ASSESSING THE RESPONSE OF TUMBLING MILLS TO THE REPLACEMENT OF BALLS BY RELO GRINDING MEDIA (RGM).

PART 1. COMPARATIVE BENCH-SCALE EXPERIMENTS AND DEMONSTRATION FULL-SCALE TEST.

***Vassil Genchev[1], Petar Bodurov[1], Nikolay Kolev[1], Donald P. Leroux[2]**

[1] *RELO-B Ltd*
No 1. Oborishte street, Sofia 1504, Bulgaria
*(*Corresponding author: vassil.genchev@digitalprint.bg*

[2] *BBA Inc.*
2828 boulevard Laurier, Suite 1345, Québec City, G1V 0B9, Canada

ABSTRACT

The need for grinding ores at higher tonnages and to finer particle sizes is driven by the increasing cost of energy and the decreasing grade of orebodies. Although grinding circuits can be optimized incrementally, radical changes are required to significantly improve their performance. The Relo grinding media (RGM), which are shaped similarly to “Reuleaux spheroidal tetrahedron”, could be the technological breakthrough that the mineral processing industry is looking for.

Multiple bench-scale comparative grinding tests were conducted to evaluate the benefits of using RGM instead of balls in tumbling mills. The Bond laboratory mill and the locked-cycle test approach were used with comparable grinding media loads (number of media, overall mass, size distribution). Consistently, the energy required to achieve a given product particle size, expressed by the number of mill revolutions needed, was shown to be significantly lower with RGM.

An assessment of the benefits that RGM can provide to a large-scale tumbling mill, operated in closed-circuit and wet-grinding mode, was also made. The test was run at the Rudozem (Pb/Zn) concentrator in Bulgaria where two identical tumbling mills of parallel closed circuits could each be loaded with a different type of grinding media. On average, the throughput (tph) to the RGM-loaded mill circuit was 89% higher than to (almost twice as high as) the ball-loaded mill circuit.

A methodology is currently being developed for predicting the performance of large-scale RGM-loaded tumbling mill from bench-scale test results. The population-balance approach, which involves the determination of the breakage/appearance function in laboratory, is envisaged.

KEYWORDS

Ball mill, grinding media, Relo, RGM, efficiency

INTRODUCTION

Tumbling mills, which typically use steel balls as grinding media, are known to be inefficient machines due to their slow breakage kinetics and high energy consumption. The results of a recent study of three SAG/ball mill (SABC) circuits revealed that on average, 91% of the supplied energy is turned into heat, leaving only 9% for mineral breakage (Bouchard, LeBlanc, Lévesque, Radziszewski and Georges-Filteau, 2017). The facts that impact breakage events are rare and that particle size reduction mainly occurs from attrition would explain this inefficiency (Morrison, Shi and Whyte, 2007).

The Relo grinding medium (RGM), which has the shape of a rounded polyhedron, was specifically designed to improve the efficiency of tumbling mills. Made of steel, they provide a larger surface area and a greater charge compactness than balls. By these principles, by replacing the balls of a tumbling mill by RGM, grinding efficiency should increase.

Many comparative (RGM versus balls) grinding tests have been conducted at bench-scale through the standard Bond grinding procedure. While the bulk of these results showed a marked increase of grinding efficiency when RGM are used, it is the Rudozem industrial-scale test (Bodurov and Genchev, 2017) that demonstrated the full potential of the technology. The reproducibility of the Rudozem test, which is yet to be tested, will be the topic of the second part of this paper.

In this first part, the RGM technology is presented, the results of the full-scale test are reviewed, a result analysis procedure is proposed for testing the reproducibility of Rudozem test results and a brand new set of bench-scale test results are discussed.

EARLIER INVESTIGATIONS

There has been many attempts to evaluate the grinding efficiency of differently shaped grinding media in the past (e.g. Norris, 1954; Cloos, 1983). Many of these evaluations focussed on the rate of breakage of particles with typically lesser attention to macroscopic parameters such as load behaviour and power draw.

An interesting study (Lameck, 2006) showed that at a rotational speed of about 72% of critical, which is within the range of typical ball mill speed, cylpebs and spherical media drew the same amount of power at all charge levels studied. However, beyond this speed, the power drawn by the mill with cylpebs started to decrease while it kept increasing when spheres were used (up to around 90% of critical). The study therefore showed that the maximum power that a mill can draw depends on the grinding media shape. Some mill power predicting models (e.g. Bond, 1961) include the effect of grinding media in a constant which suggests that, for any media shape, the maximum mill power draw is the same. The study of Lameck (2006) clearly proves that this is not the case. The mill power draw reached a maximum at a significantly lower speed with cylpebs than with balls.

In other studies, Shi (2004), Orford, LaCoste-Boucher and Cooper (2006), Brissette (2009), Ipek (2009) provided detailed information on different types of grinding media and compared them to balls in relation to media mass, size distribution, surface area, and specific energy input. Ipek (2009) investigated the effects of cylpebs and balls with equal mass and surface area on the breakage rate of quartz, using cylpebs and balls separately. Similarly, Lameck (2006) investigated the effects of balls and worn balls on breakage rate of material using worn balls as grinding environment. Recently, Conger, Dupont, McIvor and Weldum (2018) conducted a comprehensive plant-scale study on grinding media size.

Some shapes can be cheaper than spheres to manufacture with higher quality casting and lower porosity (Lameck, 2006). Cloos (1983) stated that the performance of a particular grinding media shape is related to the areal, linear and point contact of the media with each other. The grinding media should have the largest possible surface area to provide suitable contact with the material to be ground and they should be as heavy as possible to provide the energy required for breaking the ore particles.

In theory, increasing the surface area of spherical grinding media should provide greater opportunities for particle breakage. However, as pointed by Shi (2004), this statement may not be true with all shapes of grinding media.

THE RELO GRINDING MEDIA

The Relo grinding media (RGM) come in slightly different shapes that are all derived from Reuleaux geometry. (Franz Reuleaux, a German mechanical engineer, gave his name to these geometrical shapes in the nineteenth century). The Reuleaux triangle and the Reuleaux tetrahedron are the key structural shapes of RGM.

The Reuleaux triangle (Figure 1) is the intersection of three circles of radius r centred at the vertices of a regular triangle with side length r. Similarly, the Reuleaux tetrahedron is the intersection of four balls of radius s centered at the vertices of a regular tetrahedron with side length s. The type of RGM that were used for the laboratory and industrial tests is illustrated on Figure **2**. The RGM have several distinctive advantages over traditional spherical grinding media.

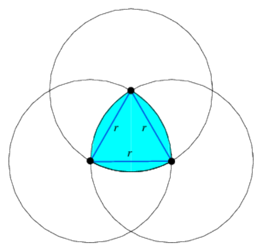

Figure 1 - Reuleaux triangle (shaded area)

Higher Packing Density

As determined by Ulam (1972), spheres have the lowest maximum packing density of all convex bodies (74%). Although, no publications regarding the packing density of Reuleaux tetrahedrons could be found, numerous papers deal with the packing density of regular tetrahedra. Kallus, Elser, and Gravel (2010) discovered a family of simple shapes with a packing density of 85.47%. This discovery was the basis of a slightly improved packing density (85.63%) obtained by Chen, Engel, and Glotzer (2010) for hard, regular polyhedra. Relatively speaking, the highest packing density of regular tetrahedrons is 15.6 % higher than the highest packing density of balls. This fact alone may explain the low efficiency of tumbling mills when balls are used as grinding media.

Given the similarities between RGM and regular polyhedron, it is fair to assume that a tumbling mill loaded with RGM has a higher packing density than a mill loaded with steel balls. Experimentally, it was found that the packing density of RGM is about 10% greater than the packing density of a charge of spheres.

Due to the higher packing density of an RGM charge, and consequently the smaller interstices between the media, the probability of contact between the RGM and the mineral particles is increased. Impact and abrasion events therefore occur at a higher frequency.

Higher Surface Area and Higher Surface of Contacts

At equal volume, an RGM has a significantly larger surface area (9.4%) than a sphere. Also, as highlighted by Penchev and Bodurov (2014), a charge of RGM has a 29 % larger surface of contact than a charge of balls. Both features improve the probability of contact between the grinding media and the mineral particles.

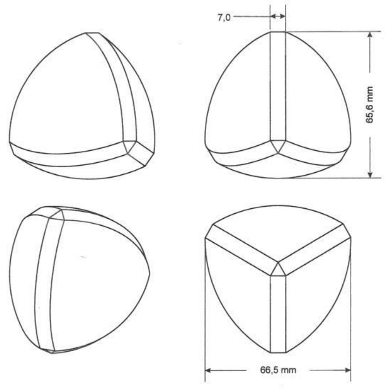

Figure 2 - Stereometric representation of the RGM used for testwork

LARGE-SCALE RGM TESTING

Rudozem Testing

The most impressive results of RGM testing were obtained at the Rudozem Pb/Zn concentrator in Bulgaria (Bodurov and Genchev, 2017). Two parallel and identical 75-kW ball mills (1.5 m x 3.5 m), each in closed-circuit with a spiral classifier, were available for the test. (Figure 3). The plant ran 16 hours/day, 5 days/week. Each milling circuit was fed with crushed ore (F_{100} = 25 mm).

Figure 3 - Photo of the two tumbling mills at Rudozem lead-zinc concentrator, Bulgaria

The charge (8 tonnes) of one of the two tumbling mills (60-mm balls) was replaced by mono-sized (60-mm) RGM. However, due to the higher compactness of the RGM charge, a torque greater than the mill motor could provide was required for initiating rotation. The RGM charge was then lowered to 7 tonnes and the test started. Make-up charges were added in each mill regularly to maintain target power draw and measure wear rare. The test lasted 60 calendar days. Results of the test, which are detailed in another publication (Bodurov and Genchev, 2017), are highlighted below.

- On average, throughput of RGM-loaded mill circuit (7.50 t/h) was 89 % higher than the ball-loaded tumbling mill (3.96 t/h) This was achieved despite the fact that the RGM-loaded mill had a significantly lower charge of grinding media (7 tonnes versus 8 tonnes).
- The product of RGM-loaded mill circuit was significantly finer. On average, the fractions passing 75 µm were 37% and 47% for the ball-loaded and the RGM-loaded mill, respectively.

- The wear rate of RGM was almost half (50 %) the wear rate of steel balls. No excessive wear of shell liners was detected in the RGM-loaded mill.
- The RGM retained their shape throughout the test (see Figure **4**).

Figure 4 - Photos of RGM charge samples taken during the Rudozem test

These industrial-scale results are far better than ever observed in bench-scale experimentation. Although further experimentation is required to explain the difference, the following factors may have contributed to generating outstanding plant results.

- The filling ratio of the large-scale mills (≈40%) was much higher than the bench-scale mill (≈20%).
- The feed of the large-scale mill was much coarser (F_{100}=25mm) than typically used for bench-scale testing were (F_{100} = 3.35 mm).
- The large-scale mills have low feed size over media size ratio. Balls are known to gain efficiency as the ratio approaches 20 (Nesset, Radziszewski, Hardie and Leroux, 2006).
- The ratio of RGM surface area to the mill shell surface area is much higher in the plant-scale tumbling mill than in the bench-scale mill (84 % versus 16 %).
- The adhesion of fine mineral particles to grinding media is greater in large-scale wet grinding circuits than in dry bench-scale tests.

Validation of Full-Scale Results

Even though extremely encouraging, the Rudozem test results need to be validated through further testing. The next tests could, or maybe should, be conducted slightly differently.

The effect of the RGM on grinding efficiency will be measured by comparing performance criteria of two parallel and identical tumbling mills (one loaded with balls, the other with RGM) or by monitoring the performance of a single tumbling mill before and after the conversion to RGM. Whether the conversion is sudden (where the mill is completely flushed and refilled with mono-sized RGM) or gradual (where balls are replaced by mono-sized RGM in make-up charges), several weeks of operation will be allowed for the RGM size distribution to reach equilibrium. In their study of the effect of grinding media shape and size on tumbling mill efficiency, Cooper, Bazin and Grant (1994) indicated that it took three months of operation for the grinding media charge to reach equilibrium after a gradual conversion.

Isolating the effect of the grinding media type from the influence of other variables on a grinding circuit performance can be challenging. Keeping constant the circuit feed characteristics (ore hardness, flowrate, particle size distribution, slurry density) over extended time periods is near to impossible. Running comparative tests on two parallel and identical tumbling mills should eliminate their effect. In practice, however, feed distribution between parallel lines is seldom perfect and differences of flowrate, particle size distribution and/or slurry density often exist.

Macroscopic Analysis

Whether tests will be conducted sequentially with one tumbling mill or simultaneously with two tumbling mills, it is equally possible to measure the response of a grinding circuit to a change of grinding media despite circuit feed characteristic variations. In both cases, the following two performance criteria will be calculated.

- E_R: Relative energy consumption (kWh/tonne of produced particles finer than a target size)
- W_S: Wear rate of the grinding media (kg of steel per tonne of ore processed)

The E_R criterion will be calculated from the power drawn by the tumbling mill (kW), the circuit feed tonnage (t/h) and the circuit feed and product size distributions. As sampling is required for obtaining the two necessary size distributions, samples of other grinding circuit streams (e.g., the mill discharge and cyclone underflow) may as well be taken, and their size distributions determined. These additional samples would generate redundant information which can be statistically reconciled for improving the precision of E_R. Data reconciliation will make it also possible to assess the circulating load around the tumbling mill which could be affected by the change of grinding media.

As E_R is affected by the mill feed characteristics, a large enough population of determinations should be generated before and after the conversion to RGM (or simultaneously on both circuits if two parallel and identical circuits are available). With enough data from which averages and standard deviations can be calculated, well accepted statistical tests (e.g. Student test) can be applied to confidently demonstrate the benefits of a conversion to RGM grinding. Alternatively, if it was possible to determine E_R at regular intervals (say, once a day), it could be represented as a time series and the autoregressive modelling approach proposed by Napier-Munn (2008) could be applied to assess the magnitude of the gain.

The W_S criterion will be calculated from the grinding circuit feed tonnage (tonnes/month) and the cumulative mass of grinding media added to the mill by the operators to keep the power drawn within a given range (kg/month). As the volumetric charges of RGM will likely be lower ball charges (for a given mill power draw), it will,be important to take advantage of every mill shutdown to measure the volume of the grinding media bed. These opportunities should also be taken for quantifying liners and lifters wear as well as for taking samples of grinding media for shape and size distribution tracking. With an appropriate device, such as the "ball charge sampler" developed at COREM (Makni, Faucher, Bouajila and Robichaud, 2012), it is possible to sample the grinding media bed from top to bottom.

Performance Curves

The comparison of primary performance criteria will make it possible to quantify the increased fineness of grind that a conversion to RGM can bring to a grinding circuit. Although some plants may welcome the production of finer particles, other may prefer to use the improved grinding efficiency differently. For example, maintaining the circuit product size distribution and increasing the circuit feed tonnage or the circuit feed coarseness or both may be more appealing to them. For these plants, the "constant-product-size" (CPS) performance curve which shows the capacity of the grinding circuit as a function of feed coarseness for a given product particle size, is very useful (Figure **5**).

In a SABC grinding circuit for example (Figure **6**), the CPS performance curve of the "ball-mill" circuit intersects with the "constant-feed-size" (CFS) performance curve of SAG-mill circuit at the optimal transfer size. When the grinding efficiency of the ball-mill circuit is improved, the transfer size is increased. By allowing coarser material to escape the SAG-mill circuit (through larger SAG-mill discharge screen openings), the capacity of the whole grinding circuit is increased.

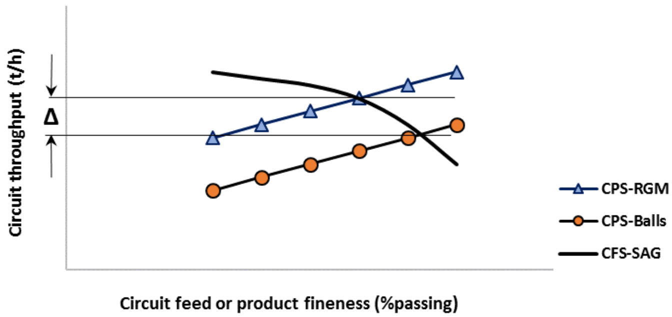

Figure 5 - Illustrative example of CPS and CFS performance curves

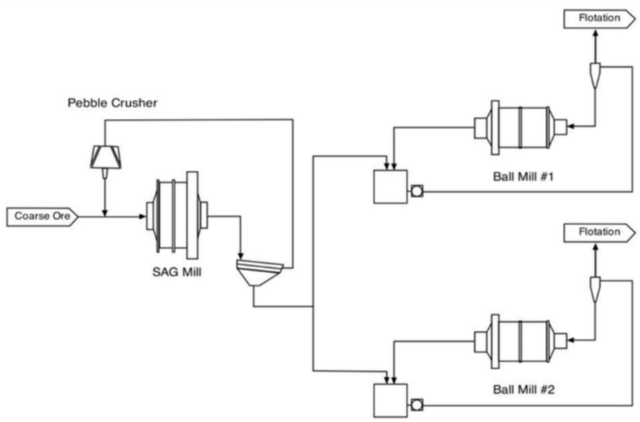

Figure 6 - Classical flowsheet of a SABC grinding circuit with parallel ball mill circuits (from Wang, Nadolski, Mejia, Drozdiak and Klein, 2013)

Both CPS and CFS performance curves can be obtained from grinding circuit simulation results. The calibration of tumbling mill models (SAG and ball mills) embedded in commercial software is often achieved through bench-scale experimentation, sampling of full-scale grinding circuit streams and statistical data reconciliation. Procedures for extracting grinding model parameters from experimental results are well known and can be found in the literature (Ipek, 2009).

BENCH-SCALE EXPERIMENTATION

From the Rudozem large-scale test results, it is clear that RGM and balls behave much differently in tumbling mills. A consequent conclusion was that the response of RGM-loaded mills cannot be predicted using models that were derived for ball-loaded mills. A new methodology needs be developed specifically for RGM-loaded mills.

The results of a single large-scale RGM test are insufficient for developing a reliable performance prediction model. Results from other industrial test are required. In the meantime, bench-scale tests are being conducted to study the effect of operating variables on RGM-loaded mill performance. The following tests were carried out to evaluate the effect of the RGM surface area and mill filling ratio on grinding efficiency.

General Procedure

All grinding tests were carried out in a Bond-type laboratory ball mill which is 30.5 cm in length and 30.5 cm in diameter. The stainless steel mill shell is smooth with rounded edges. It was operated at 70 rpm, which is 86.55% of the critical speed. The volume of the mill is 22,272 cm^3. Each test was a locked-cycle tests ("LCT") using one of the following two approaches:

- the Conventional approach, where the optimal number of mill revolutions is determined for achieving a circulating load of 250% (as proposed by Bond), and
- the Reverse approach, where the circulating load is determined for a fixed number of mill revolutions..

In all cases, results were compared on the basis of the obtained grinding efficiency determined by the measured gpr (grams per revolution) parameter.

Grinding Media

The grinding media used for the ball milling tests was a set of steel balls with a size distribution corresponding to the requirements of a standard Bond work index test. For the RGM milling tests, a set of cast-iron RGM with a size distribution equivalent to the ball size distribution was used. Photos of the two types of grinding media showing the shape and surface textures are shown on Figure **7** and Figure **8**.

Figure 7- Photo of steel RGM

Figure 8– Photo of steel balls

Tested Minerals

The mineral samples that were used for the experiments were from an albite-spodumene pegmatite deposit. They were composed primarily of quartz and plagioclase, with minor amounts of lepidolite, beryl and potassium feldspar. Main parameters of the feed size distribution were F_{100} = 3.35 mm and F_{80} = 2.04 mm. The volume of each feed sample was 700 ml with a corresponding mass of 1281.3 g. The product screen size for all tests was 106 microns. The undersize fraction of the feed samples was 9.6 % passing 106 μm.

Experimental methods

Four (4) tests were conducted. The first two tests were conducted using the Conventional locked-cycle test approach. Their purpose was to determine the grinding efficiency at a circulating load of 250% with balls and RGM. The same number (285) of grinding media was used in both experiments but due to the challenge of replicating exactly the size distribution of balls with RGM, the charge of RGM (19,098 g) was lower than the mass of balls (20,076 g) used in these experiments. However, the total surface area of the RGM charge (6,036 cm^2) was higher than the ball charge (5,724 cm^2).

The Reverse approach, was applied to the last two tests with RGM only. The number of the mill revolutions required for a 250%-circulating load was used. The objective was to gradually increase the surface area of the RGM charge and to measure the effect on grinding efficiency. The test conditions of all four tests are listed in Table 1.

Table 1– Bench-scale tests conditions

Test	**Approach**	**Media type**	**Media bed density (g/cm^3)**	**Mass of media (g)**	**Media surface area (cm^2)**	**Comments**
1	Conventional	*Balls*	4,6	20,076	5,724	Standard Bond test
2	Conventional	*RGM*	5,1	19,098	6,036	Lower mass than balls. Greater surface area than balls (5.5%)
3	Reverse	*RGM*	5,1	20,001	6,149	Same mass as balls. Greater surface area than balls (7.4%).
4	**Reverse**	***RGM***	**5,1**	**22,252**	**6,681**	**Higher mass than balls. Greater surface area than balls (16.7%)**

Results

The results of the tests are summarized in Table **2**. In the first two tests, a slightly higher grinding efficiency was observed when RGM were used (1.20 gpr versus 1.22 gpr). Considering, however, that the charge of RGM was 5.5% lower than balls (19,098 g vs 20,076 g), the advantage of using RGM was actually much greater.

The last three tests were conducted with different charges of RGM. The results show that the grinding efficiency was improved when the filling ratio (and therefore, the RGM surface area) was increased (see Figure 9).

Table 2– Bench-scale test results

Test	**Mill revolutions**	**Grinding efficiency (gpr)**	**Product size (P_{80}, µm)**
1	277	1,20	85
2	277	1,22	87
3	277	1,27	88
4	**277**	**1,43**	**88**

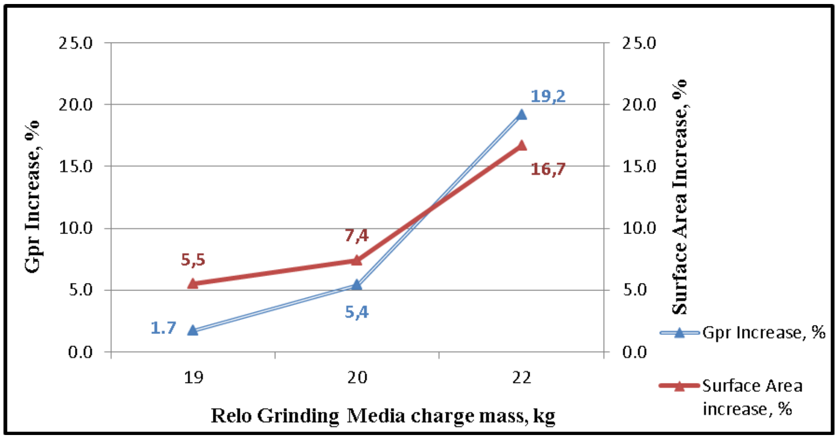

Figure 9– Variation (%) of the grinding efficiency (gpr) as a function

Discussion

The filling ratio is an important parameter in the optimization of a ball mill circuit. A study of Clermont and de Haas (2010) show that the performance of ball mills is very sensitive to the volumetric mill filling (which also affects the grinding media wear rate, throughput, power draw and product size distribution). It would exist an optimal filling ratio where the grinding efficiency is the highest (Figure 10).

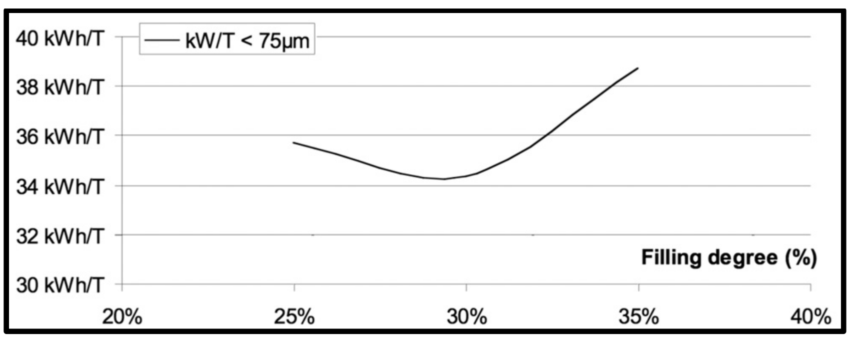

Figure 10 - Variation of a ball mill grinding efficiency (kWh/) as a function of filling ratio (from Clermont and de Haas B, 2010)

In this study, it was shown that a slight increase of the RGM filling ratio (from 19 kg to 22 kg), caused a 19.2 % increase in grinding efficiency. The optimum has clearly not been reached. Further increase of the filling ratio will likely further increase the grinding efficiency of the mill. Because an RGM has a larger surface area than a ball (of the same volume) and because RGM have a greater compactness, the grinding efficiency of a tumbling mill can only be greater with RGM than with balls at any given filling ratio.

CONCLUSIONS

The RGM truly are an exciting technology. Their design is innovative, clever and very efficient. The results of the first large-scale test are outstanding. The higher grinding efficiency of RGM can significantly increase the fineness of grind and/or the capacity of SABC grinding circuits. The greater surface area and the higher compactness they provide likely explain why the results were so good.

Other large-scale RGM tests need to be conducted to validate the reproducibility of the Rudozem test results and to build the database required for developing a reliable performance prediction model. The second part of this paper will describe the conditions of future large-scale RGM tests and compare their outcome to Rudozem results.

ACKNOWLEDGEMENTS

Wardell Armstrong International Ltd is gratefully acknowledged for performing the required laboratory test work. The authors would like to acknowledge also the technical support of Associate Director Ben Simpson from Wardell Armstrong International Ltd. for the test work and data management.

REFERENCES

Bodurov P., Genchev V. (2015). New and more effective grinding bodies for drum mills, Journal of Multidisciplinary Engineering Science and Technology (JMEST), ISSN: 3159-0040, Vol. 2, Issue 9, September, 2516-2520.

Bodurov P., Genchev V. (2017). Industrial tests with innovative energy saving grinding bodies, Journal of Multidisciplinary Engineering Science and Technology(JMEST), ISSN: 2458-9403, Vol. 4, Issue 1, January, 6498-6503.

Bond, F.C. (1961). Crushing and grinding calculations, Allis-Chalmers Manufacturing Company, reprinted from British Chemical Engineers.

Bouchard J., LeBlanc G., Levesque M., Radziszewski P. and Georges-Filteau D. (2017). Breaking down energy consumption in industry grinding mills. 49th Annual Canadian Minerals Processors Conference Proceedings, pp 25-35, Ottawa, Canada.

Brissette M. (2009). Energy savings and improved recovery with small grinding media. Proceedings of the 41st Annual Canadian Mineral Processors Conference

Chen, E.R., Engel, M., Glotzer, S.C. (2010). Dense Crystalline dimer packings of regular tetrahedra. Discrete Comput Geom (2010), Volume 44, Issue 2, pp 253–280

Cloos, U. (1983). Cylpebs: An alternative to balls as grinding media, World mining, 36.

Clermont B, de Haas B (2010). Optimization of mill performance by using online ball and pulp measurements. J South Afr Inst Min Metall 110:8

Conger W., Dupont J-F, McIvor R.E., Weldum T.P. (2018). Grinding media sizing studies: Past, present, and future. 50th Annual Canadian Mineral Processors Operators Conference©, Ottawa, Ontario, 23-25
Cooper, M., Bazin, C., Grant, R. (1994). Evaluation of grinding media at Brunswick Mining. CIM Bulletin 87 (985), Montréal, Canada. 73-76.

Ipek, H. (2009). Effect of grinding media shapes on breakage distribution function. SME Annual Meeting, Preprint 09-128, Littleton, Colorado. 1-4.

Kallus Y., Elser V., Gravel S.. (2010). Method for dense packing discovery. Physical review. E, Statistical, nonlinear, and soft matter physics. 82. 056707. 10.1103/PhysRevE.82.056707.

Lameck N.N.S. (2006). Effects of grinding media shapes on ball mill performance. A dissertation submitted to the Faculty of Engineering and The Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science in Engineering.

Makni, S., Faucher, A., Bouajila, A., Robichaud, F. (2012). Predicting the effect of grinding media size distribution on the performance of a ball mill using discrete element method (DEM) and population balance techniques. 44th Annual Canadian Mineral Processors Operators Conference. Ottawa,. 451-461

Morrison, R.D., Shi, F., Whyte, R., (2007). Modelling of incremental rock breakage by impact for use in DEM models. Miner. Eng. 20, 303–309.

Napier-Munn, T.J. (2008). Some practical problems in running statistically valid plant trials and their solution. Metallurgical Plant Design and Operating Strategies (MetPlant 2008). Perth, Australia, 249-258.

Nesset J.E., Radziszewski P., Hardie C., Leroux D.P. (2006). Assessing the performance and efficiency of fine grinding technologies. Proceedings of the 38th Annual Canadian Mineral Processors Conference

Norris G. C. (1954), Some grinding tests with spheres and other shapes, Transactions of Institute of Minerals and Metallurgy, London, 1954, February, 63(567), 197-209.

Orford I., LaCoste-Boucher P., Cooper M. (2006). Millpebs testing at Brunswick concentrator, Proceedings of Canadian Mineral Processors Annual Meeting, Ottawa.

Penchev T., Bodurov P. (2014). Comparative analysis of the parameters of spherical and Relo body balls for drum mills. Proceedings of the International Conference on Mining, Material and Metallurgical Engineering Prague, Czech Republic, 2014, Paper No. 144

Shi, F. (2004). Comparison of grinding media-Cylpebs versus balls. Minerals Engineering Vol, 17, 1259-1268.

Wang, C., Nadolski, S., Mejia, O., Drozdiak, J., Klein, B. (2013). Energy and cost comparisons of HPGR based circuits with the SABC circuit installed at the Huckleberry mine. 45th Annual Canadian Mineral Processors Operators Conference. Ottawa, Canada. 121-135.