Comminution ‘08
Falmouth, UK, June 17-20, 2008

The 5th MEI Conference on comminution was the best attended, with 157 delegates representing 31 countries gathering at the picturesque Falmouth Beach Resort Hotel, in Cornwall, UK. A couple of warm sunny days showed off the beautiful scenery at its best. The social events took advantage of the coastal path, the stunning Trebah gardens, and a final visit to the old tin mines (for the rain-coated hardy ones!). The single session in a smallish venue, with extended breaks promoted a lot of interaction, and this received favourable comment from the delegates. Comminution ’08 was held over four days with 64 papers presented in technical sessions ranging from the fundamentals of breakage, to fundamental and empirical process models, along with industrial applications and case studies. This also covered the range from crushing and HPGR applications through to fine and ultrafine grinding. The un-refereed papers are available as a Proceedings CD (www.min-eng.com/comminution/bookstore/6.html) and many will appear as peer-review papers in a special Comminution ’08 issue of Minerals Engineering, scheduled for publication in early 2009. This special issue will be Guest Edited by Prof. Malcolm Powell, of the JKMRC, Australia, and MEI’s consultant to the event.

Seven major companies provided corporate support for the event:

- JKTech
- Magotteaux
- Pangea International
- PMT-Jetmill
- Saint-Gobain Zirpro
- Sigmund Lindner
- Xstrata Technology

Details of the programme, photographs, and the delegate list can be obtained at www.min-eng.com/comminution08/

The 6th Comminution conference is scheduled for April 2010 in Cape Town, and judging by the buzz at this event and the positive feedback, promises to be unmissable!

Following is a technical overview and more detailed technical summary.

Overview
Comminution ‘08 had an overarching set of themes to the conference:

The drive to lower energy consumption
- Designing and operating energy efficient circuits
- Moving beyond size reduction
- multi-component modelling, predicting liberation

The squeeze on mills
- Are HPGR’s pushing down into primary milling territory?
- The integration of HPGR and bed breakage devices into current and future circuits.
- Are stirred mills reaching up into secondary & tertiary mill territory?
- How coarse can we go – replacing ball mills
- Media wear

Fundamental breakage understanding and modelling received a lot of coverage, which is a good sign for long-term development in the industry.

This was balanced by the empirical modelling and industrial case studies, which showed the applied nature of many in the audience.
Media efficiency and wear were hot topics in the fine grinding theme, and it is good to see some methodical testing processes being applied and fundamental correlations being developed. This becomes ever-more critical as large mills are moved to coarser main stream grinding, and suffer high gross wear rates with large throughputs, hundreds of tons per hour per mill.

Viscosity/rheology issues were raised a number of times, especially in relation to fine grinding, and clearly this is an area that should be addressed in future conferences.

The incorporation of HPGR into circuits to replace SAG milling received a lot of coverage, and it was good to see the total cost being addressed, and issues relating to simplifying their inclusion in circuits, to reduce dry screening and excessive conveying along with the associated dust issues, energy costs, and maintenance costs and reliability. It was good to be part of some lively questioning sessions, and these discussions continued in the extended tea and lunch breaks, that also allowed for plenty of networking.

**TECHNICAL SUMMARY**

Below is a summary of the papers by category, so not in the conference order. This should help highlight trends and areas of development, and assist the reader in choosing which papers to follow up on in greater detail.

**Breakage fundamentals**

The conference kicked off with an excellent session on the fundamentals of breakage, testing and modelling. From Shi we heard about the new JK rotary breakage tester (JKRBT) that is set to dramatically improve upon the productivity and range of application of the well established JK drop weight test. Ozkahraman presented relationships between a brittleness test and the standard Bond test results, and came up with a remarkably linear correlation between his friability index and the g/rev figure from the Bond test. Skrzypczak showed through micro-hardness tests that small particles (<1.5µm for marble) tend to deform rather than fracture under a single shock loading. This elastic behaviour of rocks becomes noticeable at low impact energies and for tiny competent particles. As we move into finer ore grinding such physical limits and responses will become more relevant to the industry.

There appears to be common agreement that the production of new surface is the proper measure of comminution, but it is difficult to measure. Stamboliadis presented a technique for relating breakage to new surface area, and this looks most promising. Mainza compared the products from impact, abrasion, and compressed bed breakage, and showed how the product differ for similar energy inputs. Such studies are most pertinent to the changing face of comminution circuits. The innovative work of Michaux on breakage patterns observed in rocks broken through blasting linked neatly into this, as the fragmentation picture became clear in terms of surface area, rather than size. Michaux emphasised the importance of the distribution of shape within a size interval (rather than an average shape property). Based on this he showed the self-similar nature of breakage within two distinct zones, separated at 1mm, that was independent of rock type, energy input, or microstructure. If this is a universal property of breakage (yet to be tested on products of mechanical comminution) this may well serve to simplify our understanding and modelling of breakage processes.

**Models - fundamental**

Tavares moved ball mill modelling to a new level with his application of non-linear breakage rates. He introduced two distinct modes of breakage, body and surface damage, and demonstrated how to incorporate them in a ball mill model by using particle bed breakage tests and DEM modelling of the energy distribution. Such studies must surely underlie the models of the future. Lichter demonstrated the use of DEM combined with practical breakage testing to successfully model the production from a cone crusher. Such advanced predictive models (no calibration is required) can provide performance information on the detailed design and operation of crushers, so carry great hope for efficient crusher design. Powell discussed the issues surrounding the extraction of relevant collision energy information from DEM simulations, as applied to breakage modelling, and how this may be applied to his unified comminution model. He noted how this understanding is forcing us to develop an improved understanding of breakage fundamentals.

Erdem presented a rigorous set of work on the influence of ball size on breakage rates. This was conducted in a 1.2m diameter dry batch mill to ensure that the energy and ball size suited the feed size. From this data a new function for
the relationship between ball size and maximum breakage rate was established. These outputs should be valuable in improved models of ball mills and in establishing ideal ball size.

Kojovic presented a new size dependent breakage model that will improve the predictive capability of comminution models that use impact breakage data, and demonstrated the effect this has on the SAG mill model. This should present a significant advance in modelling capability for dealing with large variations in feed size to devices.

Morrison presented a series of laboratory data on grinding the same ore in ball and tower mills, which will be used to test the predictive capability of DEM based mill models.

Cleary showed how advanced DEM modelling that includes particle shape, can be applied to model relatively complex and finely detailed double deck screens, and how these models may be used to analyse separation behaviour and thus refine screen design.

Models - empirical
Hinde presented a simplified model that applies to a range of comminution devices, and may be applied to multiple components. Hvan presented an independently developed SAG mill model derived by the engineering staff of the milling installations. The model separates out abrasion and impact breakage based on a critical rock size. Interestingly, this reflects the approaches of some of the well known comminution modellers, and is impressive for an independent development. Finch presented a simple modelling system that can be used to analyse the performance of ball mill – cyclone circuits, and is amenable to understanding and application by plant operators. This can highlight the low efficiency aspects of a circuit and guide in how to improve it, based solely on simple survey data. It may also be applied to multi-component ores. Lindqvist used a cumulative Bond function to model the energy usage of VSI crushers, and then demonstrated the sue of this in establishing the improved operating conditions of the crusher, to increase useful product an decrease energy usage.

Control
Powell presented Grind curves, that model the response of a SAG mill, in terms of throughput and grind size, to changes in feed type and rate as a function of mill filling. It appears that consistent generic forms of the curves can be derived that may be particularly useful for setting control objectives.

Clermont demonstrated the successful development of an on-line pulp and charge location measurement device, with the sensors integrated into a liner or bolt. This shows promise for load and pulp level control in ball mills. Farzanean presented the approach of using model based simulators to test dynamic control systems.

HPGR
An extensive section on HPGR operation and circuit design shows the industry interest in this technology. Morley gave an overview of the design and operation issues relating to integrating HPGR’s into a hard rock circuit. Van der Meer presented ideas on partial recycle of the edges, and discharging products into ball mill sumps to eliminate screening and reduce associated dust and conveying issues. Rule demonstrated the importance of comprehensive large-scale piloting of new technologies to gain acceptance for new project development, and to gain the buy-in of the future operations staff. A 1m diameter pilot HPG roll installed on site for a few months had conclusively demonstrated its successful application and remarkably low wear rate, and in the process paid for its self through increased production on the plant. The outcome was the application of an HPGR in the new circuit design, along with eager acceptance by the mine site.

Rosario presented a number of flowsheet design comparisons of HPGR with SAG mill circuits. Many applications indicated the favourable application of HPGR, but he did emphasise the issues of significant extra civils and power in conveying and dust suppression and associated impact on overall availability. Ghaffari continued the theme showing the good prospects of HPGR circuits, but noted that despite the higher capital costs the HPGR should have significantly lower operating costs, primarily due to the elimination of SAG mill media wear.

Alves demonstrated the viability of a simple scale-up model for practical HPGR selection.
**Fine grinding**

Hennart looked at the application of population balance modelling to the modelling of sub-micron breakage, and now this may improve our capability to model in this size regime.

Weber showed that there is a minimum in the correlation between specific grinding energy and stress intensity. The stress intensity is given by $\frac{a^3 \sigma}{\rho v_T^2}$, where $v_T$ is the peripheral (or maximum) particle velocity. This can be used to select the appropriate bead size and density.

Ayers described how Anglo Platinum are exploring using two-stage HPGR milling to prepare product suited to direct feed to coarse stirred milling.

Knopjes showed how the stirred media detritor is being used to double the grade of the rougher concentrate on a tailing retreatment plant.

Jones presented the concept of mainstream inert grinding using Isa mills, where the mill takes the entire process feed with an F80 of up to 150µm. He presented examples of dropping the oversize in the float feed to achieve improved recoveries of 2-7%, certainly worthwhile applications. The primary challenge lies in dealing with the costs of media wear.

Bedesi demonstrated the rigorous media testing program that Anglo Platinum has employed. Media are 60% of their fine grinding costs, which is a considerable expense with 17 10 000ℓ Isa Mills going into production, including in coarser in-line grinding. The tests include standard grindability evaluation, to quantify both the grinding performance and wear rate of the media. They have tested 40 different materials at two scales, and two are going forward to full-scale test. One surprise finding was that the beads dissolve, and so water tests are required to test this dissolution.

Farber presented a well researched set of work on advancing the understanding of ceramic media. He presented findings correlating bead properties, stiffness and surface friction to their grinding efficiency. He concluded that friction plays a dominant role in power utilisation in stirred bead mills, overriding even bead density in some applications.

Enderle considered the stress energy grinding devices from ball mill to agitated bead mills, and came up with the challenging observation that stress energy divided by particle size is in a closely similar range for optimum grinding rates a wide range of mills. This work is worth following up for media size selection purposes, and should attract input and feedback from investigators in this field.

Larson measured the response of a $4\ell$ Isa Mill over a wide range of conditions, and used this to set up an Isa Mill model that responds to feed size, feed rate, percent solids, ball size, mill filling, and input energy. He noted the strong response of the mill to the percent solids, and thus viscosity, stepping over a critical limit. This point prompted considerable discussion in the audience, and highlighted an area of interest and concern, that justifies greater airing at a gathering of this sort.

Davey discussed the use of the stirred mill detritor, with units up to 1.1Mw, and with a capability to process feed of 50% solids and to cope well with bimodal feeds arising form different sources within a circuit.

Mayer closed the conference with her presentation on classifying ultra-fine products, which is quite a challenge. The dry classifier is carefully designed to produce sharp cuts to below 2µm, which is impressive but energy consuming. Larson addressed the issue of the so-called pivot point found in stirred milling, where as the product becomes finer there is no more minus 1µm material produced. He conducted work using SEM images and mineral liberation analysis to try and locate possible finer particles, but despite careful sample preparation these were not evident, and it appeared that the finer end was depleted due to sample loss in the SEM. The problem is still to be resolved, with the outcomes likely to be of interest to the users of fine grinding.
Ultra-fine grinding

Palaniandy addressed the advantages of mechano-chemical modification of polymer fillers with limestone in a jet mill. Baláž also addressed the area of mechanochemistry through ultra fine grinding, for such useful applications as converting asbestos fibres to harmless balls and for PVC dechlorination.

Andres presented the application of vibrating mills with powers of up to 160kW in ultra fine grinding circuits.

Chumokhvalov stated that he has solved the issue of continuous feeding in planetary centrifugal grinding, with a four by 20ℓ chamber system accepting feed up to 5mm wet or dry, and producing products with a P80 of below 5µm.

Miranda looked at how steam pressure could be used to dramatically increase impact velocities in Jet mills and more than double impact energy, thereby rendering large industrial scale sub-micron milling more feasible.

Hassall demonstrated the use of 2 to 5mm ceramic beads in grinding 100 – 200µm feed down to 10µm. However, noting that cost remains a critical factor in these applications.

Energy efficiency

Pokrajcic used simulation, based on survey data, to study improvements in energy-efficiency of conventional SAG mill circuits. With the inclusion of the embodied energy required to produce the metal of grinding media and liners, she demonstrated that total energy savings of up to 40% should be feasible through the use of more energy efficient comminution equipment and that associated improved overall product classification should result in the added benefit of improved recovery. Morrison presented on techniques to measure energy usage in comminution. The comparison of circuit efficiency through relating energy use to the production of surface area, using final product size as a marker of this was shown to give more meaningful comparison than P80 data. Through modelling considerations, based on simple breakage data, it can be shown that crushers are about 70% – 80%; SAG mills 40%; and ball mills 30% efficient relative to practical breakage techniques.

Walstra discussed how to take advantage of the narrower product size distribution of fine grinding by separating recovery through flotation into separate stages for coarser and finer products.

Shi presented data on lab mill comparisons of balls mills and stirred mills when applied to the cross-over region of size production. It was shown how the efficiency signature of each device has a different slope and crosses over at a size that determines the region in which each is best applied.

Ommen showed how CFD analysis of flow regimes was used to redesign the cyclone geometry to eliminate regions of low velocity and thus increase classification efficiency, allowing a larger lower pressure cyclone to be sued for fine classification.

Van der Sanden presented a compelling case for working on the improved grinding and classification efficiency of coal grinding, especially in order to remove gangue, which often reduces the net energy capacity by over 10%. He also presented on direct milling for feed to the kilns of power generators, emphasising the need for a milling system that can be rapidly varied between 100% and 30% production. VSI’s are well suited to this, and he presented a more efficient design of the VSI that eliminates the slip regions that result in a loss of energy and result in high wear regions.

Applied

Christodulo showed how magnets can be installed into circuits to remove ball scraps, to achieve improved mill capacity and obtain associated downstream wear reduction.

Latchireddi discussed the importance of efficient pulp lifter operation in SAG mills, especially with pebble porting. Jankovic presented on the assessment of energy requirements for grinding magnetite ore, and noted how the standard testing and scale-up techniques were inadequate.

Pontt addressed the issues of upgrading gearless drive motors to increase the power available to SAG mills by up to 10%, by addressing bottlenecks in the whole power delivery chain.
Mainza demonstrated the issues of classification efficiency in closed circuit SAG mills, and showed how dramatically cyclones and screens differ in this application.

Pålsson presented a set of work that analysed the oxygen content in mills, and what milling parameters that this related to.

Brissette showed that using small balls (5-12mm) in standard ball mills (up to 12ft) used for finer grinding (sub 250µm) dramatically increases their efficiency, to be similar to stirred mills.

Oghazi demonstrated how they had used particle texture analysis combined with principle component analysis to track the grinding and deportment of two different ore types through a comminution circuit.

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