HIT – a Portable Field Device for Rapid Testing at Site

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ABSTRACT

The index A*b, determined from the Julius Kruttschnitt Mineral Research Centre (JKMRC) drop weight tester (DWT) results, has become well-known in the mining industry as a reliable measure of ore hardness in impact or crushing, having the inferred units of t/kWh. This index evolved from a long history of comminution studies at the JKMRC, including the development of the now superseded JKTech twin-pendulum, the industry standard JK Drop Weight Tester (JKDWT) and the faster alterative JKMRC rotary breakage tester (JKRBT). A reduced version of the DWT, the semi-autogenous grinding mill comminution test (SMC test®), also provides estimates of the A*b though the testing of only one particle size at five specific energies. Experimental determination of A*b using the above devices/tests requires samples, with sufficient mass, to be sent to designated laboratories, registered to conduct such tests. This protocol is fine for bankable and commercial testing, where material characterisation data is used in conjunction with machine specific data in modelling and simulation, and power based calculations. However, for comparative testing, where results are required at the time of sampling (eg for plant troubleshooting or spot-surveys), or for rapid ranking of geometallurgical samples, these existing tests simply do not provide a timely, viable and cost-effective solution. In order to address this critical void in the realm of comparative testing, a new device has been developed, exploiting a central feature of single particle impact testing – that the A*b can be reliably estimated using one precise low energy test. This device, for which a patent is currently pending, called the HIT (Hardness Index Tester), has been precision engineered to allow users to break narrowly sized fragments at a set specific energy, in a safe and easy manner. The manufacturing materials have been chosen carefully to ensure compatibility with the intended use and portability to any site, whilst minimising cost. The device is supplied with a novel quality assurance / quality control (QA/QC) feature, to ensure that the targeted potential energy is consistently delivered. The product from the HIT breakage test can be quickly sized using a single screen to determine the mass per cent undersize, from which the A*b index is calculated directly at site – eliminating the need to send the raw data off-site for analysis. On presized fragments, a single test using 20 fragments takes less than five minutes to complete, and the results are immediately available. The HIT is currently being tested at a major mining laboratory in the US and the results to date have proved it can deliver on all fronts. This paper describes the new prototype device, which offers users a low cost in-house mechanism for estimating the A*b at any mine site, with potential applications on fragments up to 25 mm from drill core, blast chip rejects or the grinding circuit feed. It also outlines the results of field tests carried out by an objective third party mining group and compares the results with those from current industry standard tests conducted on the same material.

INTRODUCTION

The mining industry has for the longest time been determining comminution parameters via expensive and time-consuming laboratory tests, typically Bond ball mill Work Index and SMC test® / JKDWT A*b (Bond, 1961; Morrell, 2004). Due to budgetary constraints, this has curtailed the collection of sufficient number of BMWi or A*b measurements to allow the inherent variability to be adequately quantified for direct estimation into a block model for mine planning. Ultimately operations have and continue to experience difficulties in reaching or sustaining target production rates because the mill circuit design is derived from averaged core data determined at the exploration/study phase for the project. Too often this data proves inadequate in response to the ore variability actually encountered as the resource is mined, making successful management of the process a real challenge.

SimSAGe believes the historical precedence of inappropriate mill design and suboptimal performance could have been mitigated if the industry had access to a simple, rapid and less expensive test, which could provide sufficiently reliable comminution parameters like A*b and BMWi. In order to address this critical void, a new device has been developed, referred to as the HIT (Hardness Index Tester), exploiting a central feature of single particle impact testing: that the A*b can be reliably estimated using one

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precise low energy test; and that the Bond grindability can be linked to the breakage response at one precise high energy test.

This paper focuses on the A*b measurement approach.

HIT MEASUREMENT APPROACH

Concept

The current Julius Kruttschnitt Mineral Research Centre (JKMRC) breakage model suggests the amount of breakage, or breakage index, T10, is related to the specific comminution energy as follows:

$$T10 = A[1 - e^{-bEcs}] \tag{1}$$

where:

*T*10	the per cent passing 1/10th of the initial mean particle size
Ecs	the specific comminution energy (kWh/t)
A, b	the ore impact breakage parameters determined from JK Drop Weight Test (JKDWT) results (Napier-Munn *et al*, 1996)

Graphically this relationship is shown in Figure 1 for a hard gold bearing ore, having an A*b of 23 (A = 100, b = 0.23).

The value of Equation 1 is embedded in the JKSimMet comminution models (Wiseman and Richardson, 1991), which rely on the T10 to generate a full size distribution given the relationships between T10 and Tn-family curves established from the Drop Weight Test database (Narayanan and Whiten, 1988). That is, the model only needs to know the Ecs and the ore parameters A and b to generate the product size distribution for a given breakage event.

The T10 can be interpreted as a 'fineness index' with larger values indicating a finer product size distribution. The value of parameter A is the limiting value of T10, and is related to the texture of the ore. This limit indicates that at higher energies the size reduction process becomes less efficient. The index A*b has become well-known in the mining industry as a reliable indicator of impact ore hardness, and underpins the power based modelling proposed by Morrell (2009).

The less known fact is that A*b is the slope of the curve of 'zero' input energy (Napier-Munn *et al*, 1996). A higher A*b or steeper gradient of the T10-Ecs curve indicates a softer ore.

What is clearly evident from the T10-Ecs curve is that the slope at the lowest Ecs (0.2 kWh/t) is a very good estimate of the slope at zero, ie the true A*b for the fitted curve. Clearly sample hardness, variability and the number of particles tested would be expected to affect the precision of the T10 and hence A*b (or slope) estimate at low energies. The slope at the low energy, say 0.2 kWh/t, would be expected to be marginally lower than the actual A*b, which is not surprising knowing the slope decreases for Ecs >0. Calibration against the standard SMC or JKDWT parameters is possible, taking into account the offset for the slope and effect of particle size.

Proof of concept

Almost 100 sets of JKDWT data covering 32 ore deposits were used to calculate the slope at Ecs = 0.25 kWh/t using the raw T10 values for the 31.5 × 26.5 mm size fraction. Figure 2 shows the complete set of results, confirming the strong correlation, the scatter due partly to the Ecs variation, but also differences in the properties of the material in the 31.5 × 26.5 mm size fraction from the whole sample used to derive the A*b parameters for the JKDWT sample.

The application of the concept has also shown value in rapid semi-autogenous grinding (SAG) mill feed hardness testing

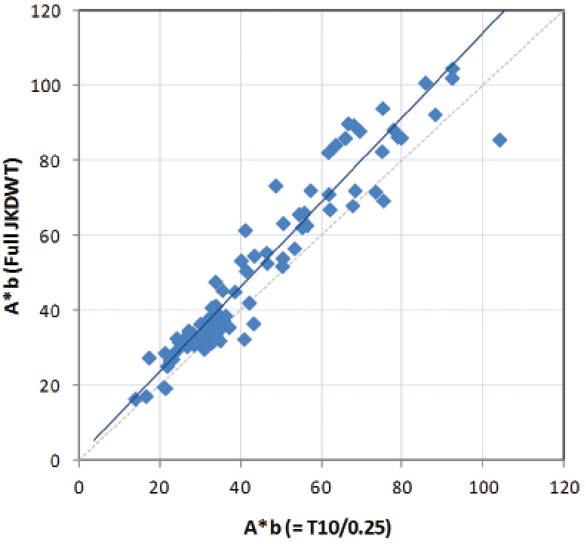


FIG 2 – Comparison of JKDWT A*b values and corresponding A*b estimates using T10 for 31.5 × 26.5 mm fraction (93 samples, 32 ore deposits).

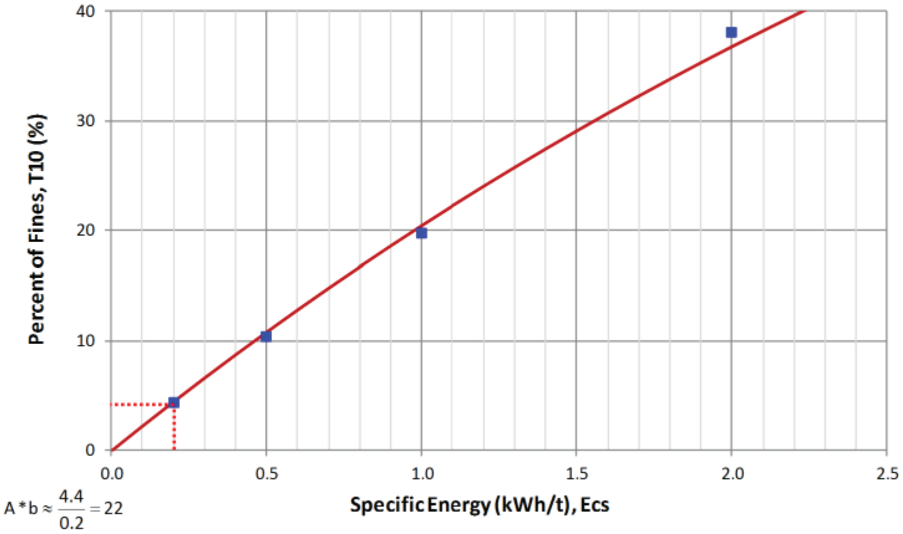


FIG 1 – Derivation of A*b estimate using slope at Ecs = 0.2 kWh/t.

ahead of mill surveys. For example, three feed ore types were sampled and the 31.5 × 26.5 mm fraction tested using the JKRBT (Kojovic *et al*, 2010) at a single Ecs (0.2 kWh/t) before plant trials. Subsequent ore characterisation using JKDWT has confirmed the relative hardness predicted by the rapid test was valid, as illustrated in Figure 3, across a wide impact hardness range.

Development of the HIT

SimSAGe believed it was possible to design and build a fit-for-purpose small device to measure A*b using a single low energy test. The device was called the Hardness Index Tester (HIT) featuring the following design criteria:

- safe to use
- portable and easy to use with minimal training
- rapid turn-around time (<5 mins per test)
- requires no power, air or hydraulics
- low noise and dust generation
- A*b index can be calculated at site – eliminating the need to send the raw data off-site for analysis
- generates on the spot results allowing for real-time decision-making.

The first prototype was built in Oct 2013 in Brisbane, and sent to Teck ART Laboratory in Trail, BC Canada for trials. The results were promising, but the machine design did not meet the above criteria adequately, requiring further development to improve its consistency. The second generation prototype was precision engineered, accurate and with repeatable results, and is safe and easy to use. The fabrication was completed in California, USA. The materials were selected to suit the intended use and portability (15 kg), whilst minimising cost when compared to other methods/equipment required for achieving similar results/data. The device is supplied with a consistency measurement feature, to ensure that the available input energy is consistently delivered, over the life of the machine. The rock top size chosen for hardness testing was 25 mm. A provisional patent was filed 15 Oct, 2015 (Kojovic, 2015). Figure 4 shows the second generation HIT prototype, which comprises a frame, a sample cup to hold the fragment to be crushed, crusher hammer assembly and dual lever mechanism to trigger the release of the hammer onto the fragment in the cup. The sample cup sits in a dedicated grooved inset on the top surface of the frame base plate, and comprises a handle allowing a user to easily remove the sample cup from the frame during testing. The apparatus includes a non-rock means of monitoring the consistency of the input energy delivered to a specimen over time (via lead shot supplied with a very low diameter tolerance, 0.44 ± 0.007 inches).

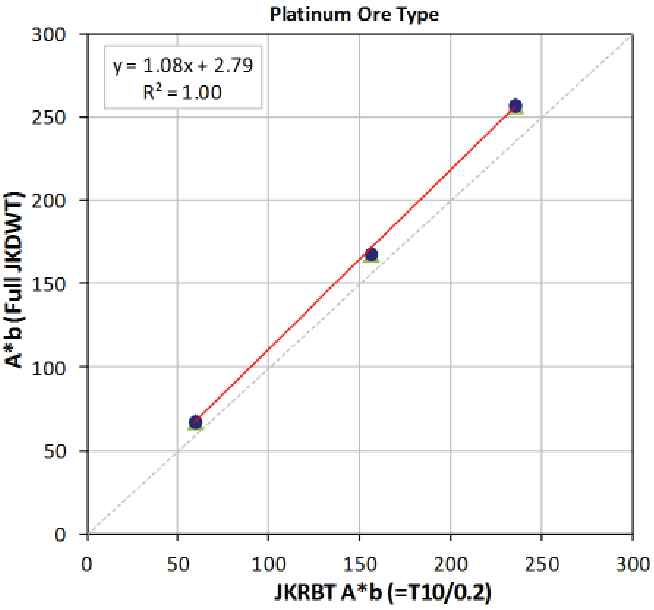


FIG 3 – Comparison of JKDWT A*b values and corresponding JKRBT A*b express estimates using T10 for 37.5 × 31.5 mm fraction.

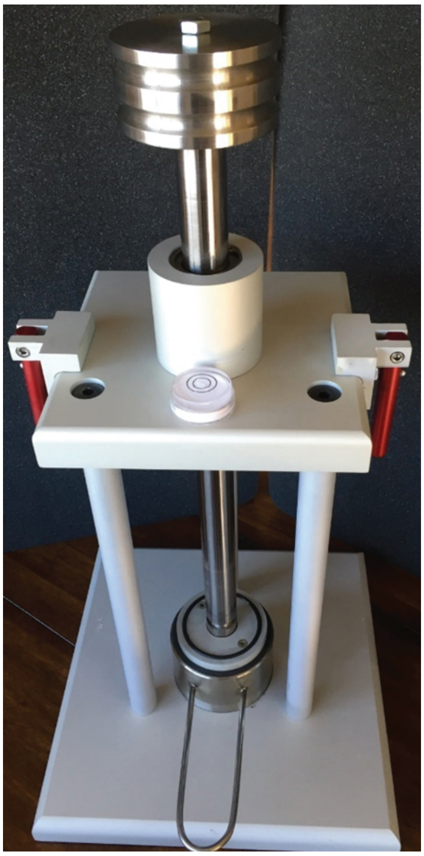


FIG 4 – HIT prototype v2, patent pending 62/241 852 (Kojovic, 2015).

HIT test procedure

The HIT test requires a minimum of ten fragments in a narrow size fraction (eg -22.4 + 19 mm or -16 + 13.2 mm). Fragments may be sorted to ensure all fragments are within a set mass tolerance around the bulk sample mean (eg ±20 per cent). This will ensure the mean mass of any set of ten fragments will be within five per cent of the population mean. As such the process was in theory in line with the particle sorting adopted by the SMC Test® protocol. The specific energy (Ecs) calculated from input energy (Ei) and average particle mass (m) as follows:

$$Ecs = \frac{E_i}{m} = \frac{MgH}{m}(J/kg) \qquad (2)$$

where:

M	represents a mass of the crusher assembly (crusher hammer, crusher shaft and crusher weight) (kg)
g	represents the gravitational constant (9.8 m/s^2)
H	represents a height of the crusher hammer (m)
m	represents a weight of the fragment of granular material in the sample cup
Ecs	can be converted to the units of kWh/t by dividing by 3600

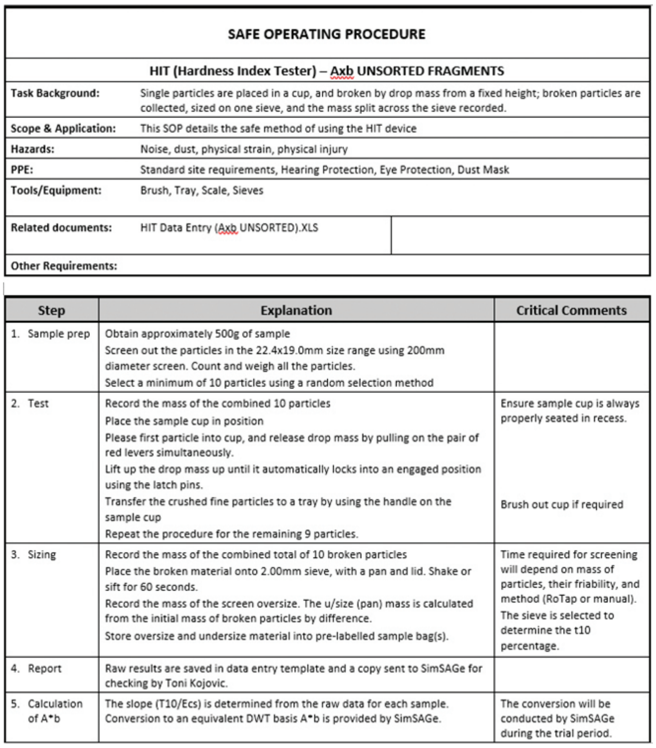
The broken product from all ten fragments is dry sized for one minute using a single sieve, representing the T10 size (eg 2 mm for -22.4 + 19 mm fragments). The mass per cent of undersize is referred to as T10. The slope, or T10/Ecs, is the raw hardness index (HDI):

$$HDI = \frac{T10}{Ecs}\left(\%/\frac{kWh}{t}\right) \tag{3}$$

HDI needs to be corrected for the slope offset and particle size to estimate the JKDWT A*b parameter. Safe Operating Procedure (SOP) and data entry sheets have been developed for HIT testing using sorted or unsorted fragments (see Figure 5a and 5b). Software is provided for the HDI corrections.

INDUSTRIAL HIT TRIAL

Following the initial testing of the second generation HIT prototype, a major mining laboratory in USA agreed to a six-month trial, starting November 2015. The question of whether the HIT device is consistent with the JKDWT was addressed using four samples from two ore deposits. Duplicate samples were prepared from the same batch of -16 + 13.2 mm fragments supplied by the mine, and tested using the JKDWT at similar specific energies. Four splits of ten fragments were tested using the HIT device. The results are summarised in Table 1, including the Coefficient of Variation (100*SD/Mean, where SD = standard deviation) for the T10 percentage. Figure 6 shows the chart with the 1SD error bars for the four samples. The inherent variability of the four samples in the comparison is evidently high, given the nominal reproducibility of the JKDWT is only ±3.6 per cent, based on the standard ore used by JKTech for round-robin studies (Napier-Munn *et al*, 1996). However, statistically there is no significant difference between the two devices, meaning the HIT can generate valid T10 measurements.



SAFE OPERATING PROCEDURE	
HIT (Hardness Index Tester) – Axb UNSORTED FRAGMENTS	
Task Background:	Single particles are placed in a cup, and broken by drop mass from a fixed height; broken particles are collected, sized on one sieve, and the mass split across the sieve recorded.
Scope & Application:	This SOP details the safe method of using the HIT device
Hazards:	Noise, dust, physical strain, physical injury
PPE:	Standard site requirements, Hearing Protection, Eye Protection, Dust Mask
Tools/Equipment:	Brush, Tray, Scale, Sieves
Related documents:	HIT Data Entry (Axb UNSORTED).XLS
Other Requirements:	

Step	Explanation	Critical Comments
1. Sample prep	Obtain approximately 500g of sample Screen out the particles in the 22.4x19.0mm size range using 200mm diameter screen. Count and weigh all the particles. Select a minimum of 10 particles using a random selection method	
2. Test	Record the mass of the combined 10 particles Place the sample cup in position Please first particle into cup, and release drop mass by pulling on the pair of red levers simultaneously. Lift up the drop mass up until it automatically locks into an engaged position using the latch pins. Transfer the crushed fine particles to a tray by using the handle on the sample cup Repeat the procedure for the remaining 9 particles.	Ensure sample cup is always properly seated in recess. Brush out cup if required
3. Sizing	Record the mass of the combined total of 10 broken particles Place the broken material onto 2.00mm sieve, with a pan and lid. Shake or sift for 60 seconds. Record the mass of the screen oversize. The u/size (pan) mass is calculated from the initial mass of broken particles by difference. Store oversize and undersize material into pre-labelled sample bag(s).	Time required for screening will depend on mass of particles, their friability, and method (RoTap or manual). The sieve is selected to determine the t10 percentage.
4. Report	Raw results are saved in data entry template and a copy sent to SimSAGe for checking by Toni Kojovic.	
5. Calculation of A*b	The slope (T10/Ecs) is determined from the raw data for each sample. Conversion to an equivalent DWT basis A*b is provided by SimSAGe.	The conversion will be conducted by SimSAGe during the trial period.

FIG 5A – SOP for HIT testing.

TABLE 1

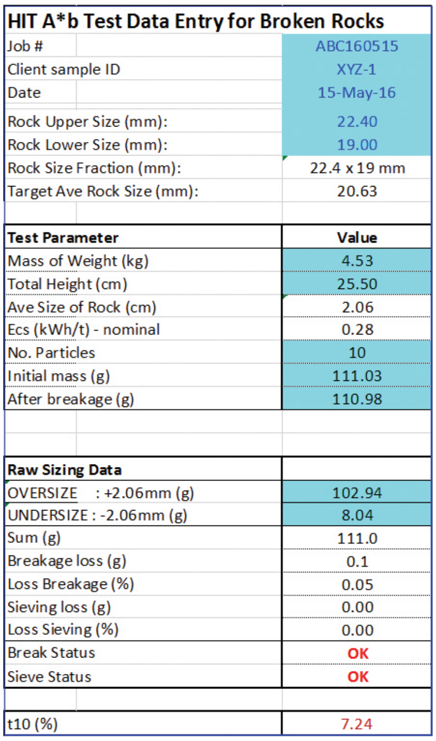
Comparison of HIT and JKDWT results.

Sample	Particle	SimSAGe HIT – T10 (%)						
ID	**Size**	**s1**	**s2**	**s3**	**s4**	**AVE**	**SD**	**CoV**
A-1	16 × 13.2	14.2	15.3	10.4	15.2	13.8	2.3	17%
A-2	16 × 13.2	9.3	9.1	8.5	9.7	9.1	0.5	5%
A-3	16 × 13.2	11.0	13.8	9.6	14.7	12.3	2.4	19%
B-1	16 × 13.2	7.1	7.6	9.4	10.6	8.7	1.6	19%
Sample	**Particle**	**Site DWT – T10 (%)**						
ID	**Size**	**s1**	**s2**	**s3**	**s4**	**AVE**	**SD**	**CoV**
A-1	16 × 13.2	15.3	12.1	-	-	13.7	2.3	17%
A-2	16 × 13.2	8.8	13.1	-	-	10.9	3.0	27%
A-3	16 × 13.2	10.2	12.2	-	-	11.2	1.4	13%
B-1	16 × 13.2	9.2	10.7	-	-	10.0	1.1	11%

Scope of trial

SMC results (summary and raw files) were supplied for three ore deposits, comprising 36 samples in total. HIT testing was completed on residue fragments of the same size from these samples, considering both 'sorted' and 'unsorted' fragments. Most HIT tests were completed using ten fragments, in either five or ten splits per sample. In the case of one ore deposit, the raw HIT data was also grouped in samples of 20 fragments to quantify the impact of the number of fragments on the variability. The site laboratory technicians were requested to monitor the wear and mechanical integrity of the HIT device throughput the trial, including quality assurance / quality control (QA/QC) checks every 500 samples using the lead shot.

The raw HIT T10/Ecs slope values for each test/size fraction were corrected and scaled to provide a final A*b estimate, commensurate with the average JKDWT size of 32.6 mm, assuming the effect of size on A*b follows the JKTech database average.



HIT A*b Test Data Entry for Broken Rocks	
Job #	ABC160515
Client sample ID	XYZ-1
Date	15-May-16
Rock Upper Size (mm):	22.40
Rock Lower Size (mm):	19.00
Rock Size Fraction (mm):	22.4 x 19 mm
Target Ave Rock Size (mm):	20.63
Test Parameter	**Value**
Mass of Weight (kg)	4.53
Total Height (cm)	25.50
Ave Size of Rock (cm)	2.06
Ecs (kWh/t) - nominal	0.28
No. Particles	10
Initial mass (g)	111.03
After breakage (g)	110.98
Raw Sizing Data	
OVERSIZE : +2.06mm (g)	102.94
UNDERSIZE : -2.06mm (g)	8.04
Sum (g)	111.0
Breakage loss (g)	0.1
Loss Breakage (%)	0.05
Sieving loss (g)	0.00
Loss Sieving (%)	0.00
Break Status	OK
Sieve Status	OK
t10 (%)	7.24

FIG 5B – Excel data entry sheet for HIT testing.

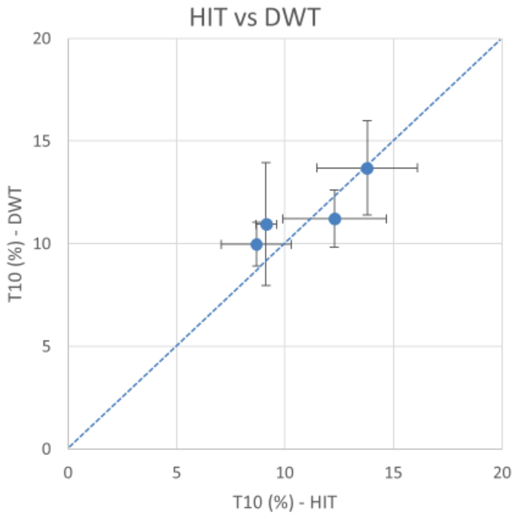


FIG 6 – Comparison of JKDWT and HIT T10 values for 16.0 × 13.2 mm fraction (four samples, two ore deposits).

Trial results

The HIT results suggest there is no significant benefit in sorting the fragments, as the differences are well within the variability for each sample (<10 per cent). Figure 7a shows all but one sample are consistent. The outlier, shown in red, was in fact in the sorted group. The trial data also confirms that the variability would reduce when using 20 fragments instead of ten per test, as expected, but there is no significant difference in the accuracy of the A*b estimates as shown in Figure 7b (comparing the averages for ten tests with ten rocks and five tests with 20 rocks). These findings bode well for the proposed application of HIT in rapid hardness testing, saving time necessary for sorting and breaking.

The comparison of the SMC A*b and HIT A*b estimates showed a consistent bias, across all three ore deposits investigated. With the exception of one sample, the HIT results consistently indicate the samples were harder than observed in the SMC test® work, albeit the overall trend in most part is the same as show in Figure 8.

In an effort to explain the reason for the bias, the site provided the raw SMC data files for review. Five samples were selected in each ore deposit to check the consistency of the particle lots used in each SMC test®, and the underlying T10-Ecs trend. This detailed analysis revealed two significant aspects that may help explain the bias:

1. the fragments chosen for SMC testing are consistently heavier, by as much as 30 per cent
2. the variability between the SMC fragment lots, in terms of the total mass, is much smaller than expected given the SMC prescribed particle sorting protocols for crushed and sized fragments.

This is clearly evident in the example shown in Table 2. Though it is impossible to say the bias is 100 per cent related to the difference in fragment mass, the evidence suggests the SMC fragments were different, possibly in mineralogy and shape, and as such, this factor renders the SMC versus HIT comparison inconclusive.

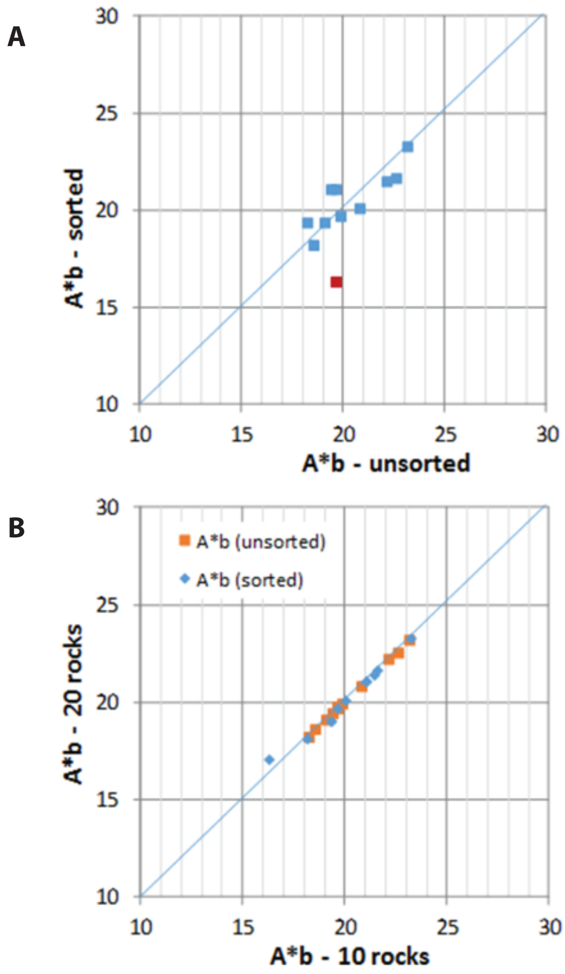


FIG 7 – Comparison of HIT A*b estimates for sorted and unsorted fragments.

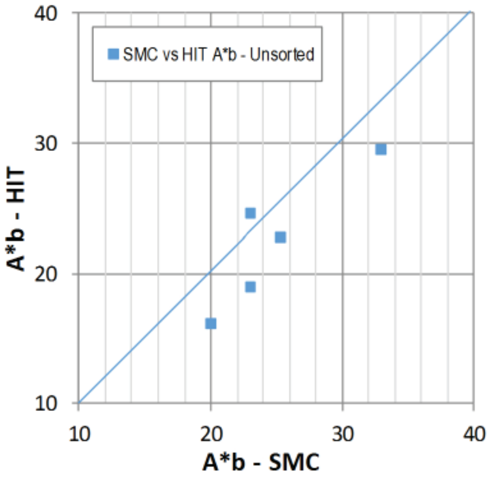


FIG 8 – Comparison of HIT and SMC A*b estimates for unsorted fragments, ore deposit A.

Although raw SMC files often show there is inherent breakage variability between the fragment lots, this fact is generally not identified to the client in the standard SMC reports. In contrast, the HIT testing does allow the opportunity to quantify the variability within a sample, which in the case of ore A is comparable to the variability across samples. This means the final SMC result for a deposit with high variability will depend on which lots of 20 particles are selected; the order they are tested (as the lower energies dominate the calibration) and as noted above, how they were sorted.

The bias between the SMC and HIT A*b estimates can partly be attributed to the difference in sizing methods, especially for softer ore types. For the HIT, the broken product from ten particles was shaken on a Ro-tap® for one minute. The site technicians usually complete five HIT tests (ten fragments each) and Ro-tap® them all together as a stack. Similar to the HIT tests, the technicians complete all of the drops for the

TABLE 2

Comparison of HIT and SMC sample mass statistics (ore A, 16 × 13.2 mm).

Sample	HIT – sorted		HIT – unsorted		SMC – sorted		Mass (%)
ID	Mean	SD	Mean	SD	Mean	SD	Rel diff
S-1	4.14	0.11	4.14	0.44	5.57	0.05	26
S-2	3.94	0.10	4.01	0.35	5.70	0.04	31
S-3	4.19	0.10	4.06	0.23	5.75	0.09	27
S-4	4.36	0.11	4.69	0.19	5.86	0.03	26
S-5	4.15	0.11	4.15	0.40	5.69	0.05	27

SMC test®, and Ro-tap® the products for five minutes due to the larger sample mass. The extended Ro-tap® shaking would be expected to generate more 'fines' in SMC testing and hence increase the T10 value, all else being equal. This would be classified as a systematic bias.

Despite the significant variability in the samples provided, if the material is the same, the direct HIT versus JKDWT comparison noted previously suggests there is statistically no difference between the two devices, as far as the amount of broken product generated at the same specific energy. This bodes well for HIT and suggests the bias between HIT and SMC A*b estimates above is likely to related to the sample selection, and to some extent the Ro-tap® time if the samples are relatively soft and friable.

In hindsight, the decision to use residues for the HIT trial has not provided a fair comparison, in light of the evidence presented. Hence a parallel test program would have been better, where fragments selected for SMC testing were also randomly set aside for HIT testing. This would have avoided the issues noted in the trial and any doubts over the nature of the sample material used in both tests. The systematic bias due to Ro-tap® sizing time could be corrected by deriving a simple correction factor for HIT results if the intent is to align exactly with SMC results.

Machine QA/QC

The site technicians regularly used the supplied 0.44" lead shot to monitor the HIT's mechanical consistency. The tolerance on the lead shot diameter is ±0.007". Their procedure was three shots per QA test, at a nominal frequency of one QA test every 500 drops. Figure 9 shows the trend of the shot thickness, indicating a very low variability (<0.3 per cent), significantly better than the expected 1.59 per cent tolerance on the diameter of the supplied shot. Though the trial has reached close to 12 500 drops, the results confirm the HIT device is consistently delivering the design input energy.

The feedback on the mechanical integrity of the HIT device at the end of the trial is encouraging. According to the photos in Figure 10, there is some wear and tear, specifically some pitting on the base plate. Also the gasket is starting to tear away from the drop head. The sample cup is holding up well and overall the unit is still in pretty good shape. It would seem reasonable to expect the impact and strike plates might need replacing >1500 tests or 15 000 drops.

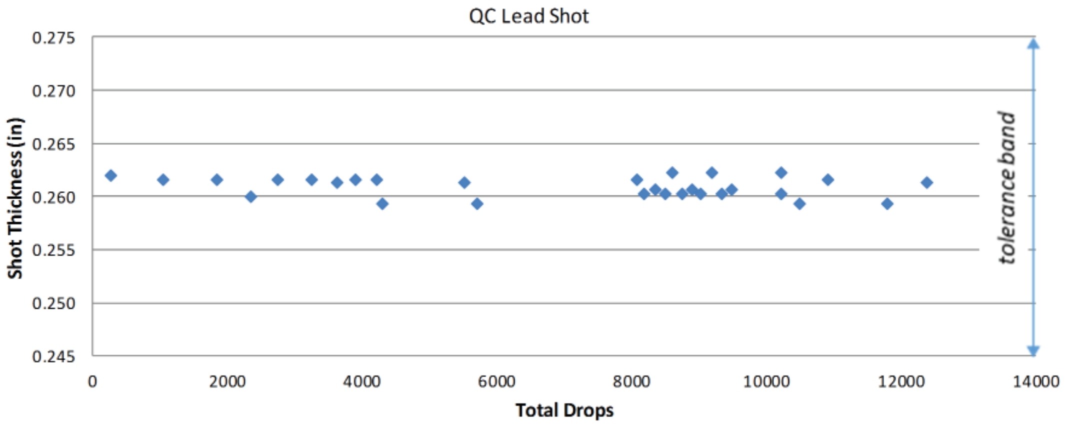


FIG 9 – Trend in lead shot thickness; based on mean of triplicates at nominal frequency of 500 drops.

FIG 10 – Images of HIT sample cup impact plate, drop striker plate and overall view after 12 000 drops.

APPLICATIONS

The ability to reliably estimate the A*b using a rapid single energy test, enabled by the precise engineering of the HIT and novel exploitation of A*b theory, opens the opportunity to a number of potential applications. SimSAGe believes the HIT device could be used to:

- quantify the hardness variability using drill core samples, in parallel to assaying of the same samples; such testing would precede the selection of drill core samples for compositing and testing using standard hardness tests like SMC and Bond at licensed laboratories
- monitor routinely the hardness of the feed to a mill (even on a per shift basis), to verify that the mill performance is optimised for the feed, and in line with expectations based on historical trends
- quantify the hardness variability within benches using blasthole reject samples, allowing reconciliation of block model hardness indices, adjustment of cut-off grade, ore blending, and in some cases adjustment of explosive loading depending on *in situ* hardness prior to blasting.

Blasthole testing

The application of HIT to blasthole testing was explored in the industrial trial. The site supplied HIT test results on 56 samples for A*b estimation, and 80 samples for Bond grindability index estimation. There were 41 samples with both types of HIT test results available. According to the site, these samples nominally represented one in every seven holes, across seven to eight blast patterns.

The A*b estimates were derived using HIT tests at lower specific energy levels (0.25 to 0.75 kWh/t depending on size fraction, 16 × 13.2 mm, 19 × 16 mm, 22.4 × 19 mm or 19 × 11.2 mm). The trial suggested 19 × 11.2 mm should provide at least ten fragments per hole, the minimum recommended for HIT testing. The Bond grindability index was derived from HIT tests at higher specific energy levels (~4.3 kWh/t) using 9.5 × 6.3 mm fragments (20 per test). Only one test per sample was conducted for the Bond grindability index, whereas on average five tests per sample were completed for the A*b estimate.

The two measures of hardness are independent, the A*b derived from the quantity of fines generated at a fixed low specific energy, the other related to the shape of the product size distribution generated at a higher specific energy, commensurate with the Bond ball mill test.

The A*b estimates for the three size fractions tested in the first set of blasthole samples are plotted in Figure 11, suggesting the same hardness can be inferred from either size, albeit variability could influence the final estimate, especially given there are fewer particles in the coarser fractions. Hence it would be prudent to select a fraction that would yield at least 10–20 rock fragments per blasthole sample. The resulting A*b and BWi distributions indicate a significant variability across the blastholes, shown in Figure 12, with the averages consistent with the typical results observed from SMC and Bond testing at this particular mine site. How the variation relates to the geology across the patterns is unclear, something the site mine planners aim to investigate in the near future.

SimSAGe believes this is the first time such data have been generated from blasthole samples, and confirms the viability of HIT testing to map the hardness variation for each pattern ahead of blasting, in parallel with assaying. Whether such information/knowledge could be used to alter the short-term mine planning and/or ore blending will depend on-site specific issues, but the potential clearly exists for rapid testing of coarser ore fragments in blasthole samples.

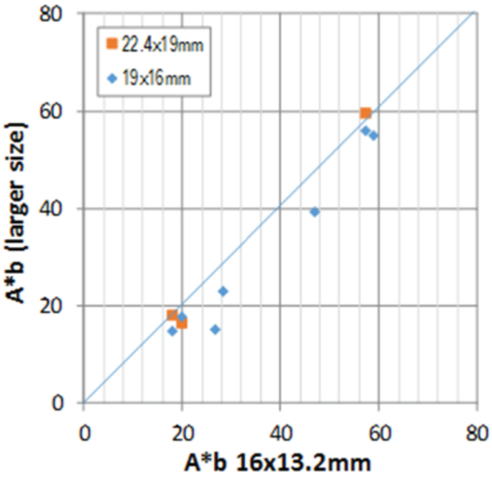


FIG 11 – Comparison of A*b estimates across three test size fractions obtained from blasthole samples.

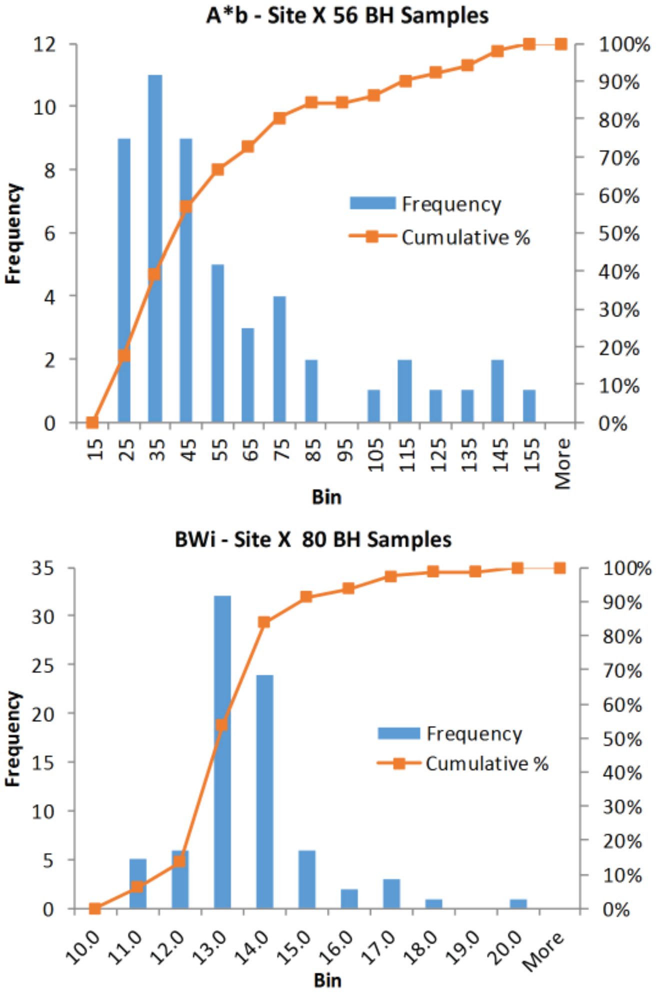


FIG 12 – Distribution of A*b and Bond ball mill work index estimates across several patterns obtained from blasthole samples.

CONCLUSIONS

A new device has been developed to address a major missing in the ore hardness testing marketplace; an inexpensive and rapid way of determining on the ore hardness at site or in the field. HIT has not been designed to replace the bankable SMC/DWT or Bond tests, but rather provides a testing protocol which allows for the collection of a large quantity of equivalent reliable data, which until now, given the high cost of standard tests, has been impossible to achieve under typical budgets allocated for ore hardness testing.

The second generation HIT prototype has enabled the user to finally realise a well-known aspect of the JKMRC T10-Ecs breakage model, that A*b can be estimated from the slope of the relationship at zero energy. Data from the HIT trials has clearly demonstrated that testing at relatively low specific energies can provide a reliable estimate of the actual A*b. This device provides an opportunity to fast track mapping of hardness across a deposit, at a scale not previously believed possible through single particle breakage testing.

The industrial trial at a major mining laboratory in USA has confirmed the integrity of device, mechanical and technical, and its potential for the rapid generation of high volume A*b and BMWi hardness information. Once the appropriate corrections to full JKDWT and/or Bond BMWi test results are applied, the HIT device should be able to provide a robust mapping tool with a minimal sample requirement, typically less than 100 g per sample depending on rock size and number of fragments. The unit deployed in the first trial will be fully inspected at the close of the trial and a decision made if any modifications/upgrades are warranted.

Key conclusions from the industrial trial are:

- the bias between SMC and HIT fragments has precluded a direct comparison of the A*b estimates, though the hardness trends are consistent
- there is statistically no difference between the HIT and JKDWT T10 measurements at the same specific energy using the same ore samples
- the HIT testing clearly shows the extent of the inherent variability within samples
- ten fragments are sufficient for HIT A*b testing, using only one sieve to measure the T10
- sorting appears non-critical, especially if the same time can be better spent to test multiple samples quickly to define the variability
- the HIT mechanical integrity is sound, with the HIT striker and impact plates having to be replaced after 1500 tests or 15 000 drops as expected
- though not discussed in this paper, the Bond grindability proxy appears to be a viable option using HIT on smaller fragments (6–10 mm, requiring the sieving of the product using three to four sieves)
- application of HIT testing to blasthole samples is viable, providing rapid generation of A*b and BMWi estimates using fragments readily available in blasthole samples.

The HIT testing approach has applications in an operating plant and mine, and during study exploration phases. In the plant, it can reliably quantify the hardness of the feed ore. If combined with SAG feed online sizing, the integrated system would provide the main variables affecting the milling plant performance. In the pit, the capacity to provide information in real-time to the mine operations may assist short-term planning and grade control. The current information on grade, combined with the hardness profiles for each pattern may identify very hard ore zones (to enable throughput adjustments to the processing plant to maximise recovery), and facilitate an economically more realistic cut-off grade to be selected for each bench. Similarly, the HIT measurement system offers the opportunity to adjust explosive properties and quantities for each bench, aiming to minimise the variation from the target throughput.

A second industrial trial is planned, aiming to demonstrate the value of HIT in the plant and in a new ore deposit comminution program.

Whilst current exploration assay protocols are well defined and observed across the industry, SimSAGe considers that the data derived from HIT to be of significant value, warranting serious consideration as an enhancement to these existing protocols by providing rapid hardness testing alongside unbiased assays.

Commercialisation of HIT will revolve around providing the industry with a cost-effective solution for managing ore hardness variability. SimSAGe seeks to differentiate the HIT from other so called ‘hardness testing tools’ by radically changing existing test practices: changing market perception away from the belief that one has to rely solely on the attainment of a limited number of expensive ore hardness test results, to a protocol for gaining vast quantities of comparable test results that better cover the full distribution of hardness within an orebody. The ability to reliably determine the nature of the material to be presented to the mill (in a real-time window to enable decisions on how best to manage that ore to optimise the process and maximise recovery/yield) presents a simple opportunity for improving the cost-effectiveness of any operation. In essence, HIT aims to generate more certainty, at an acceptable cost.

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