Article

Not peer-reviewed version

Extensive Validation of a New Rock Breakage Test

Marcos De Paiva Bueno * , Thiago Almeida , Malcolm S. Powell

Posted Date: 20 July 2023

doi: 10.20944/preprints202307.1348.v1

Keywords: Geometallurgy; comminution; ore characterization; variability; breakage test

 doi:10.20944/preprints202307.1348.v1

Article

Extensive Validation of a New Rock Breakage Test

Marcos Bueno *, Thiago Almeida and Malcolm Powell

Geopyörä, Toppilansaarentie 3 B39, Oulu, 90510, Finland; info@geopyora.com
* Correspondence: ceo@geopyora.com

Abstract: Comminution is the most power-demanding stage, and the lack of geometallurgical testing, often for financial reasons, may result in an inefficient operation. The Geopyörä Rock Breakage test was developed with the objective of making mineral variability data more accessible by providing both standard comminution parameters and rock mechanical properties at low cost, and with a modest sample size, allowing a larger number of samples to be tested to reduce uncertainties and assure productivity. The objective of this work is to present the results of an extensive validation of this new rock breakage method against two of the main tests currently in use, namely the SMC® and Bond ball mill work index tests. More than 100 samples have been tested and the results compared, showing that the new method can accurately estimate the parameters of the traditional tests. This confirms that the new test is a reliable tool for comminution and geometallurgical tests.

Keywords: Geometallurgy; comminution; ore characterization; variability; breakage test

1. Introduction

Uncertainty is a major cause of faults in mill design, and the selection of wrong design criteria occurs mainly due to lack of quality test work or misinterpretation of results and orebody variability [1], resulting from limited laboratory rock breakage characterization tests. However, the high cost and the need for many relatively large samples ends up making this option unattractive. Consequently, comminution variability is often neglected in the mining project, which leads to misleading plant designs and production forecasts.

Traditional impact breakage test methods such as the JK Drop Weight Test (JKDWT) [2] and the SMC Test® [3] utilize an equipment that drops a heavy weight onto particles to apply nominal amounts of energy. The obtained fragmentation is then correlated to the applied specific breakage energy to determine impact breakage parameters such as the Axb and the drop weight index (DWI). Another commonly used comminution test is the Bond ball mill grindability test, which uses a laboratory mill to perform a locked cycle grinding test to determine the ball mill work index (BWI) in kWh/t.

However, there is room for improving the practice of comminution, by fundamental changes in technology and introduction of novel technology [2]. Mwanga et al. described an optimal test as one that should be simple, repeatable, easy to execute, with a maximum time of execution of 1 hour, that uses less than 0.5 kg of samples and measure both crushability and grindability parameters that could be directly used in modelling and simulation of comminution circuits [4].

In recent years, the need to update these methods has become more pertinent due to the increase in energy consumption and phenomenon of reduction of global average ore grades. This has inspired research and development of new rock breakage methods such as the Geopyörä®, an equipment that consists of two counter-rotating wheels, powered by electric motors placed in a frame with an adjustable gap [5] that measures the energy in a breakage event which can be used to confidently estimate traditional comminution parameters such as the Axb, DWI and the BWI.

This paper presents an extensive validation of the Geopyörä® breakage test through numerous comparative tests carried out over the last two years on 9 different ore deposits, totaling 204 samples.

The samples were matched to reference values of traditional tests, such as the SMC® test and the Bond ball mill work index test [6], used for validating the Geopyörä test results.

2. Experimental

2.1. Geopyörä procedure

Geopyörä is an instrumented roll crusher with an adjustable gap to measure applied forces and energy consumed during breakage of individual rock particles. The prototype was developed at the University of Oulu and consists of two instrumented wheels, with an adjustable gap [5]. Since the creation of the prototype, a new product version of Geopyörä, which is pictured in Figure 1, has been developed and entered commercial operation in multiple laboratories around the world. Currently, there is ongoing work towards the development and design of new versions and updates.

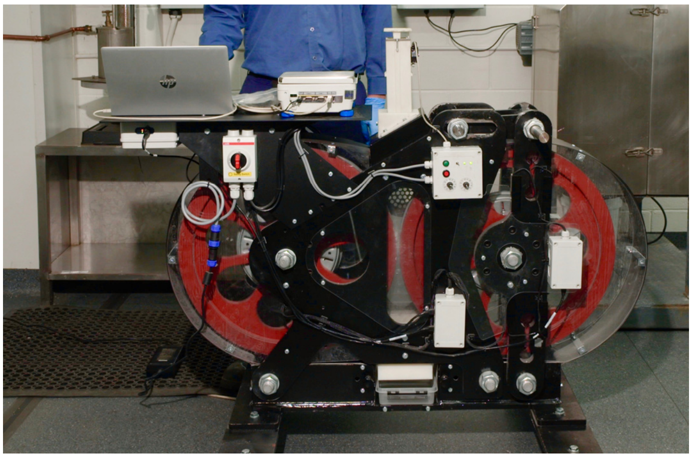

Figure 1. Geopyörä® V1. Source: Core Resources®.

The testing process can use both bulk or drill core samples, with the second option making use of halved or quartered one-meter sections of drill core. This allows one half/quarter core to be used for the breakage test, while the other part can be kept in archive or used for other purposes such as geochemical assaying [7]. If limited sample is available, the breakage product can also be used for further testing when needed. Only one narrow particle size fraction is used, and samples are crushed and sieved to ensure that enough particles in the desired size are obtained for testing. The standard test uses two energy levels, with 20 to 30 randomly selected particles for each, but the test can also be performed with three energy levels, for a more accurate test, but satisfactory results can be obtained even with just one level, in this case using the high energy. Unlike the JKDWT or the SMC Test®, where nominal amounts of energy are applied by dropping a weight on the sample, in Geopyörä the energy is a measured response at the moment of breaking, and the level of this energy is adjusted through the wheel's gap setting, which is defined as a percentage of the geometric mean of the size fraction being used, with a higher energy requiring a tighter gap. The definitions of size range and energy levels used in Geopyörä's standard procedure show a contrast with the complexity of other tests, which, by using a larger number of intervals and energy levels, end up using a significantly larger number of samples. Table 1 summarizes a comparison of the main breakage test requirements.

Table 1. Sample requirements comparison.

Test	Required size ranges	Energy levels per size range	Total required mass (Kg)
JKDWT	5	3	50
SMC Test®	1	5	20
Geopyörä	1	2	2

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 July 2023 doi:10.20944/preprints202307.1348.v1

During the test, each particle is broken individually, and the software records the mass, the breaking force recorded by the load cells, as well as the energy loss of the wheels during the breaking event, with a correction to subtract the friction loss from the wheels. After the test, the breakage product is collected for subsequent sieving.

2.2. Samples and methodology

A total of 204 samples from 9 different deposits around the world in varying size ranges were used to do this extensive validation of the Geopyörä® results. Samples were tested on the SMC Test® as well as the standard Bond ball mill test [6], while subsamples were prepared for testing on Geopyörä devices at partner laboratories following the standard sample selection and testing procedure, so that reference results were obtained for the comparative analysis with the Geopyörä results. To ensure that the samples selected for the Geopyörä test are representative in relation to the samples selected for the SMC Test®, a comparative pre-analysis was performed using the SG (Specific Gravity) values measured with the Geopyörä samples and those measured with the SMC Test® samples.

As shown in Figure 2, all but one sample fell within the ±15% dispersion range, which indicates a very good parity between samples that were sent for reference testing, and those tested in Geopyörä. It is necessary to guarantee this, because if there is a bias in the separation of the samples that go to each destination, it is possible that this bias propagates to the test results, causing variability when comparing the two results. Table 2 summarizes the statistical results of the comparison, where σ is the standard deviation and μ the mean of the dataset.

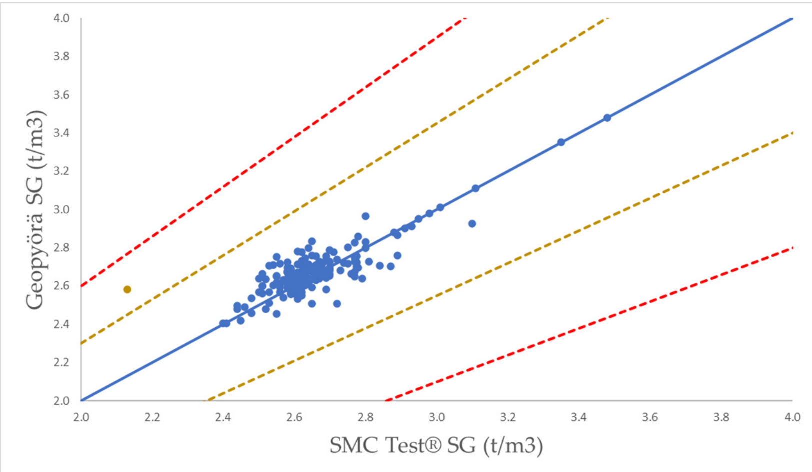

Figure 2. Specific gravity parity plot.

Table 2. Specific gravity comparison stats.

Parity R-Squared	Mean error	σ (t/m3)	σ/μ
1.0	2%	0.05	2%

3. Results and discussion

3.1. Axb parameter

The breakage data measured by Geopyörä is used to calculate the Ecs (Specific Comminution Energy), and then the product of the breakage is sieved so that the calculation of the percent passing one tenth of the initial mean particle size (t10) is performed. Equation 1 shows the mathematical relationship between breakage index (t10) and comminution specific energy (Ecs) that is used to fit A and b parameters to a data set [2].

$$t10 = A(1 - e^{-b*Ecs}) \tag{1}$$

The fit of the curve is used to obtain the Axb parameter, which is related to the slope of curve, and is universally accepted in the mining industry as a parameter that represents an ore's resistance to impact breakage and is widely used in comminution modelling. Figure 3 presents a parity plot comparing the Axb values estimated by Geopyörä with the reference SMC Test® Axb and shows that 73% of the samples are within the ±15% dispersion range, represented by the blue samples. Table 3 summarizes the Axb comparison stats.

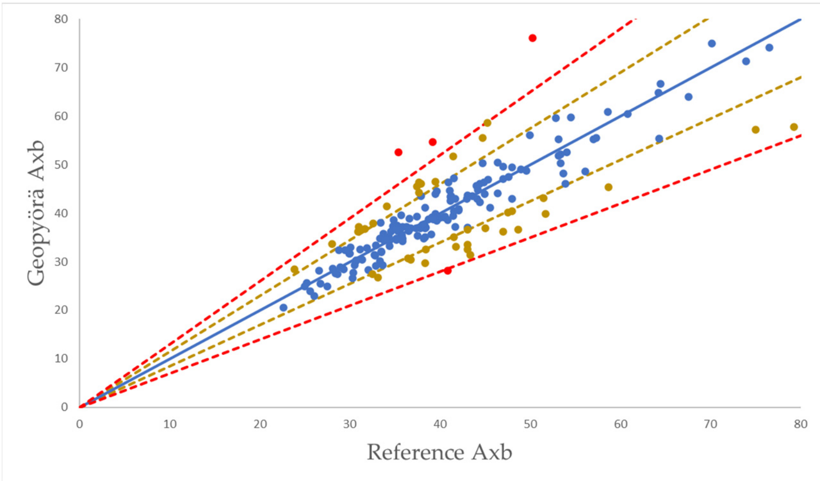

Figure 3. Axb parity plot.

Table 3. Axb comparison stats.

Parity R-Squared	Mean error	σ	σ/μ
0.93	10%	17.73	34%

Furthermore, we can make a comparison between the t10 curves generated by each test, bearing in mind that the JKDWT used three energies for each of five different size intervals, SMC Test® used 5 energy levels in one size interval, while Geopyörä® used only three energies in a size interval. Figure 4 shows the plot of the curves from each test, as well as the measured points.

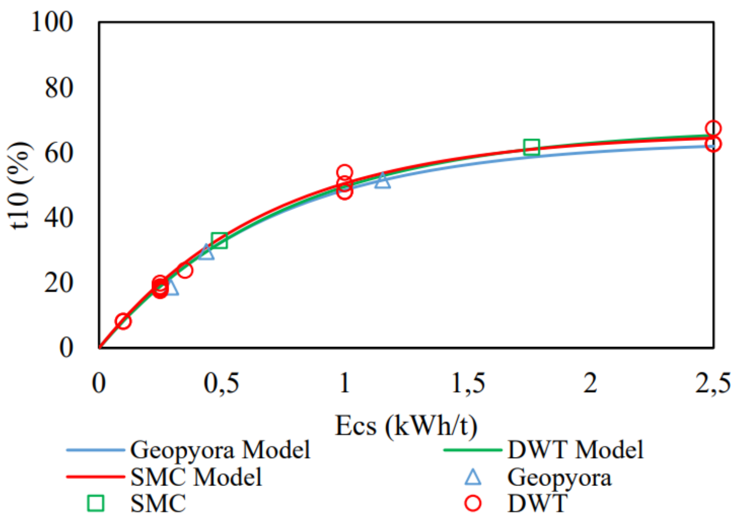

Figure 4. T10 curve comparison between tests.

3.2. SMC Test® DWi

The Drop Weight Index (DWi) is a metric derived from the SMC Test® and is a widely used measure of the strength of the rock. This test has a database of more than 35,000 measured samples from more than 1,300 ore bodies [3]. To calculate the DWi using Geopyörä results and perform the comparison with the SMC Test® reference result, Equation 2 was used [8].

$$DWi = \frac{SG \cdot 96.703}{(Axb)^{0.992}} \quad (2)$$

Figure 5 presents the Drop Weight index parity plot, and Table 4 summarizes the statistical comparison, showing a strong correlation between the Geopyörä results and the SMC Test® reference results, with a parity R-Squared of 0.99.

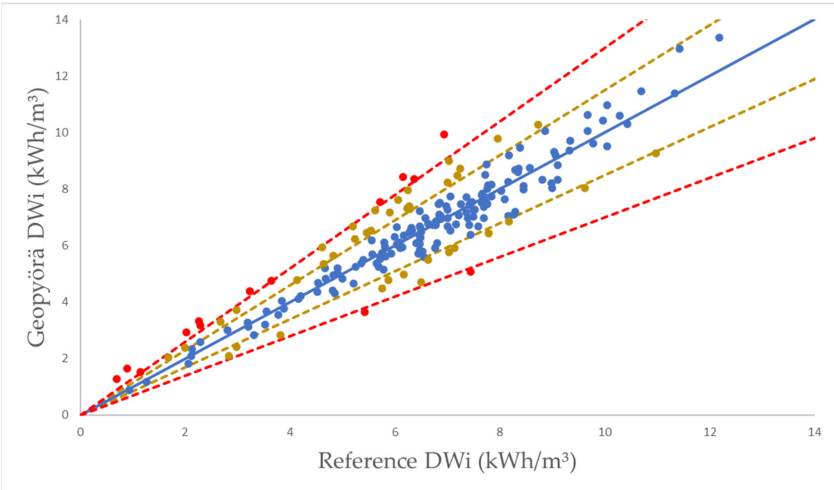

Figure 5. Drop Weight index parity plot.

Table 4. Drop Weight index comparison stats.

Parity R-Squared	Mean error	σ (kWh/m3)	σ/μ
0.99	11%	0.55	9%

3.3. Bond Ball Mill Work Index

Standard Bond Ball Mill tests [6] were carried out with the objective of making a comparison with the data calculated by the Geopyörä procedure, as was done previously with the SMC Test® for the validation of Axb and Drop Weight index. To make this possible, a correlation model was developed between the Size Specific Energy (SSE) calculated by Geopyörä and the BBMWI, using the available reference data. The SSE can be calculated using Equation 3.

$$SSE = \frac{100 \cdot Ecs}{P150} \quad (3)$$

Where P150 is the percentage of the breakage product passing 150 microns.

Most reference samples used in this validation were tested in the standard Bond Ball Mill with closing sieve sizes of 150 microns, but some had different CSS. Despite this variation in the BBMWI data, a robust model was developed using the entire database. The aim was to achieve a generic model, capable of generating accurate results for a range of closing sieve sizes used in the Bond test. The power function described in Equation XX and illustrated in Figure 6 proved to be the optimal model to correlate SSE and BBMWI, with a fit R-Squared of 0.70.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 20 July 2023 doi:10.20944/preprints202307.1348.v1

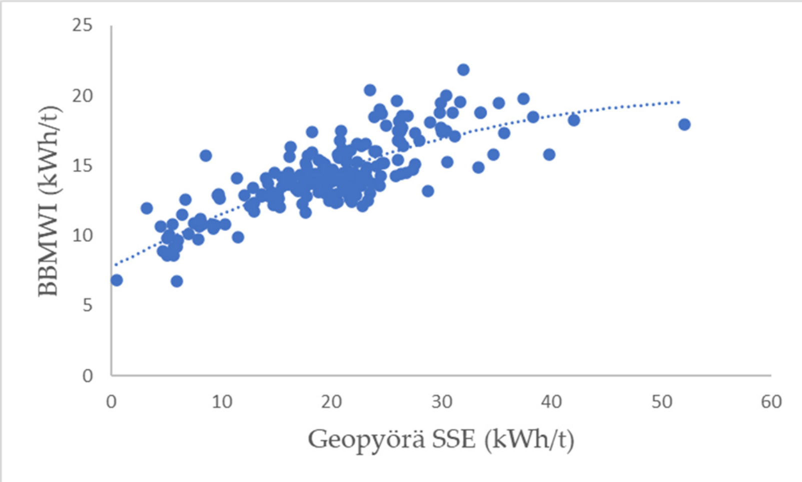

Figure 6. BBMWI x SSE power fit.

Once the model for estimating BBMWi from the SSE calculated with the Geopyörä test data was calibrated, the model was validated by comparing its predictions against the benchmark Bond test results. Figure 7 shows the parity plot, where 87% of the samples are within the ±15% dispersion range, represented by the blue samples. Table 5 summarizes the comparison stats, showing a very strong correlation, with a parity R-Squared of 0.99.

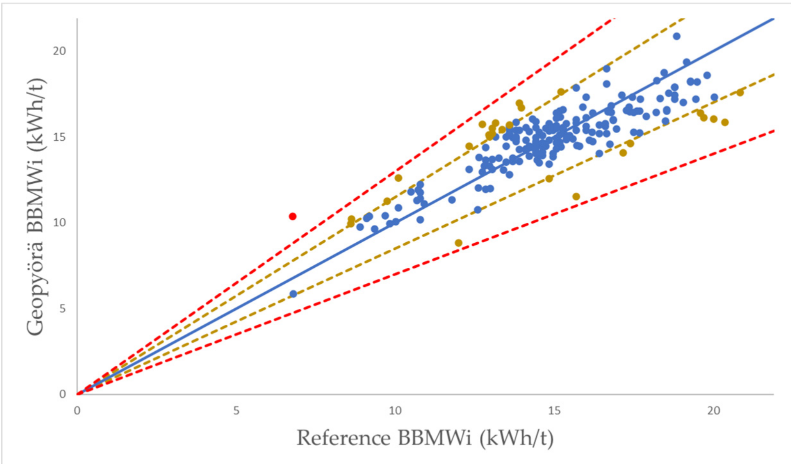

Figure 7. Bond Ball Mill Work index parity plot.

Table 5. Bond Ball Mill Work index comparison stats.

Parity R-Squared	Mean error	σ (kWh/m3)	σ/μ
0.99	8%	0.90	6%

3.4. One energy analysis

Geopyörä's standard test uses two energy levels, defined by the gap between the wheels, so that two points are defined for performing the fit of the t10 vs Ecs curve. However, there is the possibility of carrying out the same process using only one energy level, greatly simplifying the testing procedure in the laboratory, but with the perspective of providing satisfactory accurate results. Figure 8 presents the parity plot, while Table 6 presents the comparison stats.

 doi:10.20944/preprints202307.1348.v1

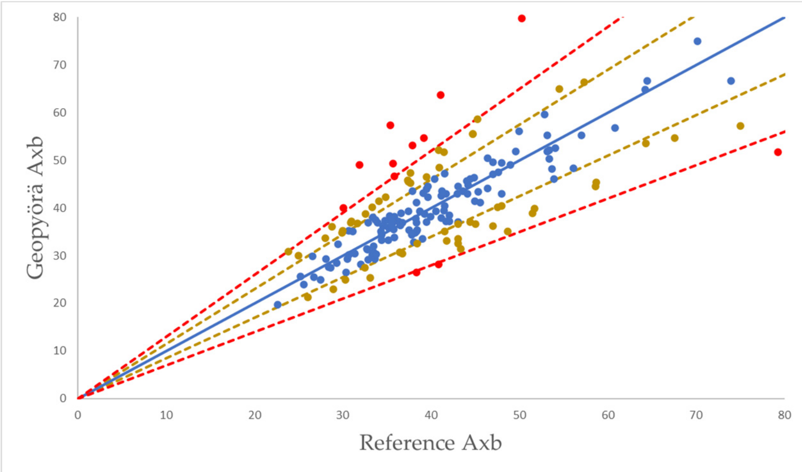

Figure 8. One energy Axb parity plot.

Table 6. One energy Axb comparison stats.

Parity R-Squared	Mean error	σ	σ/μ
0.88	16%	20.98	40%

As expected, a decrease in parity quality is noticeable, with a slight increase in the average error when compared to the results with two energy levels presented in section 3.1, but 59% of the samples remained within the ±15% dispersion interval, with only 12% of samples being found outside the ±30% interval.

5. Conclusions

Geopyörä provides a state-of-the-art method for rock breakage characterization testing. It was developed to present a viable alternative to more expensive and ore-intensive methods so that mining companies can viably build extensive breakage data sets. It presents a low-cost option, which in contrast to a number of proxy tests, does not sacrifice precision or accuracy, thus providing reliable data upon which to build the success of comminution models and plant design.

The Geopyörä results have been extensively validated against industry standards with a robust database of 204 samples. The Axb comparison showed an average error of 10% among all samples. The comparison with the Drop Weight index showed a strong correlation with an R-Squared of 0.99. The calculation of the Bond Ball Mill Work index (BBMWi), through a correlation model developed by Geopyörä itself, resulted in an R-Squared of 0.99, demonstrating a very strong correlation. And finally, the Axb results considering only one energy level, in contrast to the two energy levels of the standard test, resulted in an R-Squared of 0.88, proving to be a great option to simplify the testing procedure, while maintaining good accuracy.

The results obtained in this extensive validation work prove Geopyörä's ability to provide accurate information on comminution parameters and facilitates the need for the mining sector to adopt new technologies capable of providing the necessary ore characterization data more efficiently.

The Geopyörä company is feeding back income and funding from grants to continuously improve the relationships and data provided by the test, providing a development pathway to incorporating rock strength directly into process models and prediction.

Author Contributions: Conceptualization, M.B.; methodology, M.B. and M.P.; software, T.A.; validation, T.A. and M.B.; formal analysis, M.B. and T.A.; investigation, M.B and T.A.; resources, M.B.; data curation, T.A. and M.B.; writing—original draft preparation, T.A. and M.B.; writing—review and editing, M.B. and M.P.; supervision, M.B. and M.P.; project administration, M.B. and M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

 doi:10.20944/preprints202307.1348.v1

Data Availability Statement: Not applicable.

Acknowledgments: We would like to extend our deepest gratitude to the various mining companies who generously provided us with samples for our research. Their support has been instrumental in the advancement of this study.

We also appreciate their provision of Bond and SMC test reference data. This information was invaluable for our comparisons, thereby aiding in the validation and furtherance of our research findings.

Without their contributions, the completion of this study would not have been possible. We are immensely grateful for their collaboration and assistance.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bond, F.C. Crushing and grinding calculations. *Br. Chem. Eng.* **1961**.
2. Bueno, M.; Foggiato, B.; Lane, G. Geometallurgy applied in comminution to minimize design risks. *SAG Conference* **2015**.
3. Chavez, T, M. Development of a methodology and validation of the Geopyörä breakage test. Master's thesis, University of Oulu, Finland, 2020.
4. Chavez, T, M. The Geopyörä breakage test for geometallurgy. *IMPC 2020: XXX International Mineral Processing Congress* **2020**.
5. Doll, A. Calculating DWi from a drop weight test result. Available online: https://www.sagmilling.com/articles/26/view/Calculating%20DWI%20from%20Axb.pdf (accessed on 06/07/2023).
6. Morell, S. Global trends in ore hardness. *IMPC 2020: XXX International Mineral Processing Congress* **2020**.
7. Mwanga, A.; Rosenkranz, J.; Lamberg, P. Testing of ore comminution behaviour in the geometallurgical context – A review. *Minerals* **2015**, *5*, 276-197.
8. Napier-Munn, T.J.; Morrell, S.; Morrison, R.D.; Kojovic, T. Mineral Comminution Circuits: Their Operation and Optimisation, 1st ed.; Julius Kruttschnitt Mineral Research Centre: Indooroopilly, Australia, 1996.
9. Powell, M.S.; Morrison, R.D. The future of comminution modelling. *Int. J. Miner. Process.* **2007**, *84*, 228-239.
10. Torvela, J. Double wheel crusher prototype. Master's thesis, University of Oulu, Finland, 2020.
11. Josefin, Y.; Doll, A. Correction of Bond Ball Mill Work Index Test for Closing Mesh Sizes. *Procemin Geomet* **2018**.