APPLICATION OF RAPID HARDNESS INDEX TESTING FOR ESTIMATING ORE HARDNESS AND GRINDABILITY

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ABSTRACT

Since the commercialisation of the Hardness Index Tester (or HIT) device in 2017 the unit has been successfully deployed in metallurgical testing programs globally to help focus early resource definition, progress geometallurgical project development, and provide inputs for mill throughput modelling from SAG feed or blast rejects. As of September 2025, there are 22 units deployed across 15 sites, with over 100 000 tests completed. The HIT testing protocol has relied to date on access to larger sample fragments, typically 13.2 mm to 22.4 mm for Axb tests, and 8.0 to 11.2 mm for Bond BWi tests, requiring 50 to 500 g of sample, depending on the ore SG, type of test and size fraction selected. The experience to date indicates excellent agreement with SMC[1] and JKDWT testing when materials tested were similar (i.e. shape and mass), and that the Bond[2] Ball Mill Work Index BWi normally requires an update to the calibration model to ensure the best accuracy. The HIT Axb testing has also provided an unbiased assessment of the inherent hardness variability, which can be missed by applying set rock selection protocols. In 2024 an experimental study was initiated at the Brisbane Metallurgical Laboratory in Australia to understand if HIT testing on -2 mm fragments could provide a means to reliably estimate the Axb and Bond BWi from testing material below 2 mm using a modified HIT bed test protocol, called the Small Fragment Hardness (SFH) test. The benefit is that the HIT can be deployed on samples finer than 2 mm generated from exploration drilling, offering the potential for targeted exploration drilling and focussed geometallurgy sampling and testing/analysis, affording potential cost savings at the front end of a project/resource definition. This paper describes the current standard HIT Axb and Bond BWi measurement, some key learnings from the two tests to date, plus initial findings from the emerging new application of the HIT using 10 g of fragments in the - 2 mm size range.

INTRODUCTION

The index Axb, determined from JKMRC 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 %/kWh/t. This index evolved from a long history of comminution studies at the JKMRC, including the development of the now superseded JKTech twin-pendulum, the industry standard JK Drop Weight Tester (JKDWT) and the faster alterative JKMRC Rotary Breakage Tester (JKRBT).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 SMC Test®, also provides estimates of the Axb though the testing of only one particle size at five specific energies. Experimental determination of Axb using the 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 (e.g. for plant troubleshooting or spot-surveys), or for rapid ranking of geometallurgical samples, the existing JKDWT and SMC tests simply do not provide a timely, viable and cost-effective solution. There is generally insufficient material available in the required coarser fragment sizes, typically between 22.4 and 13.2 mm for SMC tests, to perform such tests.

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[1] Morrell, S, 2004. Predicting the specific energy of autogenous and semi-autogenous mills from small diameter drill core samples, Minerals Engineering, 17(3):447–451.

[2] Bond, F C, 1961. Crushing and grinding calculations, Brit Chem Eng, part I: 6(6):378–385, part II: 6(8):543–548.

To address this void, the Hardness Index Tester (or HIT) was developed, exploiting a central feature of single particle impact testing – that the Axb can be reliably estimated using one precise low energy test, and that the Bond Ball Mill grindability can be linked to the breakage response at one precise high energy test. The HIT has been precision engineered to allow users to break narrowly sized fragments at a set specific energy, in a safe and easy manner. On pre-sized fragments, a single test using 20 fragments takes less than five minutes to complete, and the results are immediately available. Details of the HIT development and successful applications can be found in technical papers by Kojovic[3], Bergeron et al[4], Leetmaa et al[5], and Varianemil et al[6].

In 2024 the HIT application was extended to finer fragments, recognising the limitation of exploration stage ore characterisation which can readily only provide small fragments finer than 2 mm to infer Axb and BWi hardness. This challenge was addressed at the Brisbane Metallurgical Lab who completed the sample preparation, crushing & screening, standard HIT Axb tests and new small fragment HIT tests using a bed of narrowly sized particles. This development is separate to the significant research conducted on confined particle bed compression breakage tests[7] [8] and the more recent development of Piston & Die bed breakage tests at UBC.[9] The latter tests are much slower and require equipment that is not readily available for rapid application at the exploration phase. The study into small fragment HIT tests follows Whiten[10], who in 2022 used JKDWT to break beds of particles, and the knowledge that compression breakage can be described using impact testing (e.g. SMC M_{ih} index[11]).

This paper describes the current standard HIT Axb and Bond BWi measurement, examples of the main applications (mill feed and blast hole drill rejects), plus initial findings from the emerging new application of the HIT using 10 g of fragments in the 1.7x1.4 mm range, as a bed of particles.

HIT DESCRIPTION

SimSAGe Pty Ltd developed the HIT for rapid rock-hardness determination at the mine site, allowing on-the-spot determination of rock hardness variability. The HIT exploits a central feature of single

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[3] Kojovic, T., 2016. HIT - A Portable Field Device for Rapid Hardness Index Testing at Site. Proceedings AusIMM Mill Operators' Conference 2016, October, Perth WA, pp9-16.

[4] Bergeron, Y., Kojovic, T., Gagnon, M-d-N., & Okono, P. (2017). Applicability of the HIT for Evaluating Comminution and Geomechanical Parameters from Drill Core Samples – The Odyssey Project Case Study, Proceedings from COM2017, Vancouver, August.

[5] Leetmaa, K., Bergeron, Y. and Kojovic, T., (2019). The value of Daily HIT Ore Hardness Testing of SAG Feed at the Meadowbank Gold Mine, Proceedings from SAG2019, Vancouver, September.

[6] Varianemil, D., Kojovic, T., Hakim, D., Dilaga, R. and Condori, P., 2023. Ore Hardness Mapping of Batu Hijau Ore Deposit Using the Hardness Index Tester, Proceedings from SAG2023, Vancouver, September.

[7] Schönert, K. (1988). A first survey of grinding with high-compression roller mills. International Journal of Mineral Processing, 22(1-4):401–412.

[8] Schönert, K. (1996). The influence of particle bed configurations and confinements on particle breakage. International Journal of Mineral Processing, 44-45:1–16.

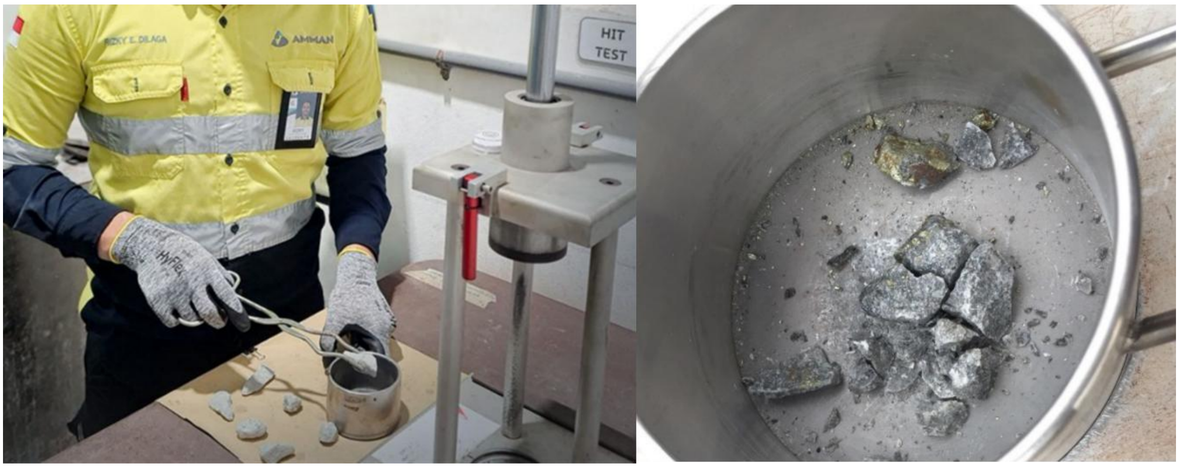
[9] Davaanyam, Z., 2015. Piston Press Test Procedures for Predicting Energy–Size Reduction of High Pressure Grinding Rolls, UBC PhD Thesis, July.

[10] Whiten, W.J., (2020). A simple method for determining the breakage properties of fine particles. Research Gate article, DOI:10.13140/RG.2.2.13567.64167, June.

[11] Morrell, S., (2009). Predicting the overall specific energy requirement of crushing, high pressure grinding roll and tumbling mill circuits. Minerals Engineering, 22, 544-549.

particle impact testing, by which the Axb can be reliably estimated using one precise low-energy test.[3] [12] Results from several industrial trials confirmed the HIT was able to align with the Axb derived using the JK Drop Weight Test or SMC Test, providing the particles are selected from the same sample set in both test methods, including the initial particle selection and product sizing protocol. Figure 1 shows the second generation HIT device, which comprises a frame, a sample cup to hold the fragment to be crushed, crusher hammer assembly, and dual lever mechanism to trigger the hammer's release onto the fragment in the cup. The sample cup sits in a dedicated grooved inset on the base-plate's top surface and comprises a handle allowing a user to easily remove the sample cup from the frame during testing.

Figure 1: Image of HIT device at Batu Hijau and close-up of broken rock in a cup



Update on HIT Users and Applications

As of October 2025, 22 HIT machines are in use: 19 at operating mine sites/laboratories, and three at commercial laboratories (ALS Kamloops, Base Metal Labs Kamloops and Brisbane Metallurgical Laboratories). The HIT users include Amman Minerals (Batu Hijau), Agnico Eagle Mines Limited (CSD Val-d'Or), Barrick (Lumwana), Consulmet (Luaxe), First Quantum Minerals (Kansanshi), Glencore (Antapaccay), Lundin Mining (Chapada and Candelaria), Newcrest (Lihir), Newmont (MTF Denver, Merian, Peñasquito), Taseko Mines Limited (Gibraltar), Teck (Quebrada Blanca), and Vale Canada (Toronto). The HIT users and their specific applications are summarised in Table 1.

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[12] Napier-Munn, T J, Morrell, S, Morrison, R D and Kojovic, T, 1996. Mineral Comminution Circuits: Their Operation and Optimization, (Julius Kruttschnitt Mineral Research Centre: Brisbane.

Table 1: Summary of HIT users and their specific applications

Site (Location)	# HIT Machines	Applications
Amman Minerals (Batu Hijau)	2	Geomet/SAG Feed
Agnico Eagle Mines Limited (CSD Val-d'Or)	1	Geomet/SAG Feed
Barrick (Lumwana)	1	Geomet/SAG Feed
Consulmet (Luaxe)	1	Geomet
First Quantum Minerals (Kansanshi)	1	Geomet/SAG Feed
Glencore (Antapaccay)	1	Geomet/SAG Feed
Lundin Mining (Chapada and Candelaria)	3	Geomet/SAG Feed
Newcrest (Lihir)	2	Blast Rejects
Newmont (MTF Denver, Merian, Peñasquito)	3	Geomet/SAG Feed
Taseko Mines Limited (Gibraltar)	2	Blast Rejects
Teck (Quebrada Blanca)	1	Blast Rejects
Vale Canada (Toronto)	1	Geomet/SAG Feed

Sample Selection for Standard HIT Axb and BWi Proxy Tests

The standard HIT Axb test constitutes of triplicate splits of ten randomly selected fragments in the 22.4x19 mm size fraction. For blast hole rejects, which typically do not have sufficient fragments in the coarser sizes, 16x13.2 mm fragments are recommended. Similarly, the standard HIT Bond BWi proxy test constitutes duplicate splits of 20 random fragments in the 11.2x9.5 mm size fraction. Figure 2 shows an example of one split of ten fragments for HIT Axb tests on 22.4x19 mm and one split of 20 fragments for HIT BWi tests on 11.2x9.5 mm.

Figure 2: Image of Hecla 22.4x19mm fragments for HIT Axb test and 11.2x9.5 mm fragments for HIT Bond BWi HIT test

It is worth noting that unlike the SMC Test®, which applies a mass filtering of chosen fragments based on the measured wet/dry SG of a random initial selection of ten fragments in the target size fraction, the HIT test protocol considers all viable fragments, thereby providing a true representation of inherent variability in the sample. This is a major issue relevant to geometallurgical testing which aims to quantify the ore variability within the size range tested. In selection of fragments for HIT testing the only stipulation of viability is that the fragments do not exhibit extremes in shape like rods or flat disks, which would respond very differently to normal angular shapes as evident in Figure 2. Figure 3 shows an example of the rock specimen selected at Batu Hijau to remove any unlikely shapes which can lead to bias in measurement.

Figure 3: Example of rejected and accepted 22.4x19 mm fragments

Similarly for mill feed testing where the ore has a variable sulphide fraction, SMC testing can miss the inherent variability if the initial ten fragments selected for SG measurement fail to reflect the true fraction of sulphides. Table 2 shows an example where HIT testing correctly identified the impact of sulphides on the hardness that was not evident in the SMC result on the same sample (B), whereas on sample A, which has more consistent properties, both tests agreed. The sulphide fraction was based on qualitative assessment by the mine laboratory, as the actual assays were not available at the time of writing the paper. This means the HIT can provide an effective Quality Control (QC) step guiding more expensive tests, especially where the deposit is highly variable in ore hardness. There is no question about the accuracy of the SMC test on a given sample, but rather its potential to miss the underlying variability if the initial selection of ten rocks for SG measurement is not representative.

Table 2: Comparison of HIT vs SMC testing on the same samples

Sample ID	**A**
HIT Axb – split #1	26.2
HIT Axb – split #2	29.7
HIT Axb – split #3	30.4
Average HIT Axb	**28.8**
Standard Deviation	2.2
CoV = Ave/SD (%)	7.8
SMC Axb	**27.4**

Sample ID	**B**
HIT Axb – split #1	43.4
HIT Axb – split #2	35.8
HIT Axb – split #3	92.2
HIT Axb – split #4	64.7
HIT Axb – split #5	51.7
HIT Axb – split #6	61.5
HIT Axb – split #7	54.8
Average HIT Axb	**57.7**
Standard Deviation	18.2
CoV = Ave/SD (%)	31.5
SMC Axb	**38.1**

HIT CASE STUDY APPLICATIONS

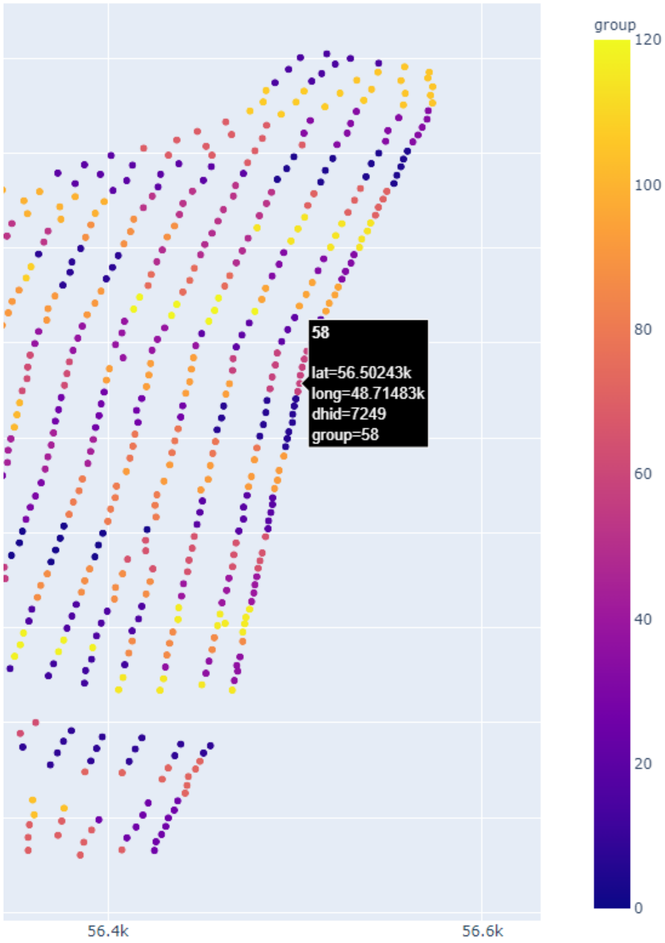
Application of HIT on Blast Rejects

The application of HIT testing to blast hole rejects is becoming increasingly common since the Gibraltar mine in BC, Canada launched their program in 2021. Gibraltar already was processing blast hole drill rejects for chemical assays as part of their mine planning. The drilling rejects samples submitted for assay have the coarse fraction (-16/+13.2 mm) removed for HIT testing, as shown in Figure 4. The +13.2 mm material is bagged separately and delivered to the Gibraltar met lab. This approach follows the findings of the Amira Gem P843 project, which showed that the hardness of coarse fragments from blast hole rejects was directly correlated with the hardness of the same size fragments from twin diamond drill core samples, across a wide range of hardness and ore zones at the Rio Tinto Kennecott Cu mine.

Samples are grouped to provide adequate numbers of coarse rocks for triplicate testing (three sets of ten rocks). HIT samples are cross-referenced against drilling and blast database for latitude/longitude. As the blast holes arrive sequentially in the drill pattern Gibraltar then uses a grouping algorithm to identify holes that are in close spatial proximity within a given drill pattern (lat/long). All the coarse samples from the selected holes for a group are combined and then ten rocks are HIT tested to determine the Axb values. Gibraltar typically aims for ~50% coverage of a given drill pattern spread out to cover as much area as possible. Gibraltar used to test 30 rocks per group to give triplicate results. However, that practice was discontinued as Gibraltar is now confident in the reliability in doing a single HIT Axb determination per group.

Figure 4: Image of Gibraltar screening station to remove 16x13.2 mm fragments for HIT Axb test

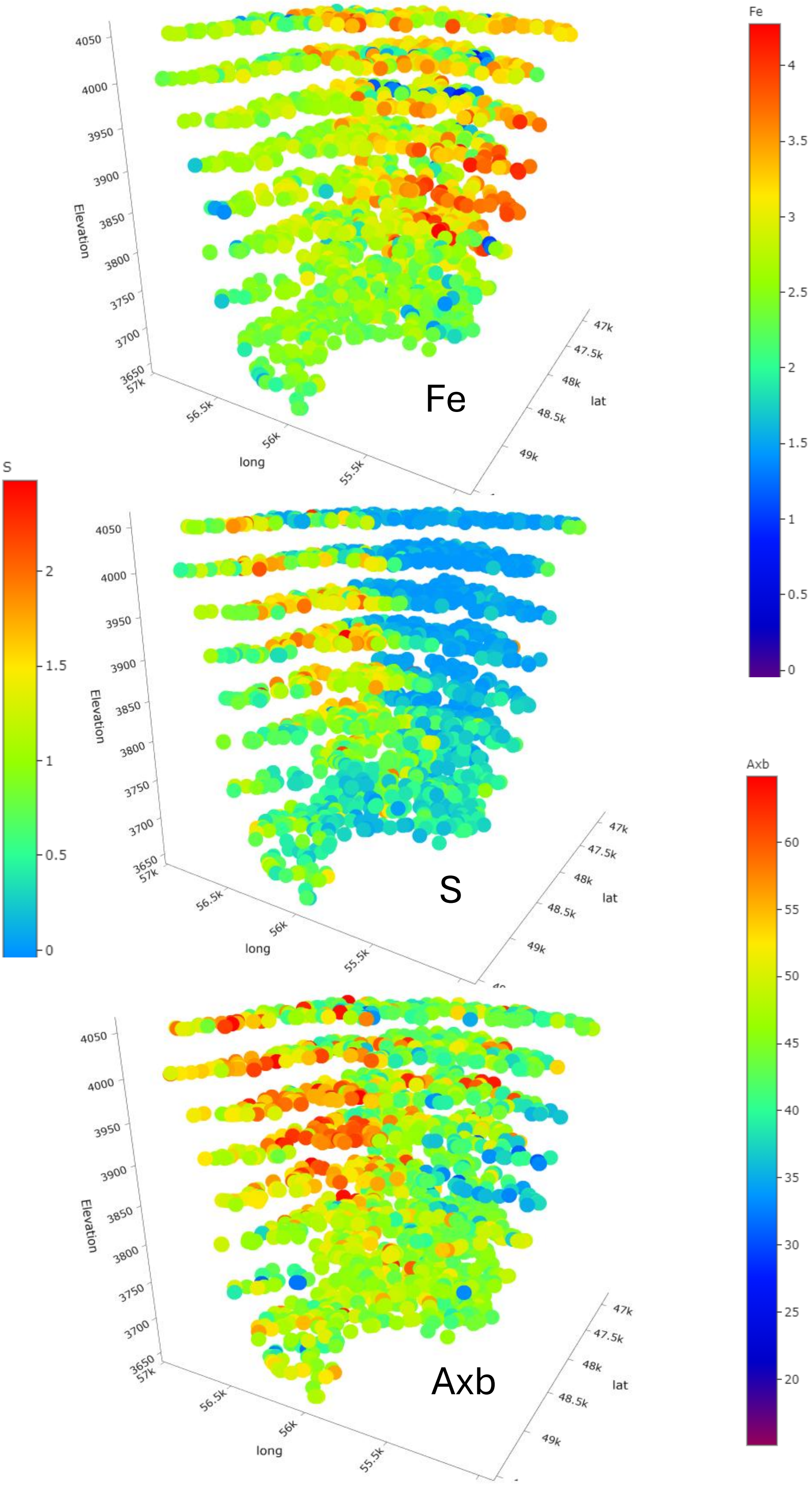
Figure 5: Example of Gibraltar grouping for HIT testing on one blast zone (colours denote different groups selected for HIT testing)



All HIT samples are analysed by XRF to tie hardness to geochemistry. Gibraltar was anticipating that with full pit-sample XRF data, Axb may be estimated across each pit from the geochemistry. The Axb shows strong dependence on Fe and S in the Gibraltar pit; regions of low S correspond to hardest samples (lowest Axb), as illustrated in Figure 6.

Gibraltar has been unable to identify clear hardness domains in their deposit over the course of multiple years of conducting this sampling, but their geology team has recently developed a model to predict hardness over shorter intervals (i.e. ~ one month) which they have started incorporating into their site's short interval mine planning process.

Figure 6: Comparison of XRF Fe and S results against HIT Axb for selected blast zones



The long-term integration of HIT at Gibraltar has confirmed that use of the HIT tester by multiple technicians requires a diligent QA/QC program. They have also recognised the importance of hardness results for operating sites lies in the relative differences in Axb rather than absolute value accuracy. This finding has certainly validated the merit of the simpler HIT device and protocol compared to other tests like SMC, which play a more important role in SAG mill design. Point load testing is not as reliable, and Equotip testing requires cut core sections, neither of which are viable for blast hole rejects samples.

According to Gibraltar, the value of the HIT device to operations lies in two main benefits:

1. Identifying the root cause of throughput variations:
    - Ore-driven (hardness, size)
    - Process deficiency (operator/control logic/process upset)
    - Equipment limitations
2. Mitigation strategies have been employed for different ore zones, including changes in:
    - Powder factor
    - Crusher operation

Application of HIT on Mill Feed

Varianemil et al[6] reported on the revised hardness mapping of the Batu Hijau deposit using the HIT device which provided a more reliable predictor of the ore hardness distribution of the pit, necessary for mine planning.

Having experienced the simplicity and cost/time effectiveness of ore hardness testing using the HIT device, Amman Mineral decided to extend the utilisation of the HIT device at their Metallurgy Laboratory to monitor the actual ore hardness (DWi and BWi) fed to Batu Hijau grinding circuit daily. In late 2021 Amman Minerals acquired a second HIT machine to provide 100% availability. The protocol was to safely collect 15 to 20 kg samples from the SAG apron feeder via spot sampling. Though these samples may not represent the overall daily ore variation, the value of building a database of ore hardness feeding the grinding circuit is recognised long-term.

The Axb values measured by HIT were converted to DWi indices using a well-known relationship as shown in Equation 1,[13] calibrated using historical SMC DWi, ore SG and Axb results:

$$DWI = \frac{96.703 \times \rho}{A \times b^{0.992}} \tag{1}$$

where DWi = SMC Drop Weight Index (kWh/m^3)
ρ = rock specific gravity (t/m^3)
Axb = impact resistance index determined using the HIT

The HIT Bond BWI is predicted using a calibration model developed from 101 broken muck samples from the Batu Hijau pit ranging from 6 kWh/t to 26 kWh/t. The average relative error for samples below 20 kWh/t, which reflects the majority of the deposit, is 7.6%.

Amman Mineral decided to utilise the daily ore hardness measurements in updating the circuit throughput model. Conceptually, there are three major factors contributing to the milling rate and then throughput, as shown in Figure 7:

(1) ore hardness,
(2) degree of size reduction (feed and product size), and
(3) equipment power utilised.

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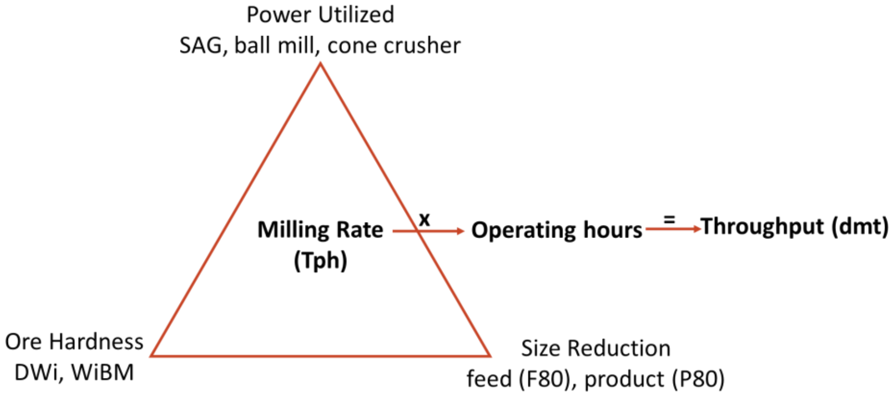
[13] SAGMILLING.COM, 2023. Calculating DWi from a drop weight test result, https://sagmilling.com/articles/26/view/Calculating%20DWI%20from%20Axb.pdf?s=1

Figure 7: Key variables affecting the milling rate



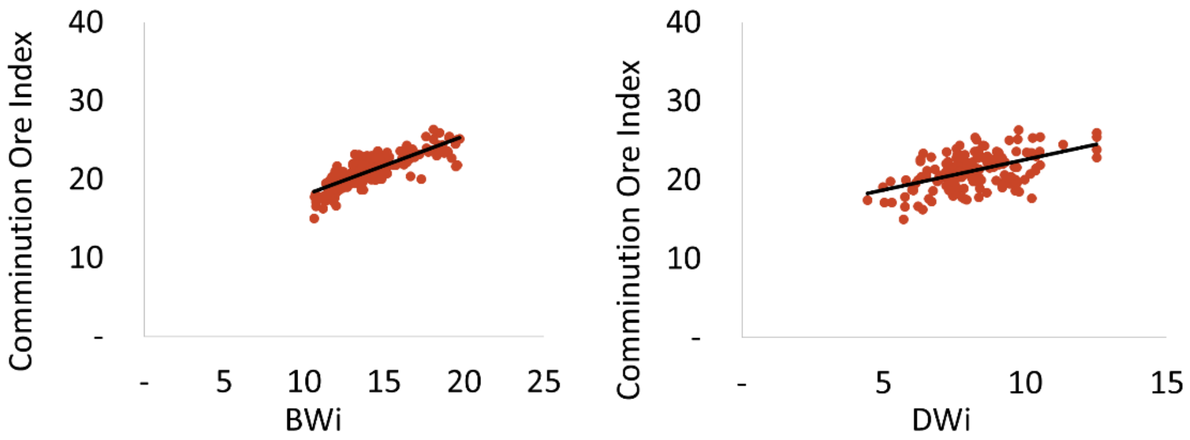
Amman Mineral adapted the Morrell[11] power-based throughput model in its approach to modelling the Batu Hijau grinding circuit throughput, based on the HIT Axb and BWi measurements. Following the SMC model structure[11], the specific energy requirement for the whole circuit, Wi (kWh/t), is given by Equation 2:

$$\mathrm{Wi} = M_i 4\left(\overset{\text{size reduction factor}}{\overleftrightarrow{P_{80}{}^{f(P_{80})} - F_{80}{}^{f(F_{80})}}}\right) \tag{2}$$

where Wi = Specific energy (kWh/t) = Total Power / Throughput
Mi = Material comminution index (kWh/t)
P_{80} = the 80% passing size for grinding product (microns)
F_{80} = the 80% passing size for SAG feed (mm)
$f(P_{80}) = -(0.295 + P_{80}/1000000)$
$f(F_{80}) = -(0.295 + F_{80}/1000)$

In the Batu Hijau adapted Morrell power-based model, the actual Mi is calculated for any given day by rearranging Equation 2, where the F_{80} and P_{80} terms are obtained from SAG feed image analysis and laboratory measurements, respectively. The actual Mi is then plotted against DWi and BWi resulting from the HIT measurements as shown in Figure 8.

Figure 8: Relationship between calculated Mi (material comminution ore index) and HIT BWi and DWi



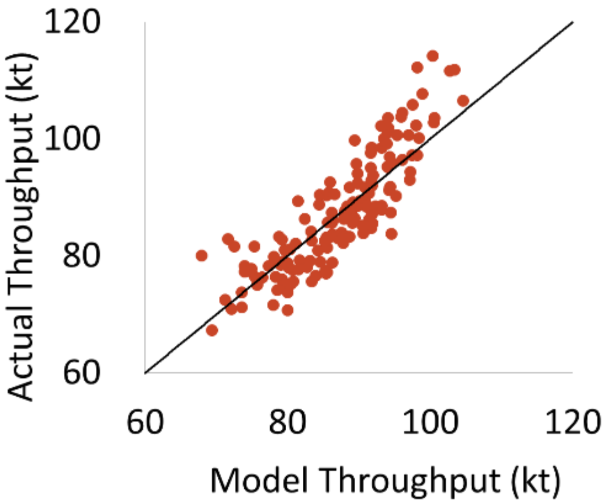
The strong trends suggest the calculated SMC material comminution index is linearly related to both DWi and BWi, since they reflect the combined SAG, pebble crushing and ball mill grinding circuits. Statistical analysis was performed to develop an empirical model for the material comminution ore index (Mi) as a function of DWi and BWi, as shown in Equation 3:

$$\mathrm{Mi} = \mathrm{A} + \mathrm{B} \times \mathrm{DWi} + \mathrm{C} \times \mathrm{BWi} \tag{3}$$

where Mi = predicted material comminution index (kWh/t)
DWi = calculated SMC drop weight index based on HIT measured Axb and rock SG (kWh/m^3)
BWi = Bond BWi estimated using HIT (kWh/t)
A,B,C = equation coefficients determined from statistical regression analysis

By combining the predicted Mi value with the daily feed size, F_{80}, product size, P_{80}, utilised power and equipment availability, the expected throughput can be calculated using Equation 2. Figure 9 compares the actual versus predicted throughput, showing a strong correlation, with an average relative error of ± 4.7%. The bias at the higher throughputs has been associated with lower BWi samples, suggesting potential to improve the accuracy by decoupling the DWi and BWi in the calculation of the overall specific energy requirement (Equation 2) into coarser grinding (Mia) and fine grinding (Mib).

Figure 9: Comparison of 2021 Batu Hijau actual versus predicted throughput using adapted Morrell power-based model)



Amman Mineral's successful integration of the HIT device as part of their geometallurgy and plant optimisation programs has resulted in a practical and acceptable daily DWi and BWi monitoring of ore feeding the SAG Mill using spot samples from the apron feeder. This approach enabled an evaluation of the milling performance via power-based throughput modelling according to the ore hardness, feed and product size, and power utilised.

Application of HIT on -2 mm Fragments (Small Fragment HIT)

The primary aim of the small study initiated by Rio Tinto Exploration (RTE) was to determine if the HIT device could be applied to exploration samples deficient in coarse fragments necessary for standard single particle hardness testing.[2] For this to be realised it was necessary to confirm if, on the same material, unconfined bed breakage of -2 mm fragments aligns with single particle breakage of coarser fragments in determining the Axb hardness index. The proof-of-concept trial was completed using seven rock samples selected by RTE, representing a wide range of geology and hardness, with the Axb ranging from 32 to 331 (22.4 x 19 mm, triplicates of ten fragments per HIT test).

To this end the key questions addressed in the trial were:

- Which size fraction to use?
- How much material to use?
- What test metrics are relevant?

The SFH test protocol was simple and quick (<10 mins per sample), constituting a single impact on 10 g of narrowly sized fragments, followed by screening of the product using five sieves starting with the top size of the fragments.

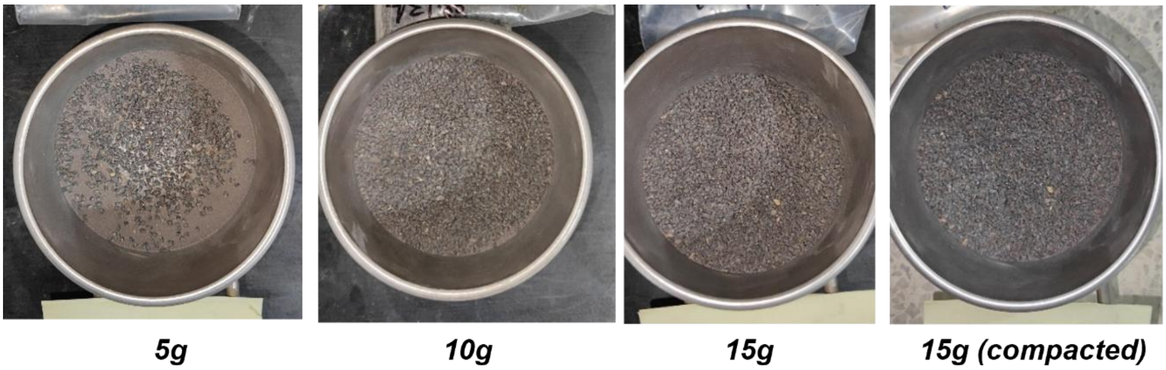
The specific energy applied to the bed can be expressed in kWh/t or J/g, as defined in the JKDWT[12], and was found to be 0.31 kWh/t for a 10 g of sample, 4.51 kg drop mass and 25.4 cm drop height.

Table 3 shows the expected number of fragments in the HIT cup for 10 g samples greatly exceed the typical number of fragments used in SMC (100) or even standard HIT tests (30). Hence, the bed testing is likely to be significantly more representative of the whole sample, avoiding the bias that is possible in SMC and HIT sample selection. As the HIT cup diameter was approximately 80 mm, 10 g represented one to three layers, depending on the size fraction, as illustrated in Figure 9.

Table 3. Expected number of fragments in HIT bed breakage tests (10 g, ore SG 2.6 t/m^3)

Size Fraction	**# Fragments**
2.0x1.7 mm	815
1.7x1.4 mm	1400
1.4x1.18 mm	2415
1.18x1.0 mm	4000

Figure 10: Images of 1.7x1.4 mm Sample 11202602 (Basalt) in HIT cup



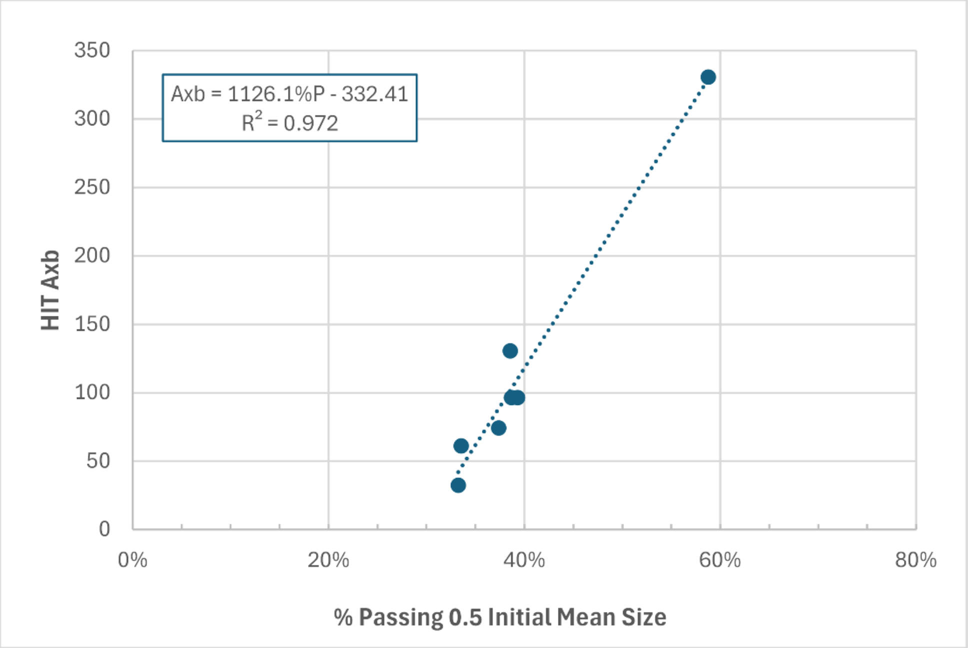
The trial compared the product size distributions (PSD) with the HIT Axb for the various conditions tested. The results were very encouraging, over a good range of rock impact hardness, as defined by the JKDWT Axb index. The trial indicates that 10 g of 1.7 x 1.4 mm material yields the most significant correlation with the Axb index. Figure 10 shows the correlation between HIT Axb and %passing 0.5 Initial Mean Size, having an R^2 value of 0.97, expressed as follows:

$$\text{HIT Axb Index} = 1126.1 \times \%P - 332.4 \tag{4}$$

where %P = %passing 0.5 initial mean size (1.54 mm)

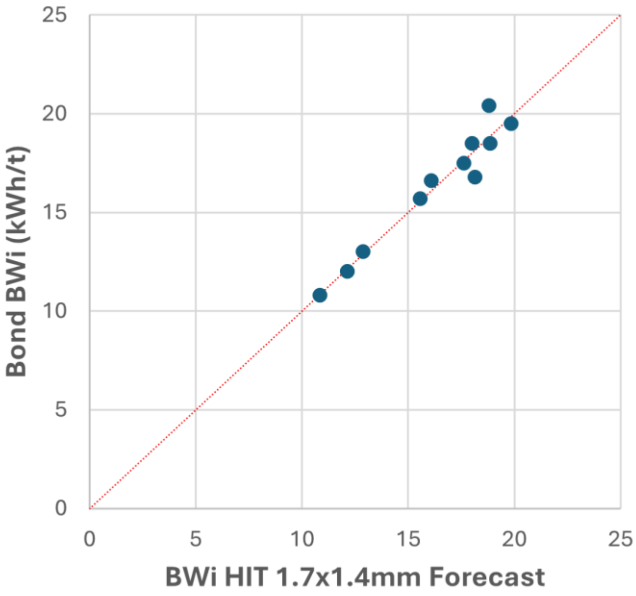
More work is required to confirm the robustness of the relationship between Axb and %passing 0.5 Initial Mean Size, if other metrics are more relevant, and to see if the relationship is ore-specific or universal.

Figure 11: X-Y plot (7 rock samples) - 1.7x1.4 mm (10g)



The SFH test has been evaluated using a limited number of samples to determine if the same approach could be correlated with other hardness indices such as the Bond Work Index (BWi). To this end Rio Tinto supplied unused -3.35 mm Bond BWi test feed material for 11 metallurgical samples, from which BML removed 10g of 1.7 x 1.4 mm fragments for SFH testing. A simple linear correlation was derived using the SFH product PSD metrics, slope and %-150 µm, which was strongly correlated with the measured full Bond BMWi as shown in Figure 11.

Figure 12: X-Y plot (11 met samples) - 1.7x1.4 mm (10g)



The results of these investigations suggest that the SFH can add value to the rapid identification leading to determination of expanded but focused testing regimes prior to investment. The investigation to date has also utilised material that would have previously been discarded, maximising the potential knowledge of all materials generated through an exploration program.

The SFH test could be easily integrated as part of geoanalytical assaying workflow, without disrupting existing protocols, providing a split of crushed material can be removed and sized to extract the necessary 10 g of 1.7 x 1.4 mm fragments. This implementation may enable early exploration programs to understand the hardness variability of the deposit and target further drilling programs and areas for advanced metallurgical testing. The SFH test is also open to applications not currently viable for standard tests, like SAG mill discharge or RC drill hole rejects, which precludes the need to stop the mill feed to collect samples.

CONCLUSIONS

The HIT device has been accepted as an inexpensive and rapid solution for measuring ore hardness using small sample volumes in mine sites, and/or laboratories. There are now 22 devices in operation, 19 at mine sites, and three at commercial laboratories. The industrial applications have confirmed the integrity of the device, mechanical and technical, and its potential for the generation of high volume Axb and Bond proxy information at an acceptable cost minus the shipping and waiting for results.

One of the unique benefits is the ability of HIT testing to provide QC for more expensive tests like SMC, avoiding issues inadvertently introduced through biased rock selection.

Application of HIT testing to SAG feed and blast hole samples is now viable as a routine process, akin to assaying samples, providing valuable knowledge on the ore hardness variability and its impact on SAG throughput.

The application of HIT by Gibraltar on blast hole drill rejects has confirmed HIT testing can easily show the difference in ore hardness and the extent of the inherent variability within the blast zone samples.

The findings from Amman Mineral suggests the HIT standard tests can be readily integrated as part of geometallurgy and plant optimisation programs. In the mill feed application, the HIT can provide practical and acceptable daily DWi and BWi monitoring of ore feeding the SAG mill using spot samples from the apron feeder. The information can be used to evaluate the milling performance via throughput modelling according to the measured ore hardness, feed and product sizes, and power utilised.

The small fragment HIT test trial results are very encouraging, suggesting the SFH tests provide a simple and quick method of testing the breakage properties of small particles which can be linked to the standard measures of impact hardness such as Axb and Bond BMWi. This test has the potential to underpin the existing HIT, SMC and JKDWT tests offering the highest volume possible through integration with geochemical assaying.