1 and 2.



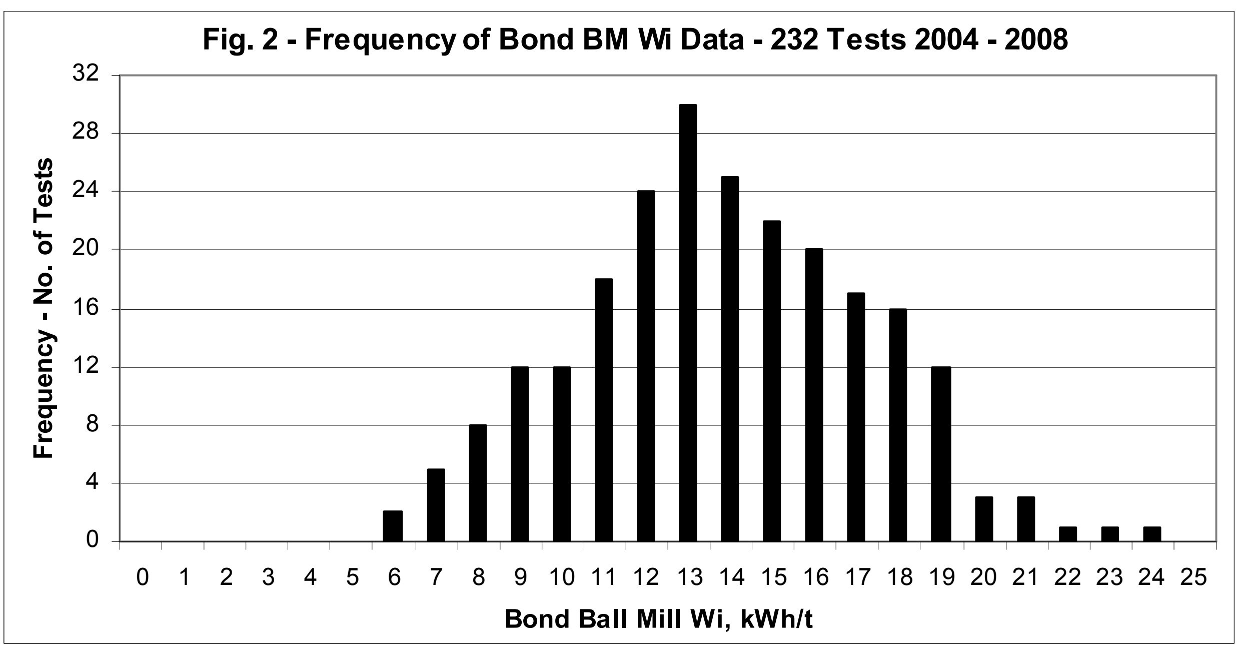
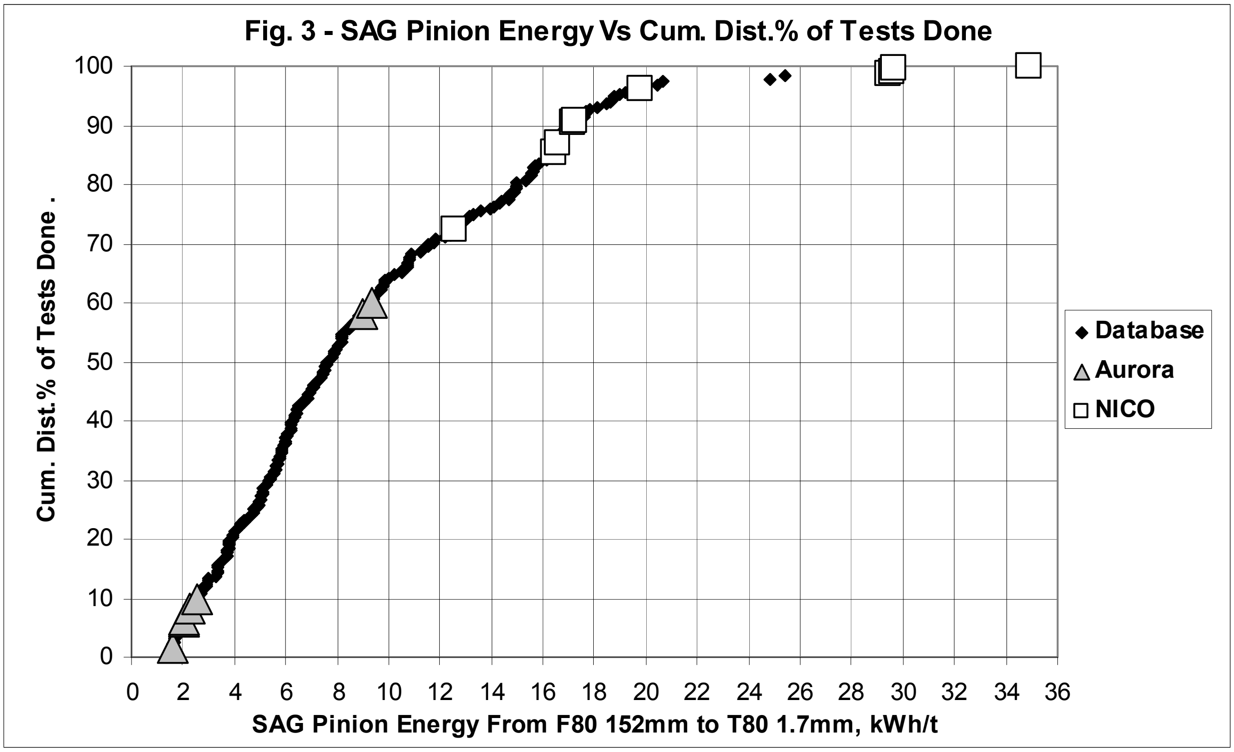
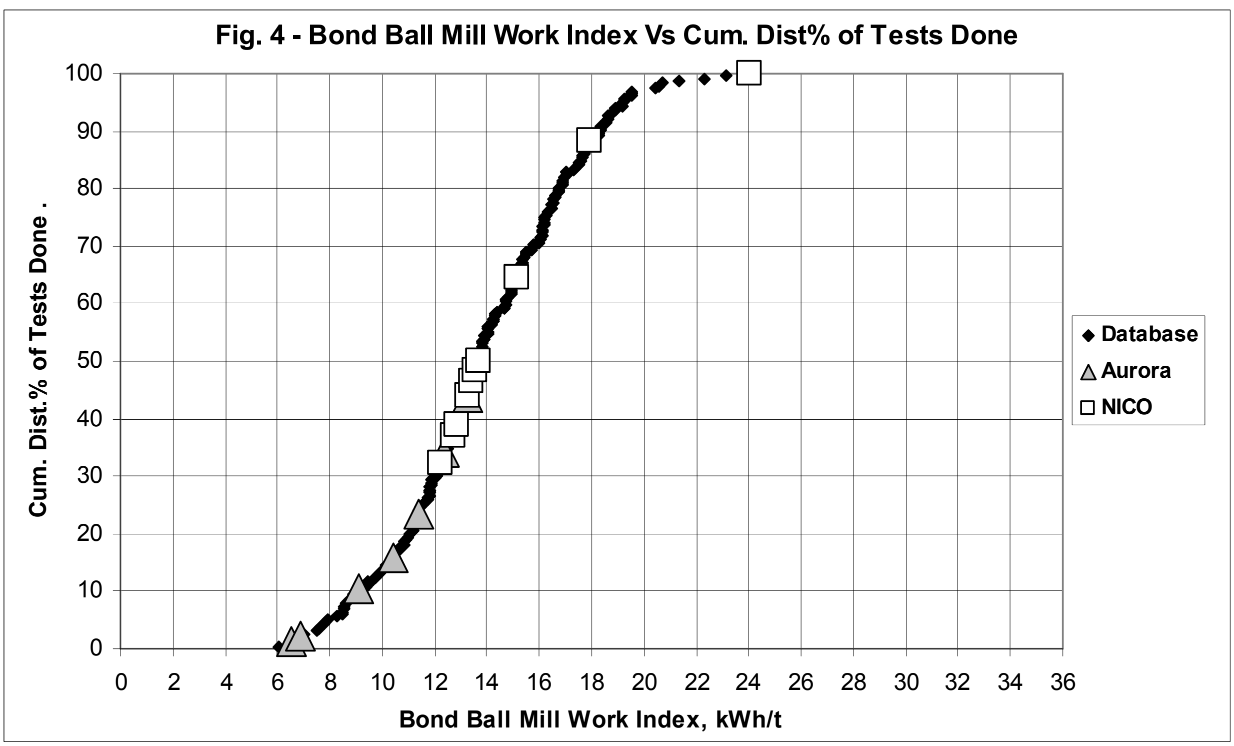


Fig. 1 shows a very different and random distribution of hardness variability when compared to Fig. 2.

A second common way to look at a large database is to show the distribution % of samples tested as a function of increasing hardness. This is done in Figs. 3 and 4 for SAG pinion energy and Bond BM Wi.

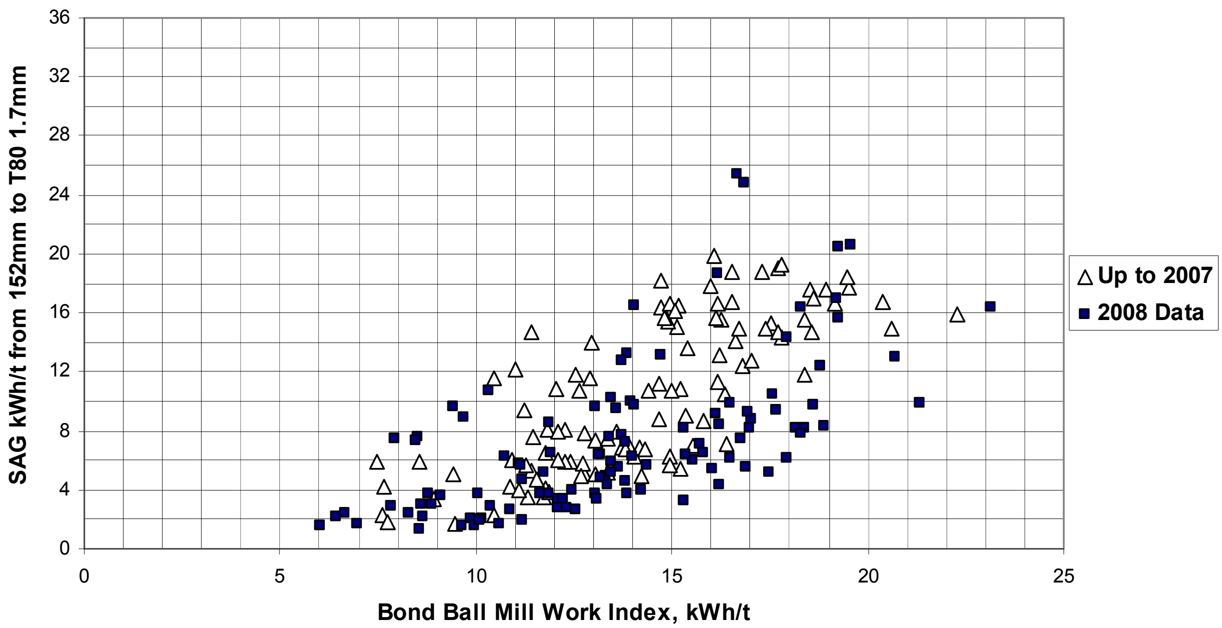




In the above presentation of Figs. 3 and 4, the NICO data (very hard) and Aurora data (very soft) are shown. This is the point where it was realized that something important had been discovered – because the variability in SAG hardness compared to the SAG pinion energy database and the Bond BM Wi in relationship to the Bond Ball Mill Wi database for the 2 projects, were quite different.

The third method to examine the database results is to plot the SAG pinion energy required to achieve a T80 of 1.7mm for every sample, against the Bond BM Wi. Traditionally, it has been assumed that SAG and ball mill hardness vary together. Figure 5 shows the database plotted this way without the NICO and Aurora results. This graph shows that in a broad sense, SAG hardness does vary with ball mill hardness but not in a way that is accurate enough to be used for mill sizing decisions. This is not surprising since one is a measurement of macro hardness (+2mm) while the other is a measure of micro hardness (-2mm).

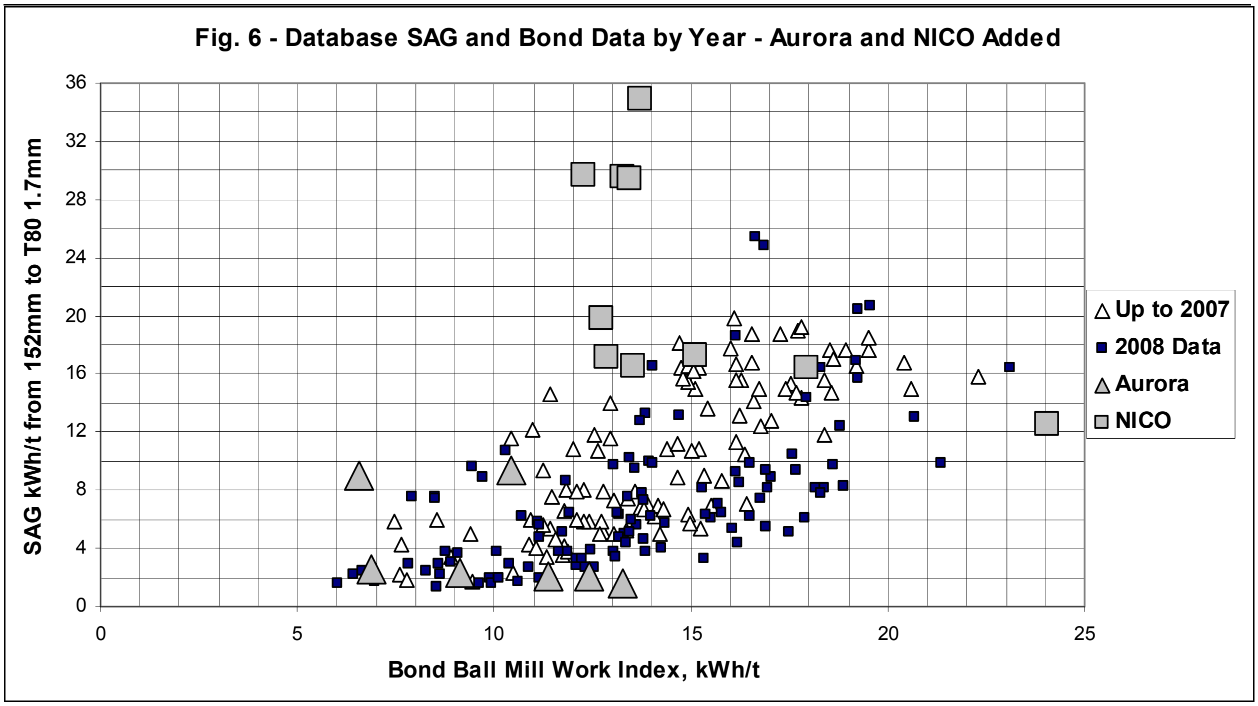
Fig. 5 - Database SAG and Bond Data by Year



This data configuration has been seen by the primary author many times except not using such accurate measurement of SAG kWh/t. The scattered points clearly show that the Bond Ball Mill Work Index is not a reliable measure of SAG hardness and so cannot be used alone to design a SAG mill. If a SAG mill is designed using only the Bond BM Wi, the design is vulnerable and will have a probability of failure.

Measurements made to design a SAG mill vary from one consulting firm to the next using alternate tests. While not discussed fully in this paper, we note that every test has a feed size specification. Each test was designed for a specific purpose and the feed F80 chosen accordingly. It therefore stands to reason that the Bond BM Wi test, using an F80 of 1.7mm, will give a different measurement than the Bond RM Wi test with a feed F80 of 10mm. Similarly, an SPI test with a feed F80 of 12.7mm will give a different result than a SAGDesign test where the feed F80 is 19mm. The F80 of 19mm in the SAGDesign test is a major reason why we are seeing new relationships between SAG kWh/t and Bond BM Wi and is a major reason why the SAGDesign test will continue to be the method of choice for reliable SAG mill design. This also explains why other design methods continue to struggle when ores are harder than previous designs.

When NICO and Aurora are added to the above graph, the following picture emerges as Fig. 6. The Aurora data includes five of the softest SAG milling ore samples ever studied while the NICO data



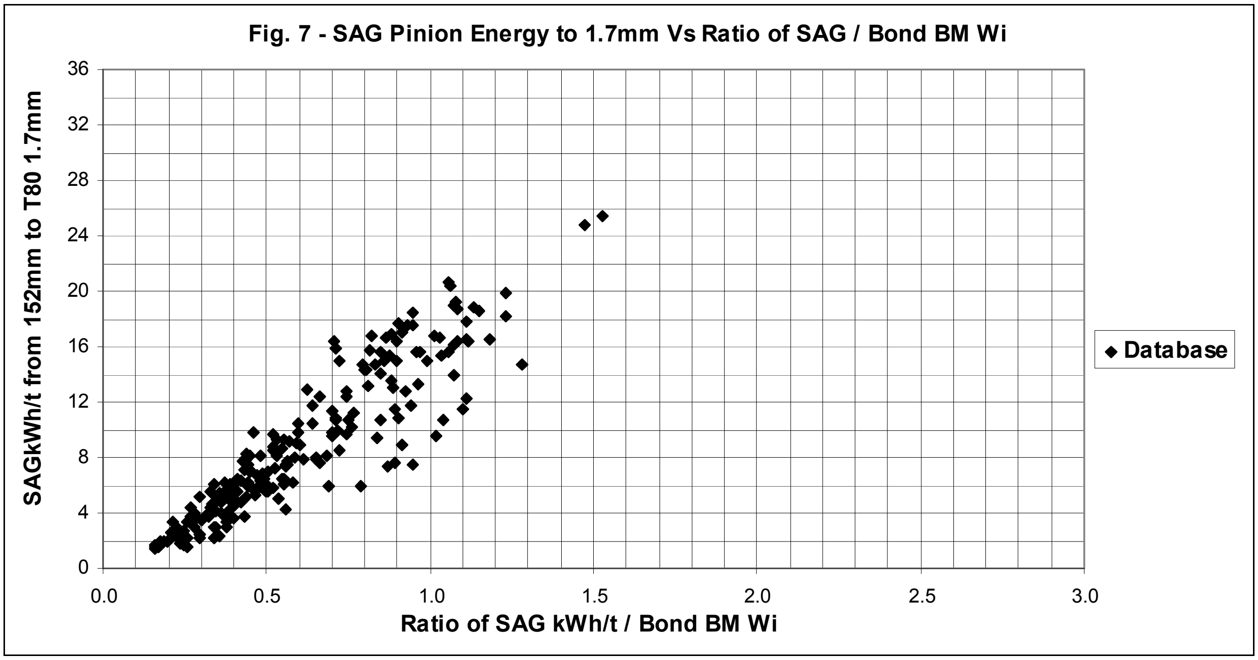
shows that that ore is harder in SAG milling than any seen in this five year period. Since both of these projects include Bond BM Wi values in the 12 to 14 kWh/t range it was realized that a new criterion was needed to describe the grinding properties of an ore for SAG mill design. We have selected the 'macro to micro hardness ratio' as a new parameter in the process of gathering data for mill design. It is simply the ratio of SAG pinion energy (from F80 152mm to T80 1.7mm) divided by the Bond Ball Mill Work Index. The value of this ratio controls to a large degree, the power split between a SAG mill and a ball mill for any particular ore and shows why a SAG mill grinding circuit based on traditional comparisons with other plants may not be successful unless those other plants have the same SAG/ball mill hardness ratio.

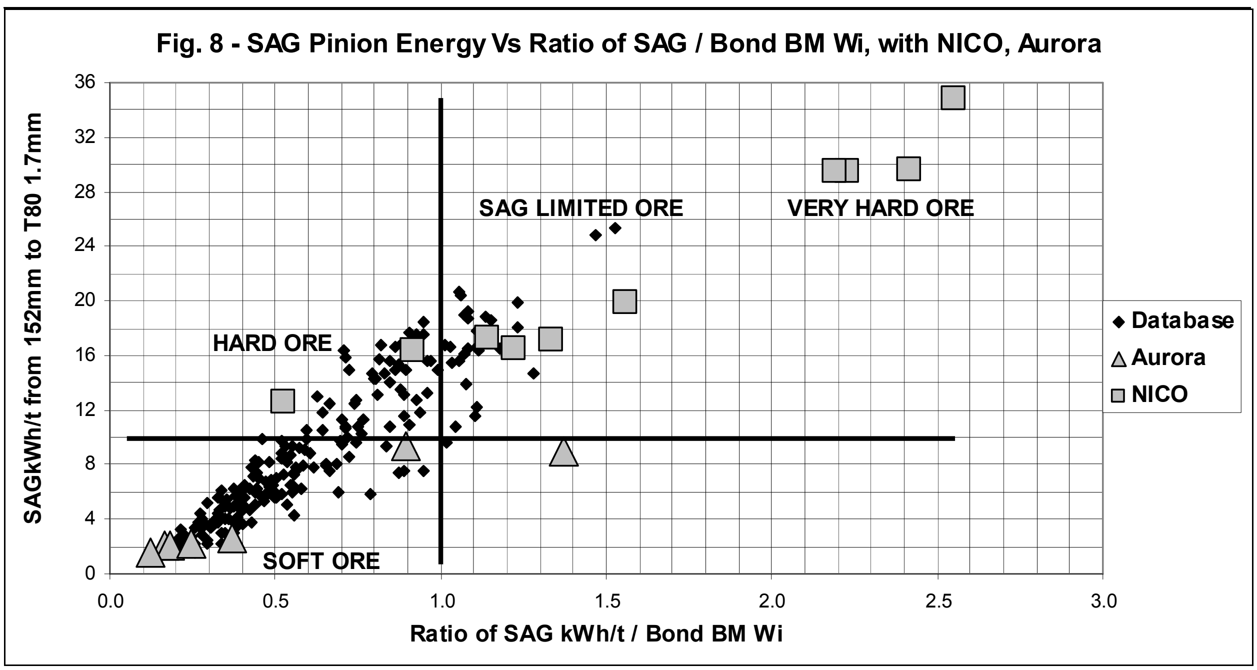
In the case of the NICO ore for example, unless the SAG energy applied is far greater than the ball mill energy, the circuit will be SAG limited and difficult to operate. The reverse is true for Aurora. Unless there is more energy applied to the ball mill than the SAG mill, the circuit will not function unless a very fine grind is demanded for the SAG mill. In fact, the Aurora project would be well served with the selection of a single stage SAG mill to do the entire grinding job.

Fig. 6 clearly indicates the difference of NICO ores from all previous ores in the database and shows why Fortune Minerals chose not to use a SAG mill for this project. By crushing the ores to an F80 of 10mm to feed a rod mill, the hardest comminution job is avoided and lower energy consumption will be achieved for the plant. In addition, since the samples reporting SAG kWht/t greater than 20 kWh/t represent deeper parts of the NICO mine, the data supports the NICO proposed mine plan that utilizes a blend of open pit and underground production in the initial years, which will minimize variability in plant throughput.

Figure 7 shows the database plotted in a fourth and new way as mentioned above, without NICO or Aurora data. SAG pinion energy is plotted Vs the Bond BM Wi. This gives a more orderly picture because all of the data is focused on SAG mill pinion energy, including its relationship to Bond BM Wi.

In Figure 8, NICO and Aurora data are added and lines are drawn to show the proposed criteria that need to be recognized when designing SAG mills and ball mills for new ores.

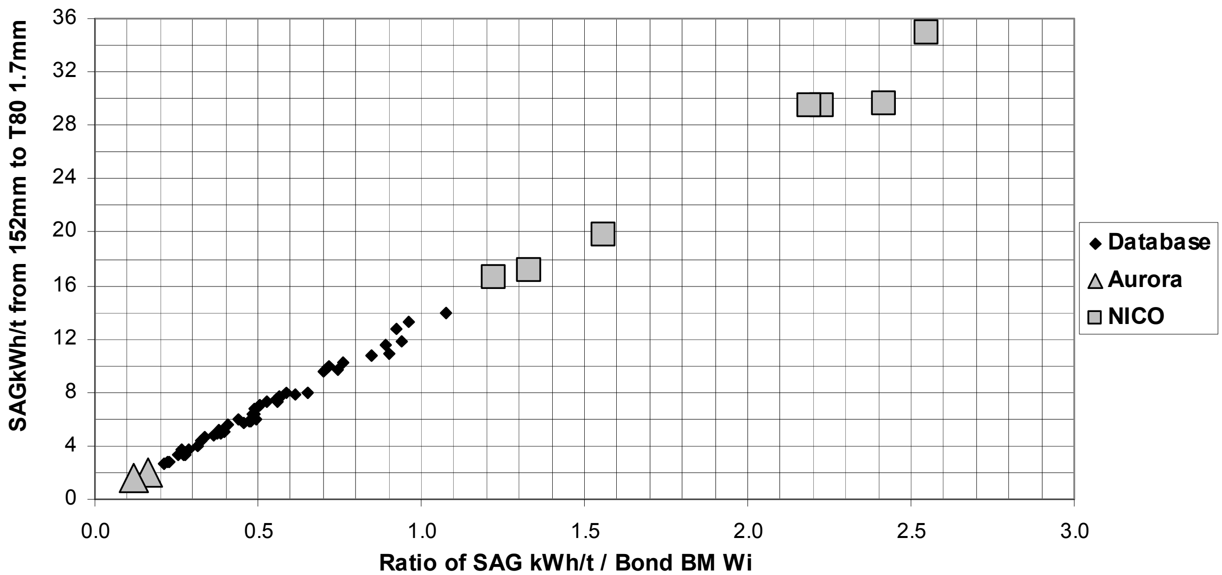




Elaboration on this topic will be the subject of a following paper. However it can be seen that the limit for "soft" ore is about 10 kWh/t and that the macro/micro hardness ratio limit for "normal" design is 1:1.

Finally, to fully explore the relationship between Bond BM Wi and SAG hardness we have plotted 58 results from the database that measured between 12 and 14 for the Bond BM Wi. These data points are shown in Fig. 9. This proves in stark detail why Bond Wi testing alone cannot be used for designing a SAG mill. It is interesting as well that data points from both NICO and Aurora, appear in this graph. For a relatively constant Bond BM Wi, SAG hardness varies from less than 2 to over 34 kWh/t.

Fig. 9 - SAG kWh/t to 1.7mm Vs Bond BM Wi, 58 Samples with Bond Wi 12 - 14



The discovery that SAG hardness can vary this much for constant Bond BM Wi is one of the reasons that this paper is called New Discoveries. Another new discovery is that the ratio of SAG pinion energy to Bond BM Wi, is required for good SAG mill design. It follows that the correct measurement of SAG mill pinion energy lies at the heart of achieving a good SAG mill design. Since every benchmark test done to date confirms the accuracy of SAGDesign measurements, we conclude that the test has correctly met its original objective and that its official name has been well chosen. (Starkey et al., 2006)

It has already been presented from grinding design projects on hard ores, that SAGDesign testing will correctly identify extreme hardness of the ores concerned and allow for the design of suitable grinding mills. (Starkey et al., 2008). For NICO, a composite of 2 samples averaging ~29 kWh/t (for SAG pinion energy) was sent for a Bond Rod Mill Work Index test. Usually SAGDesign kWh/t to 1.7mm, gives a similar numerical result to a Bond RM Wi test. Here, the average SAGDesign result was 29.6 kWh/t while the Bond RM Wi on the composite was 19.7 kWh/t. Given that there is a hardness shift between micro and macro grinding for NICO ore, it is concluded that the Rod Mill Wi test only partially identified the shift in hardness from the Bond BM Wi result which was 12.7 kWh/t for the hard composite sample (see Fig. 6 for confirmation). This difference can be attributed to the test F80 which was 10mm for the Bond RM Wi test and 19mm for the SAGDesign test. The larger question of course may be whether ore this hard should be ground in a SAG mill at all. The answer after economic evaluation may well be no.

CONCLUSIONS AND RECOMMENDATIONS

Grindability tests produce results that are valid for the purpose intended, mainly because of different feed sizes. Bond tests are excellent for designing rod mills, ball mills and crushers. The SAGDesign test is suitable for designing SAG mills. It successfully identifies hardness variations from 1 to over 30 kWh/t.

SAGDesign database results show that while not many ores require over 20 kWh/t to grind the ore to T80 1.7mm, a small percentage require up to 30 kWh/t. Because of lack of precision for other comminution tests, SAGDesign should always be used for ores requiring more than 15 kWh/t on the SAG mill.

A SAGDesign SAG test simulates the operation of a commercial SAG mill and accurately measures in kWh/t, hard ore energy requirements to give a T80 of 1.7mm, the product size for the laboratory test.

Conventional impact breakage parameter measurement methods do not adequately deal with hard ores over 20 kWh/t because the parameters can only be used with simulations to operating plants.

The ratio of SAG pinion energy to Bond BM Wi is helpful when selecting the SAG/ball mill motor power split for a new grinding circuit. We recommend that this ratio be included in the measurements needed for any new SAG/ball mill circuit design. It defines what can easily be done in a chosen configuration.

The shape of the database variability graphs is different for SAG mill pinion energy and Bond BM Wi. This shows that to achieve a good design, SAG mill data should be used with the corresponding ball mill data from the same samples. SAG data should never be divorced from corresponding Bond BM Wi data.

Bond BM Wi tests cannot be used alone for SAG mill design. A proper measurement of SAG mill pinion energy is needed. Previous assumptions that SAG kWh/t varies with Bond BM Wi are correct for some ores, but the relationship is not accurate enough to use for mill design purposes. In addition, there are exceptions noted in this paper which make this approach unworkable as a standard procedure.

ACKNOWLEDGEMENTS

We would like to thank Fortune Minerals Limited and Aurora Energy Resources Inc. for their cooperation to do SAGDesign testwork and to allow us to publish these results which have broken new ground in the quest for a better understanding of the fundamentals of SAG mill grinding circuit design requirements.

The NICO Cobalt-Gold-Bismuth-Copper deposit is located 160 km northwest of the City of Yellowknife, Northwest Territories, Canada. It is the largest IOCG-type deposit (aka Olympic Dam-type) currently recognized in Canada with Mineral Reserves of 21.8 million tonnes contained within a larger 57 million tonne, lower-grade Mineral Resource. The project, owned 100% by Fortune Minerals Limited, has been assessed in a positive definitive feasibility study, has been subject to underground test mining and pilot plant testing and is now in the permitting stage to develop a combined open pit and underground mine and process plant. The process flow sheet incorporates conventional crushing, grinding and flotation, followed by hydrometallurgical process methods including: pressure acid leach, ion exchange and electro-winning for recovery of cobalt as 99.8% cathode (with a copper cement by-product); ferric chloride leach and electro-winning for recovery of bismuth as 99.5% cathode; and cyanidation of the leach residues and cleaner float tails for recovery of gold as doré.

Aurora currently holds assets in Labrador and Nunavut, Canada. The Aurora Uranium District in Labrador has one of the largest undeveloped uranium deposits in the world. Exploration programs have proven very successful and the upside potential for additional pounds are considered to be high. The District has multiple near-surface uranium deposits clustered together in stable bedrock, with no identifiable groundwater or structural complications. Located in Canada, the world's largest uranium producer, the District has close proximity to a deepwater port for access.

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