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Variables affecting the fine grinding of minerals using stirred mills ☆

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Abstract

Base metal resources are becoming more fine-grained and refractory and minerals separation processes require these ores to be milled to increasingly finer sizes. To cope with very fine grinding to below a P_{80} of approximately 15 μm stirred milling technology has been adopted from other industries. Neither this technology, nor the basic concepts of fine grinding, are well understood by the minerals processing industry. Laboratory studies were therefore carried out in order to investigate fine milling using different types of stirred mills. The variables analysed were stirrer speed, grinding media type and size, slurry solids content as well as the feed and product size. The results of the testwork have shown that all of these variables affect the grinding efficiency. The ratio of media size to material size was found to be of particular significance. The results were also analysed using the stress intensity approach and the optimum stress intensity ranges for the most efficient grinding were determined. Application of the results for process optimisation in the industrial size units is also discussed in this paper.

Keywords: Fine particles processing; Grinding; Process optimisation

1. Introduction

The mining industry is often regarded as "conservative" because in the past it has been slow to accept new ideas. This statement may be confirmed by the fact that the majority of crushing and grinding equipment used today was "invented" in 18th century. Flotation as a major mineral separation technology was invented in 19th century. In that respect, the introduction of stirred milling technology has occurred relatively quickly. The first stirred mills were introduced in 1953 (Shibayama and Mori, 1999) and the driving force behind their introduction was the increasing need for the fine particles processing, i.e. grinding. Since their initial introduction, more than 400 Tower and Verti mills have been installed around the world (Kalra, 1999) and the number is steadily increasing. Stirred mills have become the preferred option for regrinding and fine grinding.

The most commonly used stirred mills in the minerals processing industry are:

Tower mill: Manufactured in Japan by Kubota. It was the first low speed stirred mill applied in the minerals industry. The mill operation is explained elsewhere (Stief et al., 1987; Menacho and Reyes, 1989; Jankovic, 1997, 1998; Jankovic et al., 1999; Jankovic and Morrell, 2000).

Verti mill: This is basically the same design as the Kubota Tower mill and is manufactured by Svedala. The Verti mill was introduced around 10 years ago and there are now over 220 Verti mill installations worldwide (Kalra, 1999).

ISAMILL: Development of the ISAMILL started in 1990 between Mount Isa Mines Limited and NETZCH—Feinmahltechnik GmbH (Underle et al., 1997). As the result of this development, a 3000 l and 1.1 MW motor power unit was designed and installed first in Mount Isa Mines lead/zinc concentrator (1994, two mills) and then at McArthur River Mining (1995, five mills). Six more mills were later installed at Mount Isa Mines lead/zinc concentrator and one at the KCGM Fimiston gold mine (Ellis and Gao, 2002).

Svedala detritor: ECC International developed its first mill in the 1960s and currently around 200 mills operate in kaolin and calcium carbonate processing plants (Lofthouse and Johns, 1999). The first installation in Australia was at the Elura lead/zinc mine where two

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mills are in operation. Another 18 ECC mills were installed at Century zinc mine concentrator for zinc rougher concentrate grinding down to $P_{80} = 7$ μm (Burgess et al., 2001).

Sala agitated mill (SAM): This is a vertical pin mill originally developed by Sala. To date the majority of applications are in Europe.

The *ANI-Metprotech SVM* mills: This mill, originally developed in South Africa, is similar design to the SAM. A total of seven mills have been installed to date.

2. Fine grinding for the minerals processing industry

The definition of fine grinding varies from one industry to another. For example, the fine grinding criteria for the paint and mining industry are very different. In the paint industry particles finer than 1 μm are regarded as "fine" while in minerals processing "fines" are the particles which are difficult to recover in a separation process. Depending on the type of separation process (gravity, flotation, leaching,...) the size definition of fines ranges from below 1 mm to below 10 μm.

In minerals processing, four grinding "stages" can be identified, based on the size of the grinding product. Traditionally, grinding to 80% passing 75 μm is regarded as "conventional" since many operations grind to that size. Regrinding is considered to produce the particles finer than 75 μm down to 30 μm. Fine grinding is a relatively new area and considers grinding below 30 μm down to around 10 μm. Below 10 μm, the term "very fine grinding" can be used.

The energy consumption in ball milling rises sharply for grinding products below 75 μm and below 30 μm grinding using ball mills becomes uneconomical. It can be seen from the graphical illustration of the particle size/energy consumption relationship shown in Fig. 1 that stirred mills are much more efficient for fine grinding and regrinding than conventional ball mills. With the introduction of stirred mills, fine grinding becomes economical and there are several base metal concentrators today that grind as low as 10 μm (Underle et al., 1997; Burgess et al., 2001; Ellis and Gao, 2002).

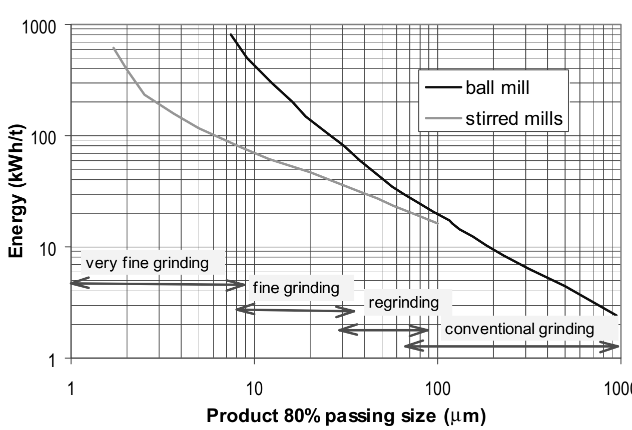

Fig. 1. Schematic of the energy consumption at different grinding stages.

3. Important stirred milling parameters

There is a large number of parameters which can affect the grinding in stirred mills. Up to 44 parameters of influence were identified by Molls and Hornle (1972). A significant number of these parameters may be classified as less important but nonetheless the complexity of the subject becomes evident. The focus in this research was to study the more important parameters: mill design, grinding media, mill speed and slurry density. The effects of the individual parameters were studied, as well as combined effect of stirrer speed, media size and density.

4. Testwork

Testwork has been carried out on several types of stirred mills in order to study the effect of the major operating variables. Power consumption and the grinding products size distribution were measured in all tests. A Malvern laser sizer was used for measuring the size distributions of the grinding products.

4.1. Pilot tower and Sala autogenous mill (SAM) tests

Continuous grinding tests were carried out in laboratory and pilot size Tower (1.5 kW) and SAM (8 kW) mills. Commercially available calcium carbonate, with an F_{80} of approximately 65 μm, was ground using the experimental setup which allowed a continuous stagewise operation. Details of the testwork can be found elsewhere (Jankovic, 1999, 2001).

4.2. High speed Netzch mill testwork

The laboratory grinding tests were conducted using a Netzsch 1.5 l bead mill (see Fig. 2) at 1500 and 1000 rpm stirrer speed. Granulated lead slag (NLS) from the content of a ISAMILL (worn) and from a slag bin (fresh) were used as grinding media in the bead mill grinding tests. Three narrow media size fractions, i.e. $-1.7 + 1.2$ mm, $-1.2 + 0.85$ mm, and $-0.85 + 0.60$ mm were prepared by sieving. Zinc concentrates with a range of feed size distributions were used in the testwork. The milling tests were run in batch-mode. The net energy consumption was calculated from the net power draw (the gross power minus the no-load power) and the slurry solids weight in the mill. A summary of the tests

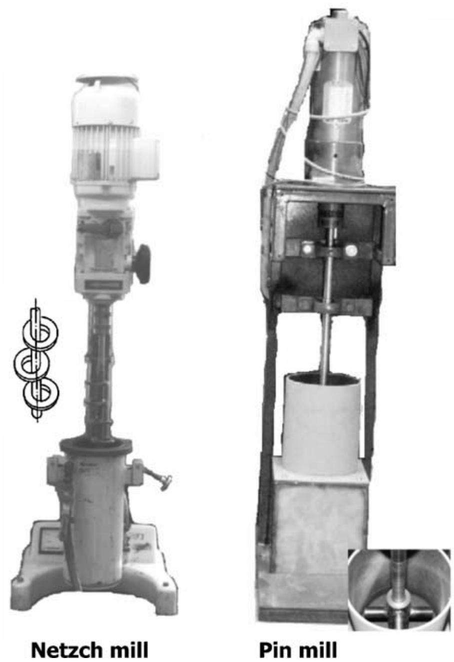

Fig. 2. Laboratory mills used in the testwork.

conducted with the high speed Netzch mill is given in Table 1.

4.3. Pin mill testwork

In order to study the variables affecting fine grinding, a 200 mm diameter pin-type laboratory stirred mill was designed at the JKMRC (see Fig. 2). The mill is equipped with a variable speed drive which has a maximum speed 450 rpm (stirrer pin tip speed 2.3 m/s).

Batch grinding tests were carried out with two different zinc concentrates. The 80% passing size for two samples was similar, around 40 μm. The variables analysed were media size, media density and stirrer speed mill speed. A summary of the test conditions is presented in Tables 2 and 3.

Table 1
Netzch mill experimental plan

Test no	Feed size F_{80} (μm)	Slurry% solids	Stirrer speed (rpm)	Media size (mm)	Media type
1	43.1	41.7	1500	$-1.7+0.42$	Fresh NLS
2	43.1	41.7	1500	$-1.2+0.85$	Fresh NLS
3	43.1	41.7	1500	$-0.85+0.60$	Fresh NLS
4	43.6	41.7	1500	$-0.85+0.60$	Worn NLS
5	46.8	41.7	1500	$-1.7+0.42$	Worn NLS
6	46.8	41.7	1500	$-1.2+0.85$	Worn NLS
7	45.7	41.7	1000	$-0.85+0.60$	Worn NLS
8	10.6	35.3	1500	$-0.85+0.60$	Worn NLS
9	10.3	35.3	1500	$-1.7+0.42$	Worn NLS
10	41.7	41.7	1000	$-1.7+0.42$	Worn NLS
11	54.7	54.7	1500	$-0.85+0.60$	Worn NLS
12	54.7	54.7	1500	$-1.7+1.20$	Worn NLS
13	28.0	28.0	1500	$-1.2+0.85$	Worn NLS
14	27.0	27.0	1000	$-0.85+0.60$	Worn NLS

Table 2
Pin mill experimental plan for the zinc concentrate A with stirrer tip speed 2.3 m/s, 250 g of solids, 550 g water, grinding media volume 1.45 l

Test no	Media type	Media size (mm)	Media D_{50} size (mm)	Media density (kg/m^3)	Media weight (kg)
J1	Steel balls	4.0–5.0	4.5	7800	6.60
J2	Steel shots	2.0–2.5	2.2	7800	6.15
J3	Silica sand N	0.4–4.0	1.5	2780	2.31
J4	Silica sand C	1.0–4.0	2.3	2750	2.23
J5	Granulated slag	1.2–1.7	1.4	3820	3.33
J6	Granulated slag	0.6–0.84	0.7	3820	3.26
J7	Granulated slag	0.84–1.2	1.0	3820	3.30
J8	Steel balls	4.0–5.0	4.5	7800	6.56
J9	Steel shots	2.0–2.5	2.2	7800	6.13
J10	Silica sand R	4.0–4.75	4.4	2760	2.30
J11	Silica sand R	2.0–2.5	2.2	2760	2.13

Table 3
Pin mill experimental plan for the zinc concentrate B with 400 g of solids, 500 g water, grinding media volume 1.45 l

Test no	Media type	Media size (mm)	Media D_{50} size (mm)	Media density (kg/m^3)	Stirrer tip speed (m/s)
S1	Silica sand R	2.8–1.4	2.1	2750	2.30
S2	Granulated slag	1.2–1.7	1.5	3820	1.63
S3	Steel shots	2.0–2.5	2.2	7800	1.36
S4	Silica sand R	4.0–3.35	3.7	2750	1.93
S5	Steel shots*	5.0–4.0	4.5	7800	1.93
S6	Silica sand R	0.1–0.5	0.3	2750	1.93
S7	Granulated slag	0.6–0.84	0.7	3700	1.93

5. Results

5.1. High speed Netzch mill

5.1.1. Fresh and worn slag media comparison

Fig. 3a presents the comparative results obtained with the same size fraction of fresh media (taken from the media stockpile) and worn media (taken from the ISAMILL contents). It can be seen that the grinding product size is finer for worn media and the difference is increasing at finer product sizes. This is predominantly due to the high wear rate of the fresh slag which has an irregular shape and where a fraction of the energy is consumed in media wear which produces more regularly shaped particles. As a result, the grinding product is continuously contaminated with abraded particles from the grinding media. A fraction of the input energy

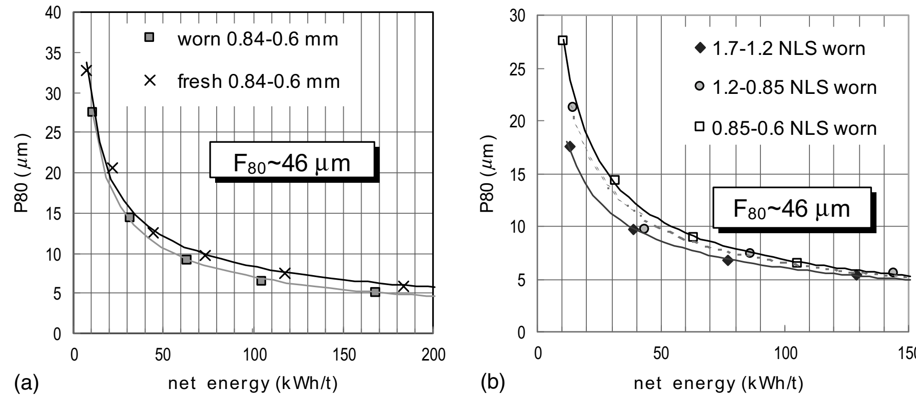

Fig. 3. (a) Netzch mill grinding performance comparison with worn and fresh NLS media; (b) Netzch mill results with different media sizes.

intended for fine grinding is lost on media wear and the product is coarser due to the presence of abraded particles. At the beginning of the test the grinding media wear is relatively small and does not affect the product size while later the amount of abraded media particles increases to 10–20% of product weight. A method to account for media wear effect has been proposed by Becker and Schwedes (1999). However, it is recommended to use previously abraded media for laboratory testing in order to mimic the conditions in the production environment.

5.1.2. Media size effect

The effect of media size on grinding efficiency was investigated for three different slurry feed sizes. The results for the coarse feed size ($F_{80} \sim 46$ µm) are presented in Fig. 4b. It should be emphasized that although the difference in size may appear to be small, the amount of energy required for such a small size reduction is large and all results should be observed in that light. It can be seen from Fig. 4b that the most efficient grinding was obtained with coarse 1.7–1.2 mm media, while the finest 0.85–0.6 mm media were the least efficient. To reduce the product size from $F_{80} \sim 46$ µm to $P_{80} = 15$ µm, approximately 17 kW h/t is needed with coarse media while approximately 28 kW h/t is required with the finest media. This is a difference of approximately 40%. As the product size becomes finer the difference decreases which suggest that smaller media was more efficient for fine products (i.e., below 7 µm).

Tests were conducted with a finer feed sample ($F_{80} \sim 20$ µm, 54.7% solids) and the resulting Netzch mill performance for two different media size fractions are presented in Fig. 4a. The coarse media were still more efficient, but the difference was less than was observed for the coarser feed. To reduce the product size from $F_{80} \sim 20$ µm to $P_{80} = 10$ µm, approximately 36 kW h/t was needed with coarse media while approximately 42 kW h/t was required with the finest media. This is a difference of around 14%.

To investigate very fine grinding below 10 µm a fine feed sample ($F_{80} \sim 10$ µm, 31.3% solids) was used. The grinding results plotted in Fig. 4b show, contrary to the previous two cases, that finer media were more efficient. To reduce the product size from $F_{80} \sim 10.3$ µm to $P_{80} = 8$ µm, approximately 28 kW h/t was needed with fine media while approximately 45 kWh/t was required with the coarse media. This is a difference of around 38%. This difference is even greater (47%) for grinding to P_{80} of 7 µm.

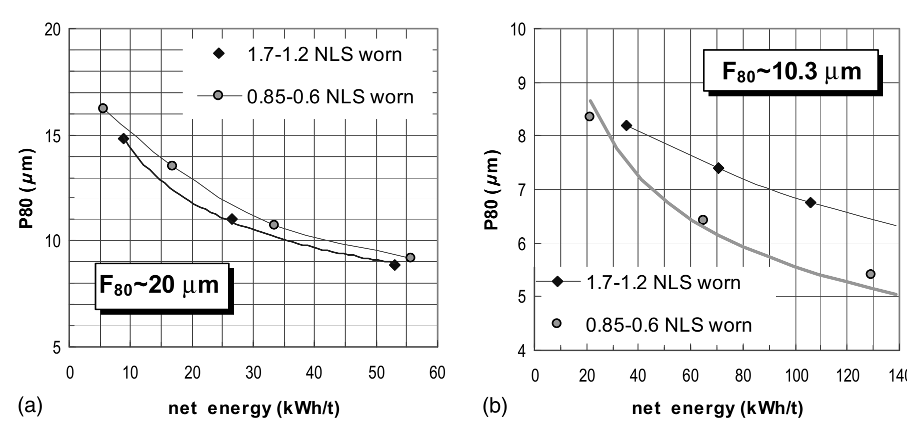

Fig. 4. Netzch mill results with different media sizes: slurry feed $F_{80} \sim 20$ and 10.3 µm.

The above results suggest that finer media should be used as feed size decreases.

5.1.3. Stirrer speed effect

In addition to specific energy input, and the grinding media size, the stirrer tip speed can affect the grinding results. Grinding results with two media sizes and two speeds are presented in Fig. 5. It can be seen that in both cases higher stirrer speed had a positive affect on grinding efficiency. For the coarser media this effect was stronger in the coarser product size range. For the finer media the stirrer speed effect was small over the range of speeds tested. It is expected that a higher speed than those tested would result in greater efficiency for smaller grinding media.

5.2. Pilot Tower mill

The detailed results from the Pilot Tower mill testwork are published elsewhere (Jankovic, 1998, 1999). This section presents a summary of the findings for the each test variable.

5.2.1. Slurry density effects

The results from the tests performed to investigate the slurry density effect have shown that the mill grinding efficiency increased with slurry % solids over the range tested. The increase in grinding efficiency at higher % solids can be explained by a drop in power draw due to buoyancy effects.

5.2.2. Effect of stirrer speed

The effect of screw speed was evaluated by running the mill at three different levels: standard 0.74 m/s tip speed (100 rpm), low 0.37 m/s (50 rpm) and higher 1.1 m/s (150 rpm). The results suggest that the energy efficiency was increasing when decreasing the stirrer tip speed.

5.2.3. Media size effect

Finer media were found to be more efficient for fine particle grinding. Several media sizes were tested in the Pilot Tower mill. By decreasing the media size from 12 to 6.8 mm the size reduction achieved in the mill was greatly increased. Further decreasing the media size to 4.8 mm caused mill efficiency to deteriorate. This indicates the existence of an "optimum media size" for a particular stirrer speed.

5.3. Pilot SAM mill

The detailed results from the pilot SAM mill testwork are published elsewhere (Jankovic, 1999). This section presents the major findings relevant to the framework of this paper.

5.3.1. Slurry density effects

Three tests were carried out to assess the effect of slurry density on mill grinding performance: at 40%, 55% and 64% solids. The results (see Fig. 6a) show that mill grinding efficiency increased with slurry % solids over the range tested. It is noteworthy that the increase in efficiency from 55% to 64% solids was not as high as from 40–55.0%. Even making allowances for difference in the % solids increase, it would appear that grinding efficiency was reaching a maximum with respect to % solids. The increase in grinding efficiency at higher % solids can be explained by the drop in power draw due to the "buoyancy" effect and the increase in the number of particles in the mill. This latter effect causes an increase in probability that a particle will be broken.

It could be concluded that an increase in slurry density will improve mill performance up to a certain point after which a decrease in mill efficiency should be expected together with slurry flow problems due to increased viscosity.

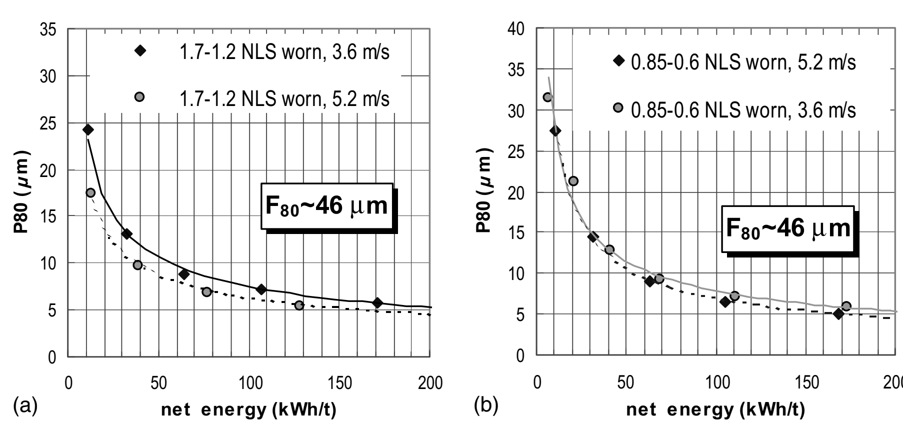

Fig. 5. Stirrer speed effect (a) 1.7–1.2 mm media; (b) 0.85–0.6 mm.

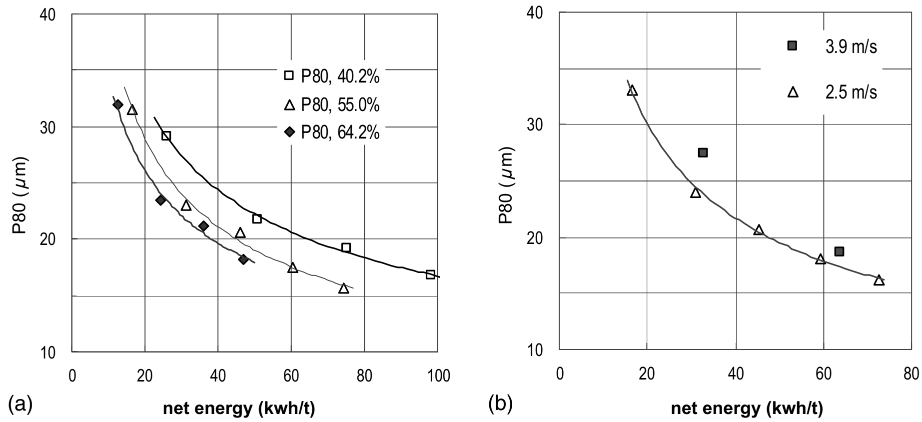

Fig. 6. (a) Slurry % solids effect in the SAM mill; (b) stirrer speed effect.

5.3.2. Effect of stirrer speed

The effect of tip speed was evaluated by running the mill with two different gearboxes which allowed two different speeds to be obtained, namely 2.5 and 3.9 m/s. The grinding media size was 8 mm in both tests. According to the results shown in Fig. 6b, it seems that better energy utilisation, i.e. efficiency, was achieved at the lower 2.5 m/s stirrer tip speed.

5.3.3. Media size effect

Media size is claimed to be a crucial operating parameter for fine grinding, with finer media producing fine particles more efficiently. Several media sizes were tested in the Sala mill and the results with calcite are presented in Fig. 5b. As can be seen, with a decrease in media size, at a constant stirrer speed, the size reduction was increased significantly. It has been found, however, from video footage of the laboratory glass stirred mill that at a fixed stirrer speed the transfer of momentum from the stirrer to the bulk of the media charge reduces as the ball size decreases. As a result, if the ball size is too small then a proportion of the grinding media fails to move and hence does not cause breakage. Only by increasing speed can these stationary balls be made to move and therefore cause breakage. It is expected therefore, that there must be a media size for a particular stirrer speed below which further decreases in media size will have a deleterious effect on grinding performance (see Fig. 7).

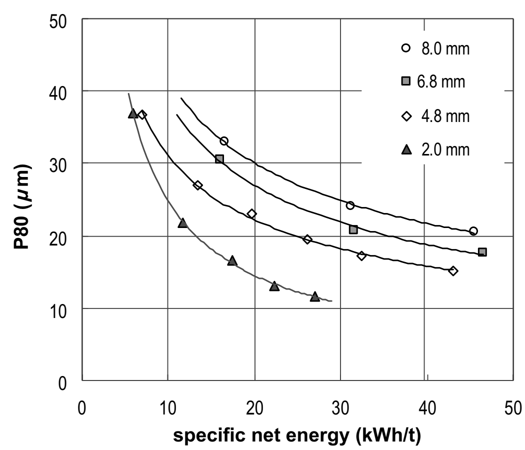

Fig. 7. Media size effect in the SAM mill.

5.4. Pin stirred mill

The test results with different grinding media in the pin mill are shown in Figs. 8 and 9. The test material was the zinc concentrate B, 80% passing size around 47 μm.

When lead slag grinding media was used, the milling was more efficient with coarser 1.7–1.2 mm grinding media (Fig. 8a). Contrary, Fig. 8b shows smaller 2–2.5 mm steel media was more efficient. Note that for the energy inputs above 100 kW h/t, there was little difference in the product size for the coarse and fine slag media (Fig. 8a).

Very similar grinding results were obtained with the coarse and fine quartz grinding media (Fig. 9a). This results indicate that apart from grinding media size, other operating variables such as mill speed and type of grinding media also affect the grinding efficiency. Fig. 9b shows that a more efficient grinding was obtained with the coarse (4–3.35 mm) quartz sand than with 4–5 mm steel balls.

5.5. Grinding media stress intensity

The results presented suggest that all of the variables tested had some effect on the grinding performance. However, there is no definite "trend" that could be derived. Even for the same mill type "mixed" reactions to the change in one variable were observed. For example, increasing the stirrer speed was beneficial in some test, but in others the opposite occurred. Grinding at higher slurry densities was more efficient until the viscosity

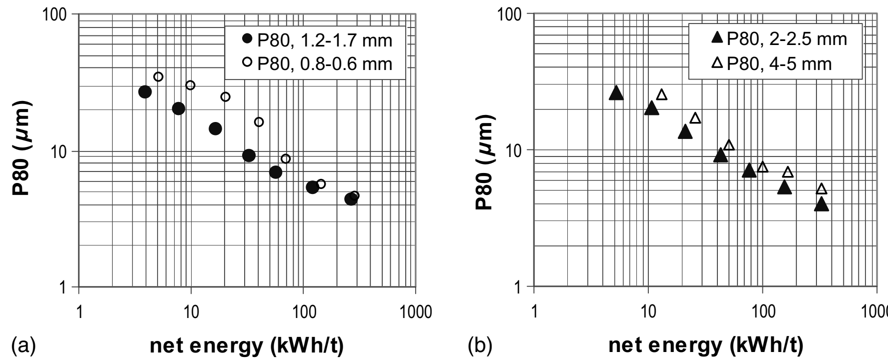

Fig. 8. Media size effect—(a) lead slag grinding media; (b) steel grinding media.

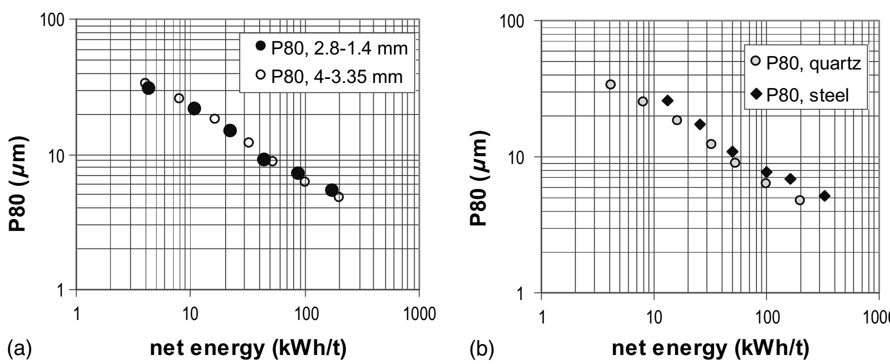

Fig. 9. (a) Media size effect—quartz sand grinding media; (b) material effect—quartz (3.35–4 mm) and steel (4–5 mm) grinding media.

became an issue. The coarser grinding media was more efficient for the coarser feed sizes but less effective with the finer feeds. All of this suggests that there are strong interactions between the variables. It is therefore incorrect to evaluate the effect of one variable without considering the others. For example, it is common to determine the optimum media size for an industrial application using laboratory scale testwork (Ellis and Gao, 2002). As the conditions in the industrial size units are significantly different (tip speed, mill/media size ratio, design and transport), there is a possibility that the selected media size may not be the most appropriate one (Kwade and Stender, 1998).

The above observations suggest that a generalised approach to the stirred mill performance analysis is required. Work published by Schwedes et al. (1996) reveals that in high speed stirred mills the effect of mill tip speed, media size and density can be evaluated simultaneously using the grinding media "stress intensity" approach:

$$SI_m = D_m^3(\rho_m - \rho)v_t^2 \tag{1}$$

where D_m is the grinding media size (m), ρ_m is the grinding media density (kg/m^3), ρ is the slurry density (kg/m^3), v_t is the stirrer tip speed (m/s), and SI_m is the stress intensity of the grinding media (Nm).

It was shown that the vertical stirred mills, where the gravitational forces are dominant due to media bed height and low stirrer speed, can also be analysed using a "modified" stress intensity definition (Jankovic, 2001). The plot of milling product 80% passing size versus the stress intensity for the Pilot Tower and SAM mill is presented in Fig. 10. The graph indicates that there is an

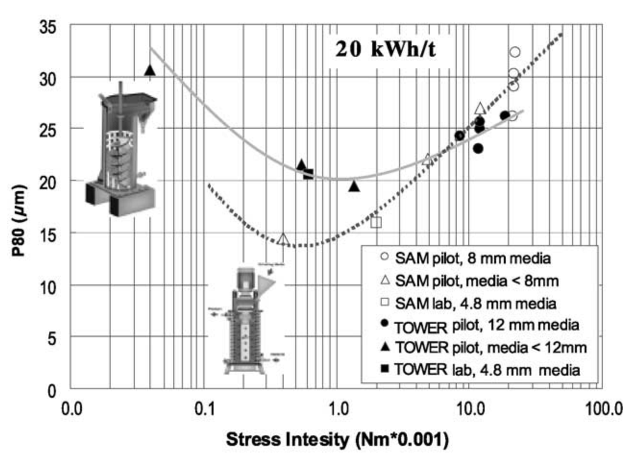

Fig. 10. Grinding product size at 20 kW h/t energy input as a function of stress intensity—after Jankovic, 2001.

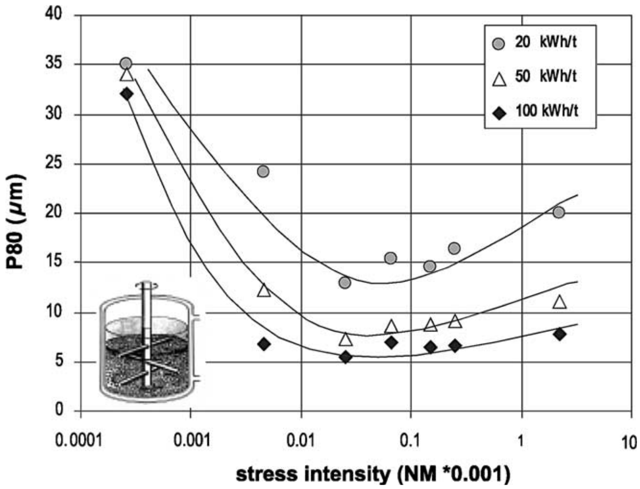

Fig. 11. Stress intensity plot for the zinc concentrate B milling in the pin mill.

optimum stress intensity range where the finest product is obtained for the same 20 kW h/t net energy consumption. The two mills appear to have different trends and different optimum stress intensity ranges. This suggests that the stress intensity analysis from one mill design cannot be applied directly to a different type of mill.

The stress intensity graph at different energy inputs using the laboratory pin mill is presented in Fig. 11. The test material was the zinc concentrate B, 80% passing size around 47 μm. It can be seen that the optimum stress intensity is in the 0.02×10^{-3}–0.1×10^{-3} Nm range irrespective of the energy input, i.e. required product size. This is in slight contrast with results from a horizontal stirred mill (Kwade et al., 1995) where the optimum stress intensity increases when the product size increases. It is possible that this trend is hidden due to scatter in the data.

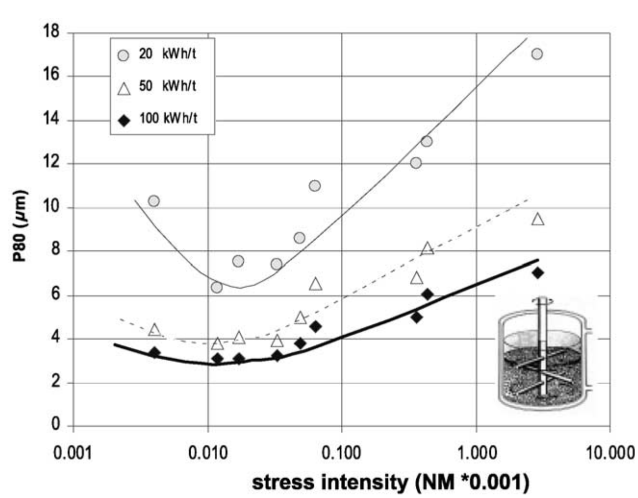

Fig. 12. Stress intensity plot for the zinc concentrate A milling in the pin mill.

Fig. 12 shows the stress intensity graph for the pin mill test with concentrate A. An optimum region between 0.01×10^{-3} and 0.05×10^{-3} Nm can be observed from the graph, which is lower than for the concentrate B. The graph also shows that for the same energy input, a significantly finer product was obtained compared to the concentrate B. This indicates that this is a softer to grind material and it agrees with the lower optimum stress intensity range.

6. Conclusion

The work presented in this paper aimed to provide a contribution to the understanding of stirred milling technology for minerals processing. Test results from different stirred mills (Tower, SAM, Netzch and pin mill) were presented and the effects of operating variables was discussed. It was found that the characteristics of the grinding media (size, density, shape), the mill speed and slurry properties (feed and product size, slurry density and hardness) have strong effects on the grinding efficiency. More importantly, the interaction between these variables is very strong which means that the effect of one variable cannot be generalised.

The fine grinding process is controlled by the grinding media "stress intensity" a term that combines effect of grinding media size, density and bed height, slurry density and stirrer speed. The stress intensity reflects the energy involved in a breakage event. If the energy is too small, several events would be required to break the particle which means a reduction in breakage rate. If the energy is much higher than required for breakage, it will be wasted.

The stress intensity analysis was applied in this work and the optimum stress intensity regions were found for all of the stirred mills tested. In these regions the grinding efficiency was highest as the finest product was obtained for a given specific energy input (kW h/t). It is therefore concluded that the "stress intensity" method should be used for the stirred milling process optimisation and scale-up.

References

Becker, M., Schwedes, J., 1999. Comminution of ceramics in stirred media mills and wear of grinding beads. Powder Technology 105, 374–381.

Burgess, F., McGuire, I., Willoughby, R., 2001. Operation of sand mill detritors at Pasminco operations. In: Fine Particle Processing and Tailing Summit, July, Perth, Australia.

Ellis, S., Gao, M., 2002. The development of ultra fine grinding at KCGM. In: SME Annual Meeting. 25–27 February, Phoenix, Arizona, preprint 02-072.

Jankovic, A., 1997. Power modelling of stirred mills. In: Proceedings of the Second UBC-MCGILL BI—Annual International Symposium on Fundamentals of Mineral Processing and the Environment, Sudbury, Ontario, August. pp. 463–470.

Jankovic, A., 1998. Tower mill grinding efficiency. Journal of Mining and Metallurgy-Collection of Papers Section A: Mining 34 (3–4), 163–173.

Jankovic, A., 1999. Mathematical modelling of stirred mills. Ph.D Thesis, University of Queensland, JKMRC, Brisbane, Australia.

Jankovic, A., 2001. Media stress intensity analysis for vertical stirred mills. Minerals Engineering 14, 1177–1186, Special issue from MEI Conference Comminution 01, Brisbane—Australia.

Jankovic, A., Morrell, S., 2000. Scale-up of tower mill performance using modelling and simulation. In: Proceedings of XXI IMPC, Rome, Italy, pp. A3 1–8.

Jankovic, A., Young, M., Hinds, D., 1999. Tower fine milling experience at Mount Isa Mines. In: Jackson, N., Dunlop, G., Cameron, P. (Eds.), Mineral Processing and Hydrometallurgy Plant Design, Australian Mineral Foundation, ISBN No: 0-908039-70-0.

Kalra, R., 1999. Overview on alternative methods for fine and ultra-fine grinding. In: IIR Conference, Crushing & Grinding '99, Perth.

Kwade, A., Stender, H.H., 1998. Constant grinding results at scale-up of stirred media mills. Aufbereitungs-Technik 39, 373–381.

Kwade et al., 1995. Motion and stress intensity of grinding beads in a stirred media mill. Part2: Stress intensity and its effect on comminution. Powder Technology 86, 69–76.

Lofthouse, C.H., Johns, F.E., 1999. The Svedala (ECC international) detritor and metals industry. Minerals Engineering 12 (2), 205–207.

Menacho, M.J., Reyes M.J., 1989. Evaluation of the tower mill as regrind machine. In: Proceedings Annual Meeting of the Canadian Mineral Processors Division of CIM. pp. 124–145.

Molls, H.H., Hornle, R., 1972. DECHEMA—Monography 69 Tl 2. pp. 631–661.

Shibayama, A., Mori, S., 1999. A history of the tower mill pulverizer. Journal of Resourcess Processing Society of Japan 46 (1), 24–30.

Stief, D.E., Lawruk, W.A., Wilson, L.J., 1987. Tower mill and its application to fine grinding. Minerals and Metallurgy Processing 4 (1), 45–50.

Underle, U., Woodall, P., Duffy, M., Johnson, N.W., 1997. Stirred mill technology for regrinding McArthur river and Mount Isa zinc/lead ores. In: Proceedings of XX IMPC—Aachen, 21–26 September, pp. 71–78.