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What Can Go Wrong in Comminution Circuit Design?

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ABSTRACT

The design of semi-autogenous grinding (SAG) mill based comminution circuits for the treatment of competent ores, similar to those at Geita and Boddington, involves the same process of sample selection, test work, data analysis and data modelling/interpretation as that used for ‘average’ competency ores. However, over the past couple of years a number of issues have arisen that are common to the design of circuits for the comminution of ‘highly’ competent ores. The impact of these issues on project viability is generally more pronounced when treating hard ores than average to soft ores due to the greater impact on capital and operating costs.

The issues encountered have included:

- standard test procedures have been modified;
- test equipment has worn or been damaged;
- different procedures yield different data and varying interpretation; and
- modelling and empirical calculations have been based on poor benchmarks, or used incorrectly in the case of JKSimMet, yielding misleading outcomes.

The purpose of this paper is to present, discuss and clarify some of the issues associated with conducting test work and designing comminution circuits for the treatment of ‘highly’ competent ores in order to reduce the level of conflict arising from interpretation and application of test work data.

Specifically, the issues associated with the bond crushing (impact) and rod work indices measurement, the various SAG mill specific energy tests, and the interpretation of the resulting data will be discussed in the context of case studies.

INTRODUCTION

Over the past two years a number of copper and gold projects have involved the processing of competent ores.

The measurement of the level of ore competence has historically relied on the use of bond crushing and rod mill work indices, unconfined compressive strength, point load strength, drop tests or media competency tests such as those developed by Allis Chalmers (Mosher and Bigg, 2002).

More recently, a number of other tests have been developed to suit the requirements of autogenous grinding (AG) and SAG mill design, namely the:

- Advanced Media Competency Test (Siddall, Henderson and Putland, 1996);
- the JK Pendulum Test, then the JK Drop Weight Test (Napier-Munn *et al*, 1996);
- the SMC Test® (Morrell, 2004);
- the Starkey Test, then the SPI Test (Starkey and Dobby, 1996); and
- SAG Mill Design Test (Starkey, 2006).

There are reasonable correlations between all the tests’ data that generally allow any or all of the data to be used to design a SAG mill based grinding circuit for ‘typical’ ores of a moderate competence range.

Issues have arisen where the expected SAG mill specific energy is greater than 10 kWh/t. These issues have been associated with the way crushing and rod mill work index tests have been conducted, issues associated with JK Drop Weight Test machine calibration, issues associated with the relevance and interpretation of SPI data and the way in which JKSimMet has be used as a design tool.

A key point of context is that test work is not conducted just to gather data, test work is conducted to mitigate risks associated with the selection and design of a circuit and the cash flow that the project generates. Hence, a full understanding of the implications of the test work methods and data interpretation is required to effectively mitigate the risks.

TEST WORK METHODS

The consistency of test work results has been recognised as an issue in data analysis for some time. The following discussion highlights some of the issues associated with test work used in for designing comminution circuits.

Historical work

Dunne and Angove (1997) conducted an audit of comminution methods across laboratories in Australia and the USA and concluded that:

- the bond ball mill work indices determinations gave reasonably reproducible results,
- significant variation was observed in the measurement of the bond rod mill work index on at least one sample tested, and
- large variations in abrasion index and crushing work index were due to variations in the test method across the laboratories.

Bond crushing (impact) work index

In general, the impact or crushing work indices (CWi) calculated from test work carried out on machines conforming to Bond’s original design correlate well with the drop-weight index (DWi) which is obtained from the SMC Test® (see blue diamond points in Figure 1). However, recently, for several projects the CWi

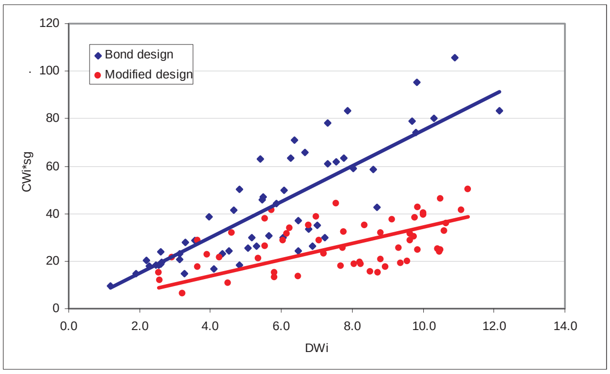

FIG 1 - Correlation of crushing work index and drop-weight index.

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values have fallen well below this relationship and this has led some metallurgists to claim that the ore is not overly competent. Closer investigation of the source of these data indicated that they came from a modified design of testing machine the results from which followed a very different relationship to the DWi as seen by the red circular points in Figure 1. It is believed that these data were derived from the same (modified) design of machine which were manufactured by a company in North America, one of which ended up in a laboratory in Australia and the other three were bought by laboratories in North and South America. Part of the modifications involved the impact heads which are different in shape to Bond's original. When the Australian laboratory started to use their new machine one of their clients indicated that the CWi values were far too low. The impact heads were then changed to match Bond's original and the resultant values increased by 100 per cent. Some comparative tests were then done with a lab which had one of Bond's original design machines and similar results were obtained.

As a consequence, metallurgists requesting impact work index test work should understand what equipment is being used and how the data should be interpreted.

Bond rod mill work index

The Bond rod mill work index (RWi) is used by some practitioners to determine specific energy based on empirical methods.

JKTech conducts a regular program of testing for each of the laboratories licensed to conduct Drop Weight tests using a standard rock sample. The results of this testing for the Drop Weight Test are discussed in the next section. The test program also includes the conduct of both the RWi and Bond ball mill work index (BWi) tests on the same standard rock sample. The results of the comparative testing of RWi across seven laboratories around the world are shown in (Table 1). The standard deviation of the RWi measurements is 12.1 per cent compared with value of 3.4 per cent for the BWi measurements.

TABLE 1

Summary of Bond rod mill work index test work

Laboratory	Bond rod mill work index, kWh/t
A	22.1
B	22.4
C	18.1
D	17.3
E	16.8
F	19.5
G	16.2
G	18.3
G	17.1

Again, interpretation of the data is reliant on empirical relationships that may be have been developed based on data from one laboratory, that is not transportable without adjustment to data from another laboratory. Importantly, a large proportion of the historical data on ores in Australia was generated by laboratories A and B. This data is not 'wrong', but models that use those data may need recalibration for data sourced from, say, North or South America.

JK Drop Weight Test

The JK Drop Weight Test (JKDWT) data has historically been represented in terms of the 'A × b' parameter. The 'A' is the asymptote of a plot of specific energy against T10 (per cent of product below ten per cent of the feed size) and 'b' is a measure of the 'slope', represented by $T10 = A \times (1-e^{-b.ecs})$.

JKTech's routine testing mentioned above has indicated that the standard deviation of JKDWT A × b values from all the licensed test laboratories on the same standard rock sample is 4.2 per cent. These results prompted an investigation by JKTech into the source of the variation in JKDWT results. The outcomes of the investigation are reported in Stark, Perkins and Napier-Munn (2008). The investigation involved a set of 24 JKDWTs on homogeneous material conducted by three operators. The standard deviation of the A × b values was 5.7 per cent. The largest contribution to the variation was the selection of particles to be tested.

There have been reports of some issues with the JKDWT machine if the machine is not maintained effectively. This outcome is rare but running check samples at other laboratories can alleviate this type of risk. This is the reason for the JKTech routine comparative testing at all licensed laboratories.

SMC Test®

Recently, Morrell has developed a simpler approach, the SMC Test®, and a Drop Weight Index (DWi) that is related to the A × b parameter and particle SG (Morrell, 2004).

Both the SMC Test® and JKDWT rely on being able to select samples of competent rock or quartered core of a certain size in narrow size intervals in the range -63 mm + 13.2 mm. Details are given on the JKTech website (JKTech Pty Ltd, 2009).

For low competence ores this approach places a potential bias on the data as the more friable component of the ore is not able to be tested. However, for competent ores this issue is not relevant.

Recently, when comparing the results for the A × b values determined from the SMC Test® and JKDWT indicates there can be a discrepancy between the two test results. The JKDWT results can be lower (ie appear more competent) than those from the SMC Test®. Based on experience with competent ores, this difference appears to be at least in part due to the way in which the data are fitted to determine the A × b values. In one example, JKTech fitted the JKDWT data to get an A = 100 and a b = 0.2 (ie A × b = 20) for three of the four JKDWT Tests in this example. In fitting the JKDWT data, JKTech constrains A to its theoretical maximum value of 100. This approach has varied over the last fifteen years and has led to related variation in the A × b valued determined from a given data set. If the A value is relaxed, fitting leads to A × b values between 22 to 23.5 for the same test data. The latter values compare reasonably with the SMC A × b values of 23.2, 23.7, 23.0 and 24.4 for the comparable samples. The fitting methodology used to determine A and B is particularly sensitive at the extremities of the ore competence scale and can have significant implications for competent ore where a ten per cent difference in A × b has a significant impact on the subsequent calculated SAG mill specific energy.

Veillette and Parker (2005) published a graph of A × b versus SAG mill specific energy (per Figure 2). The product A × b has no formal units although its value is inversely related to ore competence, ie the lower values of A × b indicate harder rock. In contrast to A × b, the DWi parameter has the units of kWh/m^3 and hence tends to be more linearly related to SAG specific energy for a given circuit configuration. These relationships are used to indicate the potential deviation in SAG mill specific energy at extreme A × b values (<30). The uncertainty that exists with SAG power determinations for A × b values below 30 is illustrated by the pink region in Figure 2. Based on recent experience, with an A × b value of 25 SAG power predictions could range from 12 to 18 kWh/t, a range of 50 per cent, dependent on the consultant doing the evaluation and the mode of SAG mill operation.

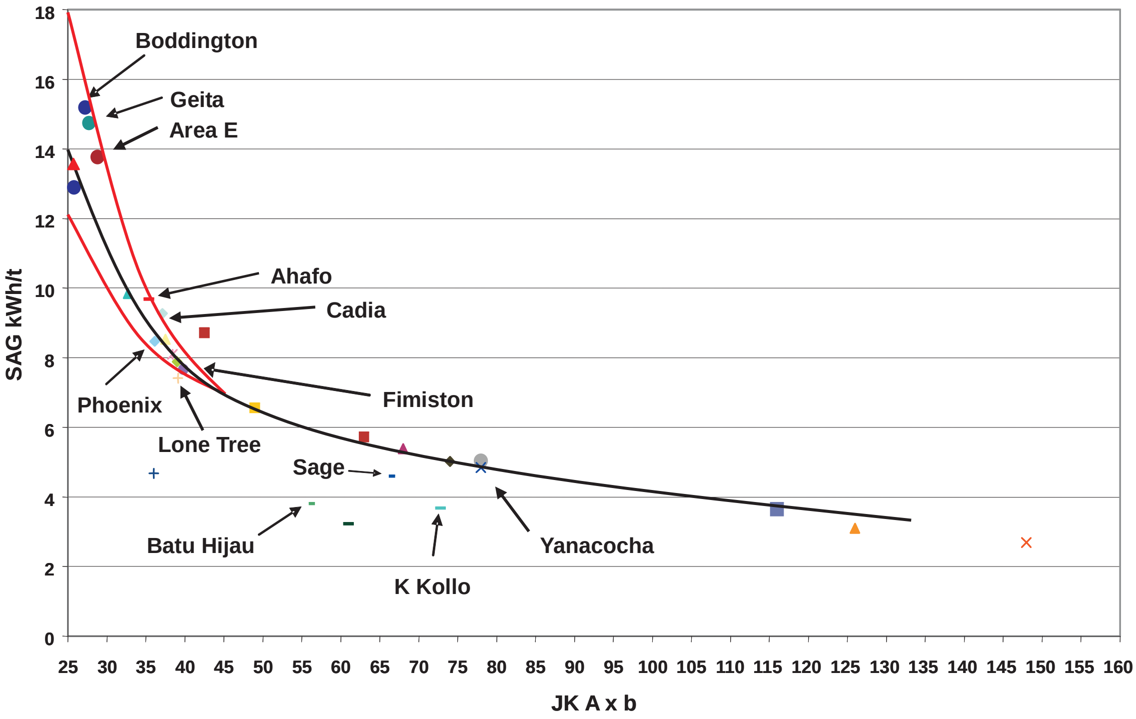


FIG 2 - Relationship between JK A × b parameters and SAG mill specific energy (modified from Veillette and Parker, 2005).

At least some of the variation is due to feed size distribution, although other factors such as aspect ratio, mill speed, ball load and whether pebble crushing is in-circuit also contribute. SAG mill specific energy is sensitive to SAG mill feed size distribution. Thus, the selection of the primary crusher and the mine blast design are critical inputs to SAG mill throughput determination which are often ignored or at least, under estimated.

SAG Power Index Test (SPI)

There are two aspects to the design of either single stage SAG or two stage SAG/ball mill circuits. First is the energy required to grind the ore, taken from test work data and second is the application of grinding equipment required to provide this energy, with its empirical factors to allow for grinding efficiency using that equipment.

The grinding power based tests, SPI (circa 1991) and SAGDesign, were developed by John Starkey (Starkey and Dobby (1996); Starkey (1997); Starkey, Hindstrom and Nadasdy (2006)). These tests are conducted on -12 mm and -19 mm feed, respectively and interpretation of the data is applied to a nominal standard feed size of 80 per cent minus 150 mm (primary crushed ore) to a plant.

The SAGDesign Test (discussed further below) was developed, in part, to overcome some of the concerns regarding the ‘grindability’ of the ‘critical size’ material in the SAG mill, hence the coarser feed size.

The SPI Test data interpretation relies on empirical relationships to describe the impact of feed size, pebble crushing and other operating factors on the SAG mill specific energy, much like most other mill specific energy calculation methods.

Figure 3 compares the SPI and DWi data for a range of projects. The DWi data incurs some scatter as the DWi parameter relates to the volume of the ore rather than the mass (used by the SPI data) and ore specific gravity therefore has an impact. The correlation between DWi and SPI is moderately good for low competence ore (SPI below 100) but diverges for high competence ores.

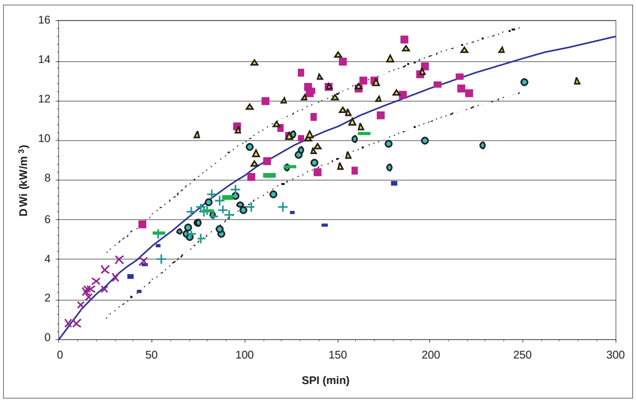


FIG 3 - Comparison of SPI and DWi data for various ore samples.

SAGDesignTest

Starkey developed and markets the SAGDesign Test. The SAGDesign Test was created specifically for sizing of new SAG and ball mills. It was patented by Outotec who guarantee throughput and grind for Outotec supplied grinding mills based on the test data.

The SAGDesign Test has some potential advantages over the SPI Test in that the feed size is coarser and arguably better indicates the impact of critical size on SAG mill specific energy and the feed mass (10 kg) allows a ball mill work index test to be conducted on the product.

On recent projects dealing with competent ores, the SAGDesign approach has yielded similar outcomes to those using Morrell’s approach (Morrell, 2008) and Ausenco’s in-house design approach based on Bond work indices, A × b values and an empirical model of operating efficiency.

SPECIFIC ENERGY DETERMINATION

All methods used for the calculation of grinding circuit specific energy are empirical, although some methods have a superior level of packaging (eg JKSimMet). In general there are three types of models:

1. the Bond based methods;
2. the proprietary test (eg MacPherson, SPI, Starkey, SMC Tests®) based models; and
3. the more sophisticated population balance/breakage model/classification model based methods.

Using all three methods successfully requires a high level of appreciation of the limitations of the methods. Some consultants use a combination of all three approaches for comminution specific energy determination.

For the vast majority of ores, experienced consultants find that each of the methods tends to give similar results.

Some specific issues related to ball mill specific energy calculation are:

- whether large mills are inherently more efficient than small mills, per Bond's efficiency factor, and
- use of the phantom cyclone to factor for 'fines' produced by the SAG/AG mill.

Starkey (2006) states that:

> *… benchmark testing at large (mill) installations shows conclusively that the diameter correction factor proposed by Bond is valid and perhaps even conservative. This factor is: Operating Wi = bond Wi x (8/D)$^{0.2}$ or 0.80 x BWi for a 24 ft diameter grinding mill. C Rowland proposed a limiting value of 0.914 on this factor, but that value was based more on the size of mill available in his time rather than on an empirical analysis.*

Starkey also sets out eight rules for design that are reasonably consistent with general grinding circuit design practice. However, Starkey's assertion concerning Bond's diameter correction factor is not supported by Morrell (2001) who could find no relationship between energy efficiency and mill diameter, as inferred by Starkey's benchmarking.

The authors of this paper do not use the 'phantom cyclone' methodology. That SAG mills, and more so AG mills, produce product size distributions containing considerably more fines than rod mills or tertiary crushers is not in question. However, AG/SAG mill product size distributions can also contain more coarse particles as well. This, combined with the fact that AG/SAG mills are good at preferentially breaking the softer particles in the feed and leaving the coarse end of the product distribution harder, reduces or eliminates any effect of extra fines production in the primary stage of milling.

Recently, the determination of specific energy for SAG mill based circuits treating competent ores has resulted in some diverging views. In the opinion of the authors, these diverging outcomes are related to two factors:

1. limitations of the SPI Test when determining the competence of competent ores, and
2. incorrect application of the JKSimMet package.

Limitations of the SPI approach

The SPI approach was developed by Starkey and commercialised by Minnovex (Starky and Dobby, 1996) and now SGS.

In the opinion of the authors the SPI approach to SAG mill performance correlation is less applicable for the determination of SAG mill specific energy for competent ores. Differences in calculated specific energy have been observed between the SPI and DWi based approaches for several large recent projects in the study phase where the A × b values have been less than 30.

The SPI method has been used successfully to predict performance correlations when treating soft ores, and is arguably a better statistical approach to sample selection and testing when compared with the JKDWT or SMC Test® as the latter rely on the selection of single particles of a predetermined size and this in itself may create a bias in the test method for soft ores.

When testing competent ores, the SPI data shows a poor correlation with the DWi data. Starkey, who developed the SPI method, has used a modified approach in developing the SAG Design Test that appears more consistent with the JKDWT and SMC Test® based methods.

Limitations of the JKSimMet package

JKSimMet is a comminution and classification simulation package based on 45 years of research at the Julius Kruttschnitt Mineral Research Centre (JKMRC), University of Queensland. The package is developed and marketed by JKTech, the technology transfer vehicle for the JKMRC. In excess of 350 JKSimMet packages are in use around the world. The JKSimMet package is the most widely accepted population balance/breakage model/classification model and differs from the other approaches due to the more fundamental rather than empirical bases of the models.

JKSimMet is frequently used as one of the methods of estimating SAG mill power requirements, using ore specific parameters from JKDWT or SMC Test®. However, as with any simulation tool, understanding the models and their limitations is critical and there are several usage rules which must be observed to get accurate predictions. The AG/SAG mill model used in JKSimMet is known as the Variable Rates Model and is described in detail in Napier-Munn *et al* (1996).

Perhaps the most important limitation of this model is that the variable rate equations were based on operating data from a series of mills with an average total load volume of 25 per cent. It is well known that the breakage rates vary with the mill load but the effect of this variation is not included in the model. This means that all design simulations should be conducted at 25 per cent load.

A second limitation arises when using this model to simulate modern, all pebble port, grate mills. It is essential to set the Xm parameter (fine size) to a small number, say 1.5, the Xg parameter (nominal grate size) to a small number, say 1.5 and control the discharge from the mill by specifying the pebble port size with the pebble port open area set to 100 per cent of the total open area.

A third limitation is that, in some circumstances, JKSimMet predicts excessive pebble recycle. Experience dictates that pebble recycle rarely exceeds 30 per cent of new feed, so JKSimMet predictions of greater recycle ratios should be treated with caution.

JKMRC is currently constructing and testing an upgraded variable rates model which is aimed at overcoming several of the limitations discussed above. This work is funded by JKTech.

Random variation in the ore properties measured by the JKDWT or the SMC Test® can lead to variation in the predicted specific energy requirements. In association with the JKDWT variation study discussed above, Stark, Perkins and Napier-Munn (2008) reported a design simulation study involving 100 repeat simulations using correctly distributed random values of A and b. For the particular mill configuration chosen, the mean predicted throughput was 339.4 t/h with 95 per cent confidence limits of ±25.0 t/h. This equates to ±7.4 per cent of the throughput. This is the sort of variability that can be expected simply from random variation of A × b values.

One of the advantages or disadvantages (depending on one's point of view) of using JKSimMet is the requirement for a full feed size distribution. Crusher manufacturers publish product size distributions which generally vary with crusher gap and sometimes broadly with ore properties. However, these are almost always based on scalped feed and the scalping process can remove as much as 50 per cent of the feed. This will seriously under estimate the quantity of fines (<10 mm) in the AG/SAG feed.

Morrell and Morrison (1996) reported a relationship between AG/SAG mill new feed F_{80} and the abrasion parameter ta which is derived from a laboratory abrasion test and is reported as part of the JKDWT methodology. This relationship is a function of crusher gap as shown in the relationship:

$$F_{80} = CSS - 78.7 - 28.4 \times \ln(t_a)$$

where:

F_{80} = primary crusher discharge 80 per cent passing size in mm (or AG/SAG mill feed)

CSS = primary crusher closed side setting in mm

t_a = abrasion parameter from the JK Drop Weight Test

The standard deviation associated with this regression relationship was ten per cent of CSS.

More recently Morrell has provided an updated relationship:

$$F_{80} = 0.2 \times CSS \times DWi^{0.7}$$

where:

F_{80} = primary crusher discharge 80 per cent passing size in mm (or AG/SAG mill feed)

CSS = primary crusher closed side setting in mm

DWi = drop weight index from the SMC Test®

Once the F_{80} of the comminution circuit feed is known, a suitable size distribution is selected from the database and adjusted to match the estimated F_{80}.

It is important to note that the F_{80} predicted from both these relationships is mostly less than the primary crusher CSS, sometimes a lot less. For the latter relationship, it is only for DWi values of 10 kWh/m^3 or higher that the F_{80} value is greater than the gap.

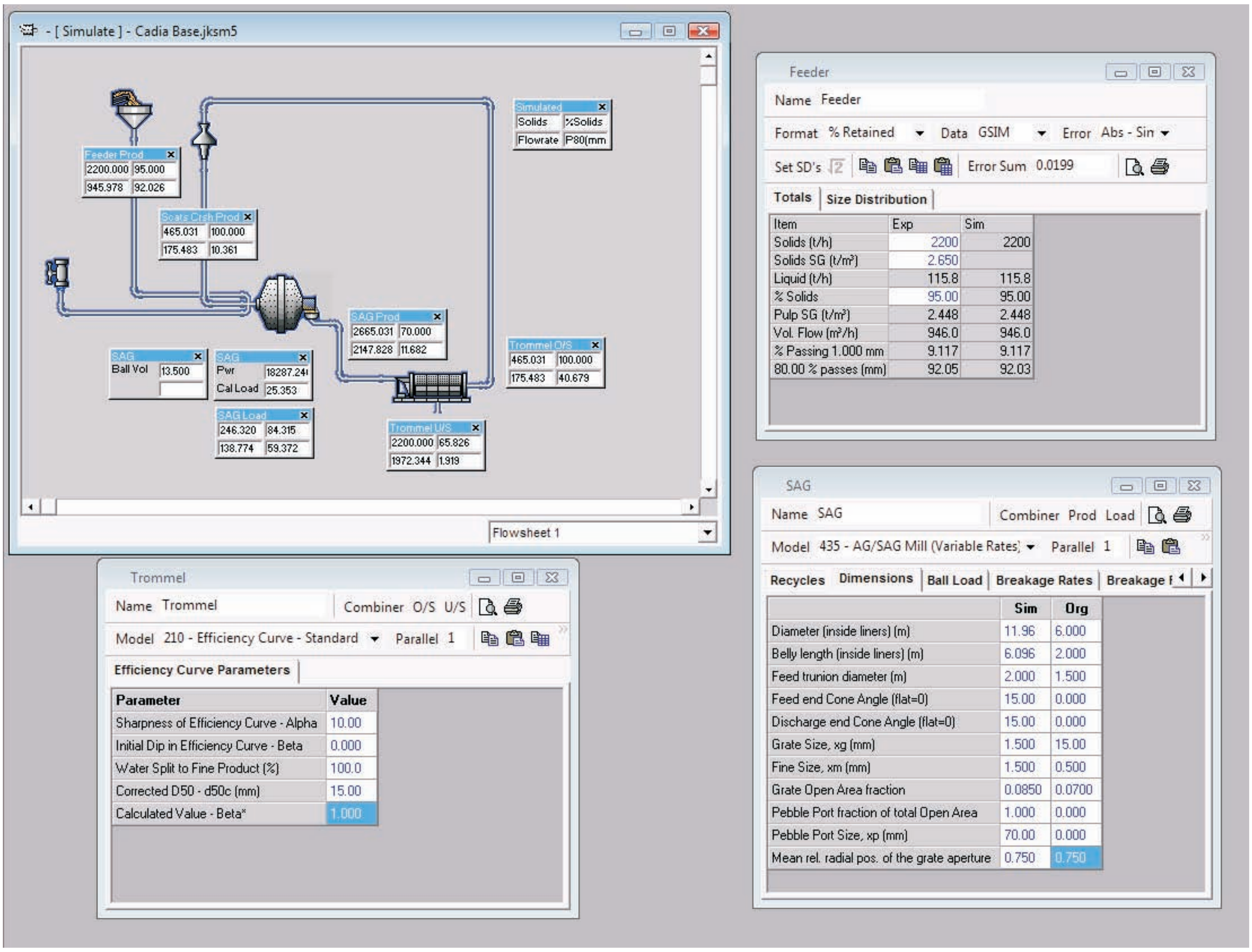
Guidelines for JKSimMet modelling and simulation

When used strictly according to rules provided in the JKSimMet training manual, the so-called variable rates model usually gives reasonably realistic throughput predictions for AG and SAG mills, including mills up to 40 ft in diameter. In particular, it is important that appropriate breakage rates, mass transfer parameters and feed size distributions are chosen. In a number of recent projects failure to obey these rules has lead to throughput predictions for 40 ft SAG mills that are unrealistically high. Specific mistakes that have been found to have been made are:

- The incorrect setting of the grate parameter (xg) to the actual pebble port aperture in fully ported grates. The correct approach is to set xg and xm to 1.5 and to set the pebble port aperture parameter to the minimum dimension of the actual pebble ports.
- Use of breakage rates from an existing mill which have either been fitted in an inappropriate manner or represent operating conditions very far from those being used for design purposes. The best (most foolproof) method is to rely on the variable rates model's default rates.
- Incorrect use of the F80 parameter and/or unrealistic feed size distributions. In most cases reliable operating plant data indicate that AG/SAG mill feed size distributions are linear in log-log space and distributions chosen for design purposes should follow this pattern. The F_{80} should also be realistic and should be determined using either the DWi-F_{80} relationship recommended by JKTech or from an existing plant with a similar ore hardness. The F_{80} parameter should be set to 100 mm regardless of the actual F_{80} used in cases where the default breakage rates are used. Where breakage rates have been taken from fitting data from an existing operation the F_{80} parameter value for the fitting should remain unchanged.
- The ta value, usually obtained from tests in parallel with the JKDWT, should not be changed in the model when simulating the performance of ores with different A and b parameters. The ta value assists in modelling the fines production in a SAG mill but simulation of ores with different ta test values using models developed on other ores can lead to misleading results.
- The JKSimMet models should always be checked using a power based empirical model to make sure the model outcomes are reasonable. Most comminution design practitioners have power based models that are used for this purpose. It is critical that these models have been 'calibrated' for the range of ore characteristics being considered.

Other mistakes in setting up the model are possible either through lack of sufficient knowledge or simple inattention to detail. It is therefore recommended that the designer apply his/her model to a 'standard' circuit before using it in a real design situation. If the model does not predict the standard mill performance to within about ten per cent then it can be assumed that the model is not appropriate and needs to be corrected. It is suggested that the standard adopted is the '40 ft SAG mill' at Cadia Hill (Figure 4). The reasons for this choice are that it is a large mill, it treats reasonably competent ore and has much detailed information published concerning its design, operating performance and ore hardness (Dunne *et al*, 1999, 2001; Dunne, Morrell and Lane, 2000; Hart *et al*, 2001). The following data have been taken from the published literature and are suggested for use as this standard:

Diameter inside shell	40 ft
Diameter inside liners	11.96 m
Length (EGL)	20 ft
Belly Length (inside grate and liners)	6.096 m
Cone angle	15°
Open area	eight to ten per cent
Pebble port aperture	75 mm (fully ported)
Trommel effective	15 mm
Ore Sg	2.65 t/m^3
A	65
b	0.58
ta	0.49
F_{80}	90 - 100
Ball load	12 - 14 per cent
Total load	25 to 26 per cent
Speed	78 per cent of critical
Power draw	18 - 18.5 MW
Throughput	2000 - 2200 t/h
Transfer T80	1.5 - 2.5 mm
Pebble rates	400 - 500 t/h



Feeder Prod: 2200.000 | 95.000 | 945.978 | 92.026

Scats Crsh Prod: 465.031 | 100.000 | 175.483 | 10.361

SAG Prod: 2665.031 | 70.000 | 2147.828 | 11.682

Trommel O/S: 465.031 | 100.000 | 175.483 | 40.679

Trommel U/S: 2200.000 | 65.826 | 1972.344 | 1.919

SAG Load: 246.320 | 84.315 | 138.774 | 59.372

SAG: Ball Vol 13.500

SAG: Pwr 18287.24 | Cal Load 25.353

Feeder

Name Feeder

Format % Retained | Data GSIM | Error Abs - Sin

Set SD's 2 | Error Sum 0.0199

Totals | Size Distribution

Item	Exp	Sim
Solids (t/h)	2200	2200
Solids SG (t/m³)	2.650	
Liquid (t/h)	115.8	115.8
% Solids	95.00	95.00
Pulp SG (t/m³)	2.448	2.448
Vol. Flow (m³/h)	946.0	946.0
% Passing 1.000 mm	9.117	9.117
80.00 % passes (mm)	92.05	92.03

Trommel

Name Trommel | Combiner O/S U/S

Model 210 - Efficiency Curve - Standard | Parallel 1

Efficiency Curve Parameters

Parameter	Value
Sharpness of Efficiency Curve - Alpha	10.00
Initial Dip in Efficiency Curve - Beta	0.000
Water Split to Fine Product (%)	100.0
Corrected D50 - d50c (mm)	15.00
Calculated Value - Beta*	1.000

SAG

Name SAG | Combiner Prod Load

Model 435 - AG/SAG Mill (Variable Rates) | Parallel 1

	Sim	Org
Diameter (inside liners) (m)	11.96	6.000
Belly length (inside liners) (m)	6.096	2.000
Feed trunion diameter (m)	2.000	1.500
Feed end Cone Angle (flat=0)	15.00	0.000
Discharge end Cone Angle (flat=0)	15.00	0.000
Grate Size, xg (mm)	1.500	15.00
Fine Size, xm (mm)	1.500	0.500
Grate Open Area fraction	0.0850	0.0700
Pebble Port fraction of total Open Area	1.000	0.000
Pebble Port Size, xp (mm)	70.00	0.000
Mean rel. radial pos. of the grate aperture	0.750	0.750

FIG 4 - Example of JKSimMet model for the Cadia mill based on published data.

Other considerations

There are several other considerations that are important in determining the most effective comminution circuit design and subsequent equipment selection. These include:

- selecting a design point that strikes a balance between contingency and operational variation and cost (capital and operating),
- marrying the perspectives of designers and operators to target the best business case, and
- differentiating between instantaneous performance and performance over a period (to achieve budget) that may incorporate operational upsets.

In the early stages of a study where limited data is available the design may require a suitable contingency to reflect uncertainty due to lack of variability data. As the study proceeds and data is more 'representative', using the 75th percentile data point for each recognised ore type and mapping the ore types against the mine schedule may be a reasonable strategy. Final selection of the design case needs to reflect a business case that includes operational factors that may relate to variation in ore characteristics, ore segregation (critical for competent ores due to the potentially large impact on SAG mill capacity), equipment availability (such as that for lower availability units such as pebble crushers) and other site related factors.

CONCLUSIONS

Comminution circuit design relies on input and interpretation of comminution test work data. Understanding of the pitfalls inherent with these tests is critical to ensure robust designs are achieved in the end.

Comminution circuit design for average competence ores is more straight forward than for very competent ores, many of which have been studied recently. The application of a methodology which works well for lower competence ores does not guarantee accurate predictions for all ores.

Recently, it has been observed that engineers and consultants have, at times, under estimated the SAG mill specific energy for treating competent ores due to:

- lack of relevant data for comparable benchmark operations,
- lack of understanding of the test work methods used by various laboratories, and
- poor use of packages such as JKSimMet.

This paper is aimed at assisting practitioners in understanding the potential pitfalls.

The selection of the correct design point and judicious application of contingencies needs to be carefully understood and tailored for the application in order to achieve the desired throughput outcome an annual basis.

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