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Comminution '12

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Tuesday 17th April

08.00 Opening Remarks
B.A. Wills (MEI, UK)

08.20 *Technical Session 1*
Chairmen: A. Hinde (AH Consulting, South Africa) and D. Meadows, FLSmidth, USA

08.20 **Keynote Lecture: 2020 - what will the typical PGM Concentrator flowsheet look like?.....001**
C. Rule (Anglo American Platinum, South Africa)

The PGM industry has in the last decade adopted significant new technologies in Concentrator flow sheet design. The drivers have been a combination of a major switch to UG2 and Platreef ore mining as Merensky reef declines in importance and the need for better extractions of PGMs as plant feed grades decline and PGM recovery harder to achieve with known technology due to more complex and difficult mineralogy. Finer grinding for better liberation and a legacy of higher power densities in flotation brings into focus the impacts of progressively higher power costs. These dynamic changes are being fuelled by the PGM market dynamics - a supply/demand driven progressive rise in the basket price of metals recovered and the higher costs of mining deeper. With an enviable commitment to progressive research and development the PGM industry is willing to aggressively pursue routes to meet the goals going forward. What will the flow sheet change to in the next few years?

09.00 **Comminution design for 2020 and beyond - the GCC contribution.....N/A**
M.S. Powell (JKMRC, Australia), H. Benzer (Hacettepe University, Turkey), A.N. Mainza (University of Cape Town, South Africa), C.M. Evertsson (Chalmers Rock Processing Research, Sweden) and L.M. Tavares (Universidade Federal do Rio de Janeiro, Brazil)

This paper presents an overview of how the newly formed Global Comminution Collaborative (GCC) is addressing future design needs and challenges. The drivers and needs of the industry are evolving, so our tools and capabilities need to advance to adequately address these.

New drivers that require a considerable step change to meet the new challenges facing our industry include: Energy – The mining industry is being targeted as an excessive user of energy; Water - the limitation in production due to a shortage of availability; massive low grade ore bodies – the dropping ore grades lead to vastly increased tonnages and treatment of waste and thus processing costs; Increasing demand for natural resources – driving up the total energy and water usage within the mining sector.

The paper addresses the new knowledge needs that arise from these changing drivers; the tools that are required to supply these needs; the capability that is required to deliver on these; and what the new outputs relative to today's capabilities may be. The paper reviews where we are in addressing these needs and the route forward with international collaboration underpinning our capability to rise to this challenge.

09.20 **Early rejection of gangue - how much energy will it cost to save energy?.....021**
G. Ballantyne and M.S. Powell (JKMRC-SMI, Australia)

Comminution accounts for approximately 30 – 40% of the energy consumed on an average mine site, 4 – 9% of Australia's energy and possibly more than 50% additional energy is embodied in steel grinding consumables. Energy savings of up to 50% are theoretically possible by employing novel circuit designs and using smart separation techniques that reject coarse liberated gangue. A range of different strategies such as selective mining, screening, ore sorting, coarse flotation and dielectrophoresis can be used to reject the coarse liberated gangue at different particle sizes. These technological advances have the potential to increase the throughput in the comminution circuit, while decreasing the energy consumed per tonne or ounce of metal produced. This presentation will investigate the energy consumed through early rejection of gangue and the optimum position in the flow sheet for these technologies in terms of energy, cost and risk.

09.40 **A granular flow model for tumbling mills.....N/A**
I. Govender, M. Richter, G.B. Tupper, A.N. Mainza (University of Cape Town, South Africa) and D.J. Parker (University of Birmingham, UK)

A continuum based granular flow model of charge motion that combines the inherent frictional nature of particles with its distinctly fluid-like structure is presented. Starting with Newton's 2nd Law on a volume element of charge, we derive the velocity field in the bed free-surface and the rising *en-masse* region. Invoking flux conservation within the two regimes of interest then yields a (simple) differential equation for the free-surface of the charge body. Combining the velocity field equations with a suitable constitutive choice for the shear stress completes the picture with a description of the in-situ rate of shear power dissipation in a tumbling mill – a mechanistically correct account of power dissipation in a tumbling mill. Positron Emission Particle Tracking (PEPT) is used measure the in-situ flow fields for direct verification of the granular flow model predictions. In this regard a range of milling conditions is investigated.

10.00 **The influence of equipment settings and material properties on the fragmentation process produced by high voltage breakage.....033**
K.P. van der Wielen, R. Pascoe, F. Wall (Camborne School of Mines, UK) and A. Weh (SELFRAG AG, Switzerland)

High voltage breakage is a novel comminution method that relies on highly energetic electrical pulses to weaken or fully fragment materials. The potential of this technology to improve liberation and increase grindability of ores has been demonstrated, but the fragmentation process is still poorly defined. In the present study a total of 20 materials were treated in a SELFRAG high voltage breakage device to determine the influence of equipment parameters on fragmentation. In parallel to this research, rock mass properties and Bond work index were determined for each material to identify their relation to breakage. Results suggest a change in fragmentation behaviour from lower to higher energy levels, and that feed size is of major influence. Evidence is also presented for the importance of shockwaves during fragmentation. Bearing in mind these findings, the potential for integration of high voltage breakage into existing processing circuits will be discussed.

10.20 Coffee

11.00 **Recent international concentrator start-ups – do and don'ts for effective grinding mill design.....053**
D. Meadows (FLSmidth, USA), P. Scinto and J. Starkey (Starkey & Associates Inc., Canada)

A review of recent concentrator start-ups has been done to examine the methods that were used to design the grinding circuits for these new plants. A number of these start-ups were reported at SAG 2011. Large differences between design tonnage and actual tonnage were reported, with actual tonnage both above and below the design target by wide margins. This paper will examine these international plant start-ups, compare design tonnage Vs actual tonnage achieved and review the sampling programs, the grinding test procedures, and mill design methods that were used. From this, dos and don'ts for effective grinding mill design will be derived and discussed.

At the same conference (SAG 2011), recommended design and test selection procedures were presented. These will be compared to the findings from the case studies above to determine if the recommended design procedures need to be amended.

11.20 **Investigating the effects of ball filling through SAG-ROM ball mill pilot trials.....N/A**
U. Erol, A. Mainza (University of Cape Town, South Africa), M. van den Heever, B. Claremont (Magotteaux (Pty) Ltd, South Africa) and N. Plint (AngloAmerican Platinum, South Africa)

Run-of-Mine (Rom) ball mills are used for primary grinding applications in operations where it is difficult to get a consistent proportion of coarse competent rocks in the feed to act as grinding media. Although these mills have been in operation for some there is little information on the influence of the degree of ball filling and total charge filling on their performance. Due to the presence of high ball fillings (15-35%) compared to traditional SAG mills which use ball levels of 4-15% by volume the performance of this type of mills deviates to that of the traditional SAG mills.

Pilot plant studies were performed to investigate the effects of ball load for a range of operations which includes the transition from SAG mill to RoM ball mill. For each ball filling degree used in the experiments the total charge filling was varied to assess the performance of the mill at different operating regimes.

11.40 **Multi-component AG/SAG mill model.....N/A**
M.P. Bueno, F. Shi, T. Kojovic and M.S. Powell (JKMRC, Australia)

The JKMRC has been studying and modelling industrial AG and SAG mill for over 30 years, but the ability to simulate the effects of blending hard and soft components in mill performance is still quite limited. Therefore, a series of laboratory, pilot scale and full scale tests using multi-component feeds were conducted, under AMIRA P9O project, to quantify these effects and data for modelling.

The obtained data shows a non-linear trend between the measured mill throughput and the proportion of soft component in the feed, as well as the effect of fresh feed composition in mill product size distribution and load. Therefore a new multi-component AG/SAG mill model structure was developed to account for these observed effects, and it was validated using pilot and full scale data.

12.00 **Predicting the evolution of rock size distribution, throughput and product size using different modes of breakage in AG and SAG mills.....N/A**
R. Morrison, M. Powell (JKMRC, Australia), P.W. Cleary, S. Cummins, G. Delaney (CSIRO Mathematics and Information Services, Australia) and B. Loveday (University of KwaZulu-Natal, South Africa)

Applying DEM to prediction of tumbling mill performance is challenging because several different modes of breakage are active in the process. Here we use breakage data from a well characterised ore in a well instrumented, 1.2 m diameter pilot scale mill to validate direct DEM predictions of particle breakage, size and shape change. The key mechanisms for AG/SAG breakage in a mill of this scale are: 1) incremental breakage where non-round parent particles broken into non-round progeny based on the cumulative energy absorption above the E0 threshold for creating incremental damage, 2) abrasion, and 3) chipping/rounding. Body breakage does not occur for single impacts because the collision energies are too low to break particles. This inclusion of these breakage/mass loss mechanisms in DEM simulation allows the prediction of the evolution of the rock particle size and shape distributions and prediction of product size distribution and throughput. This paper reports the results of modelling of AG and SAG operating conditions using a combination of abrasion and incremental damage. Issues such as relating modelling inputs to particle breakage characterisation data and the accuracy of the predictions of the models will be discussed.

12.20 **Media type effect on grinding efficiency.....061**
L. Guzmán Rivera (Moly-Cop Adesur S.A., Peru)

The consumption of energy in the grinding process is significant in both the amount used and the cost involved. Both imply that it is important to maximize the throughput for a given grinding task; which in turn implies it is important to maximize mill power draw, which is related to the efficiency whereupon this power is used.

In order to optimize the process it is first necessary to know the effects of the operative parameters on the ore grindability because it is the grinding efficiency that is to be evaluated; that is to say, the efficient use of the energy from the metallurgical point of view in conventional ball grinding, recognizing that such concepts and criteria also apply to other types of applications such as SAG and vertical mills.

It was demonstrated that it is possible to optimize the grinding process by means of the correct selection of grinding media that allows maximizing the effectiveness (power draw) and the power efficiency of the process.

12.40 **Analysis and validation of a run-of-mine ore grinding mill circuit model.....072**
J.D. le Roux and I.K. Craig (University of Pretoria, South Africa)

A novel reduced complexity nonlinear phenomenological model of a run-of-mine ore grinding mill circuit, developed for control and estimation purposes, is analysed. The model makes use of a reduced number of states and parameters, and it incorporates an original measure of the pulp density within the mill. It consists of separate feeder, mill, sump and hydrocyclone modules that can be connected to model different circuit configurations. The model uses five states: rocks, solids, fines, water and steel balls. Rocks are defined as too big to be discharged from the mill, whereas solids, defined as particles small enough to leave the mill, consists of out-of specification coarse ore and in-specification fine ore fractions.

The model parameters are fitted to an existing plant's sampling campaign data. Simulation test results of the model are compared to results derived from an established population balance cumulative breakage rates model of the same plant.

13.00 Lunch

14.00 *Technical Session 2*
Chairmen: L.M. Tavares (Universidade Federal do Rio de Janeiro, Brazil) and M.H. Moys (University of the Witwatersrand, South Africa)

14.00 **Improved comminution circuit simulations using new set of equations of a hydrocyclone classifier** /
M. Narasimha (Indian Institute of Technology, India), A.N Mainza (University of Cape Town, South Africa), P Holtham, M Brennan, and M.S Powell (JKMRC, Australia)

Simulations are commonly used to design and optimize comminution circuits. Unit models are either used in spreadsheets or well organized simulators to simulate possible circuit designs or modifications to existing circuits in an attempt to achieve improved productivity. Since classification plays a key role in regulating the particles that leave the comminution circuit and in controlling the nature of the circulating loads around the comminution circuit, it is important to incorporate reliable classifier models in the simulation tools employed. An improved hydrocyclone model has been developed and incorporated in JKSimMet simulating software. Data from plant surveys performed at concentrators with different comminution circuit configurations was used to assess if the new hydrocyclone model can be used to provide improved circuit simulations. The circuit simulations indicated that the simulation results obtained using the new cyclone model matched the experimental data closely.

14.20 **The influence of a change in pulp rheology on hydrocyclone classification.....N/A**
J. Waters, A. Mainza and I. Govender (University of Cape Town, South Africa)

Many hydrocyclone models consider feed solids content as an indicator of viscosity when predicting the performance of the device. However, feed viscosity is affected by many factors, including solids content, particle size distribution, particle size, mineralogy, pulp chemistry, particle shape and carrier fluid temperature. Previous models did attempt to incorporate slurry viscosity but were developed for very low solids concentration systems due to the difficulty in viscosity measurement at higher concentrations. Current hydrocyclone models being applied in industry have difficulty in predicting rheological fluctuations at constant solids content.

Experiments were performed on three hydrocyclone sizes (75,100, 165mm) using two ore types. A change in rheology was investigated by altering the viscosity of the carrier fluid (water) by the addition of sucrose and modification of the slurry temperature. A custom made on-line tube rheometer allowed viscosities of feed concentrations of up to 43% (by vol.) to be measured over a range of shear rates ($200s^{-1}$ to $1500s^{-1}$). Both ore types appeared to exhibit Bingham plastic behaviour. Rheological characterisation of the slurry was then linked to hydrocyclone performance.

14.40 **Improving grinding performance with high efficiency classification**
J. Roettle (ECUTEC Barcelona S.L., Spain)

A classifier is the unit that extracts particles with desired fineness and rejects bigger particles for further grinding.

There is the key for improving grinding performance and save energy. The better the classification the less good product is sent back to the mill wasting energy which should be used for grinding fresh feed. Latest classifying technology and sophisticated process know how can lead to 40% efficiency increase.

With two examples of Ball Mill – Turbo Classifier – Systems we will see what improvements can be achieved.

At a $CaCO_3$ plant a substitution of an existing classifier resulted in:

- Reduction of classification energy by 20%
- Ball Mill [A] smooth and reduced by 10%
- Constant product quality

At a Calcined Bauxite plant a clever two stage classification process resulted in:

- Production increase of 40% (compared to existing system)
- Less wear at classifiers

15.00 **Interactions in a multi-component hydrocyclone feed – the effect of operating conditions.....N/A**
A.R. Collins, P.N. Holtham and T.Kojovic (JKMRC, Australia)

Classification models described in the literature fail to take into account the range of particle densities present in a realistic hydrocyclone feed; a critical factor which is known to affect the cut-point and overall partition curve. Ideally, the models should predict the partition curves for each significant density class in the feed, given the cyclone geometry and operating conditions. A model should also take into consideration that components of different densities within a feed are unlikely to be independent of each other, and that the degree of interaction may vary due to cyclone operating conditions.

This paper investigates how changing feed percent solids affects the interaction between components of differing densities within the feed. The paper also discusses the implications of this effect and possible theories to explain the behaviour.

15.20 **Using the three product cyclone to improve the operations of the comminution circuit – a pilot plant study.....N/A**
A.N Mainza (University of Cape Town, South Africa) and M.S. Powell (JKMRC, Australia)

High circulating loads and poor energy utilization are expected from when hydrocyclones are used as classifiers in the comminution circuits for plants treating ores containing different density components. Pilot trials were performed to assess the effect of replacing the conventional hydrocyclone with the three product cyclone operated in conjunction with fine screens on circuit performance. The results from the testwork showed reduced circulating loads for the comminution circuit operated with the three product cyclone in conjunction with fine screens compared to the circuit containing the conventional hydrocyclone. The specific energy required to produce sub 75 microns product was lower for the circuit utilizing the three product cyclone when compared with the circuit containing the conventional hydrocyclone. Mineralogical studies were also performed to assess if there were significant differences in the liberation characteristics between the final products from the two circuit configurations.

15.40 Coffee

16.10 **Development of a dynamic simulator for modelling complex flows in mineral processing circuits.....N/A**
H. King, M. Daniel, R. Chandramohan and G. Lane (Ausenco, Australia)

In mineral processing, simulators are used to optimize and understand the complexities of flow in various processing devices. Currently, there are a number of steady-state simulators available in the market that aim to reproduce the conditions of the mineral processing plant operations. Steady-state simulators, provide an instant snap-shot of operations. One of the limitations of using steady simulators is that, not knowing the design implications on bulk handling systems for varying ore conditions.

The paper presents a working concept of a dynamic simulator that incorporates discrete event modelling and Ausenco comminution models. The discrete event modelling provides a link between the processing equipments and bulk handling systems. The simulator aims to model the variability of ore strength and conditions and design implications on bulk handling systems. The shows the response of the circuit to variability of ore characteristics, feed size on bulk handling and storage systems, and plant operating conditions.

16.30 **Tuning of real-time algorithm for crushing plants using a dynamic crushing plant simulator.....107**
E. Hulthén, G. Asbjörnsson and M. Evertsson (Chalmers University of Technology, Sweden)

Real-time algorithms have earlier been successfully implemented in crushing plants for the selection of set-points. The algorithms build on principle models of how the on-line adjustable parameters affect the process. The dynamics in a crushing plant are usually consequences of altered states of the plant due to factors such as natural variation of the processed material, degrading equipment performance and more or less stochastic discrete events. Although the real-time algorithms are carefully designed in order to optimize the process, they are not fine-tuned themselves.

In this paper a method for tuning real-time algorithms using a dynamic crushing plant simulator is presented. With the plant realistically modeled in a simulator the constants of the real-time algorithm can be selected before the algorithm is implemented in a real plant. Thus the algorithm can optimize the plant better and quicker. The method is demonstrated on a real case.

16.50 **Dynamic modeling and simulation of cone crushing circuits.....114**
P. Itävuo, M. Vilkko (Tampere University of Technology, Finland), A. Jaatinen (Metso Automation, Finland) and T. Onnela (Metso Minerals, Finland)

As a common practice in the industry, static models are used for steady-state simulations and process dimensioning of crushing circuits. However, they do not provide tools for compensation of disturbances, and thus the intended circuit performance is rarely achieved. This gap between theoretical and effective performance, sometimes up to 30%, holds development potential for real-time control.
Currently existing control applications are heavily biased towards heuristic and non-analytic approaches due to the lack of dynamic process models. This is one of the main reasons why advance in real-time crushing process control and optimization is slow; it is difficult to design control schemes unless simulation is possible.

This paper presents an effective way to produce dynamic process models out of existing steady-state models. The resulting simulator makes it possible to develop control methods that fully utilize the capacity potential of crushers and facilitates the efforts for energy-efficient operation of crushing circuits.

17.10 **Modelling and simulation of dynamic crushing plant behaviour.....133**
G. Asbjörnsson, E. Hulthén and M. Evertsson (Chalmers University of Technology, Sweden)

Traditional process plant simulations are performed with steady-state simulation, which are limited to give the performance in an ideal situation. However, plant performance usually tends to deviate away from the predicted plant performance. These dynamics are usually consequences of an altered state of the plant due to factors such as natural variation of the processed material, unmatched, inappropriate or degrading equipment performance and stochastic events.

This paper presents a novel approach for simulating plant behavior and evaluating effects from process modification through dynamic simulations. Simulations revealed that the overall plant performance can saturate at a certain level before reaching the predicted output. Above this level the overall capacity does not increase with increased feed rate. The results and knowledge gained from the simulation can provide a base for optimizing a robust production with respect to utilization, energy efficiency or high product quality.

Wednesday 18th April

08.20 *Technical Session 3*
Chairmen: A. Weh (SELFRAG AG, Switzerland) and S. Martins (McGill University, Canada)

08.20 **Keynote Lecture: Step change in the context of comminution.....144**
R. Bearman (Bear Rock Solutions Pty Ltd, Australia)

Much has been written about innovation and the need for “game-changing” step change. There is no doubt that there are many challenges facing the mining and minerals industry and hence it is appropriate that the industry examines the level of response required. “Step Change” should not be regarded as a tightly defined, prescriptive descriptor, rather the industry needs to consider what it should mean in the context of the industry.

In terms of comminution, the area bears much of the burden for the use of energy in the mining-processing system. Given this specific issue it is reasonable to consider that step change should be targeted at the reduction of the energy input per unit of metal produced. It is important to consider energy in terms of the final output as without this effort could be misdirected.

To ensure the maximum effectiveness of innovation in this field, comminution must be regarded as a component of the wider system that encompasses the size reduction from the in-situ rock mass to a saleable product. In regard to the total system, some of the key considerations are philosophical, not technological. Such points include the need to simplify circuits, increase flexibility, examine the impact of variability and consider the end-game.

In essence the total system is not about breaking rocks to a size, it is about breaking only what requires size reduction, to the point at which a saleable product can be generated. With this in mind the context for step change is set and this forms the basis for the discussion.

09.00 **Closed circuit ball mill –basics revisited**
A. Jankovic and W. Valery (Metso Process Technology and Innovation, Australia)

Since the early days, there has been a general consensus within the industry and amongst grinding professionals that classification efficiency and circulating load both have a major effect on the efficiency of closed circuit ball mill. However, the effect of each is difficult to quantify in practice as these two parameters are usually interrelated. Based on experience acquired over the years and the investigative work conducted by F.C. Bond, it was established that the optimum circulating load for a closed ball mill – cyclone circuit is around 250%. This vvalue is used as guideline for the design of new circuits as well as to assess the performance of existing circuits.
The role of classification in milling appears to have been neglected in the current efforts to reduce the energy consumption of grinding. Two past approaches, one experimental and one modelling, to quantify the individual effects of classification efficiency and circulating load on the capacity of closed ball mill circuit are revisited and discussed in this paper. Application to the optimisation of existing circuits and design of new circuits is also discussed, with special attention to the development of more energy efficient circuits.

09.20 **A dynamic Ergun equation for slurry transport in tumbling mills.....N/A**
G.B. Tupper, I. Govender and A.N. Mainza (University of Cape Town, South Africa)

Ultimately the resolution of the slurry transport issue hinges upon the question: what replaces the static-bed Ergun equation in the dynamic mill environment? Here we extended, to non-vanishing Reynolds number, the modelling approach to slurry transport in dynamic beds, based upon combining space- and time-averaged Navier-Stokes equations with a cell-averaged model for the permeability. Solutions of the resulting dynamic Ergun equation are exhibited for a simple charge-motion mode, which serves as the prototype for a slurry transport equation.

09.40 **Investigation of particles with high crack density produced by high pressure grinding rolls (HPGR) and its effect on percolation of heap leaching in the long term operation process.....N/A**
Y. Ghorbani, A.N. Mainza, J.Petersen, M. Becker, J-P. Franzidis (University of Cape Town, South Africa) and J.T. Kalala (Mintek, South Africa)

Extraction of metallic values by the heap leach process, can take place on the articles with partial exposure of mineral grains, if it can provide sufficient surface front for chemical attack by leaching solution. The application of comminution technology such as the High pressure grinding rolls (HPGR) which is able to generate a high density of cracks in the ore particles is favourable for leaching processes. The aim of this study was to assess the limiting size below which benefits of high crack density from the HPGR diminish due to inadequate percolation of the leaching agent.

A bulk sample of the zinc ore was crushed by the HPGR at three different pressure settings (45, 95 and 120 bar); the ore crushed with a Cone crusher a control experiment. Subsamples from the ((-25 +19), (-16+9.5), (-5+4.75) mm) size fractions were characterized and packed into leach reactors. The reactors were stopped from time to time to investigate the progress of crack and micro-crack growth and its effect on metal extraction, using the X-ray computed tomography (CT), SEM and QEMSCAN. Investigation of the leach reactors residue indicated significant changes in the particle size distribution (PSD) of initial feed toward the fine size fraction. This trend were up to 15% more in the residue of tests performed using the ore particles produced by HPGR compare to ore particles prepared using the Cone crusher. The fine particles generation during the process could have a negative effect on

percolation especially over long time periods of heap leaching operation. Results of experiments also indicated that the (-16+4.75) mm is the limiting size fraction for heap leaching.

10.00 **Determination of UG2 particle parameters to optimizing product size distribution for flotation purposes.....173**
N. Chimwani, D. Glasser, D. Hilderbrandt and M.J. Metzger (University of Witwatersrand, South Africa)

It is the aim of most industrial comminution processes to operate under optimal design configuration so as to achieve the maximum profit (highest mineral recovery and lowest operational costs). The desired particle size is determined by the downstream processes, in our case flotation, since particles that are too course or too fine cause complications during floatation. Presented here is the use of the population balance model framework to determine the selection and breakage function parameters for three mono size classes feeds (850 – 600µm), (600 -425µm) and (425 - 300µm) using three different ball sizes (10, 20 and 30mm) of a UG2 platinum ore. This information was then used to obtain the product size distribution (PSD) for a given set of operational parameters. Such a framework enables one to determine the grinding conditions for optimal flotation using both the population balance model and the attainable region (AR) analysis.

10.20 Coffee

11.10 **A new approach for evaluating the performance of industrial regrinding mills based on grindability and floatability.....184**
D. Hamed, S. Abbas (Bahonar University of Kerman, Iran), P. Parviz (Sahand University of Technology, Iran) and B. Asghar (NICICO, Iran)

The aim of locating the regrind mills in mineral processing circuit is liberating of locked particles. To evaluate the regrind mill performance, different methods were proposed and used to evaluate the efficiency of the regrinding mills, but none of them is working properly. This paper presents a new approach to determine the performance of regrinding mills based on the grindability and floatability of locked particles in copper sulfide minerals. The approach combines the grindability factor, in which only the grinding of coarse particles are considered, with the floatability of the regrind feed and product. The approach was examined in Sungun industrial regrind mill and it was found that the performance of the regrind mill is extremely low and some practical ways and means are suggested to operate the regrind mill efficiently.

11.30 **Industrial application of the attainable region analysis to a joint milling and leaching process.....193**
N. Hlabangana, D. Vetter, M.J. Metzger, D. Glasser and D. Hildebrandt (University of the Witwatersrand, South Africa)

Size reduction is an integral and expensive) part of almost all mining processes especially for the down -stream leaching process. Therefore, significant energy and cost savings exist even with slightest increase in milling efficiency to a certain degree of liberation. In this work, the attainable region (AR) is used to explore the effect of grinding media fill level, grinding media size and grinding time on the resulting size distribution. The resulting particle sizes are then leached to determine the optimal size for maximum gold recovery as a function of operation time (grinding and leaching), energy consumption and other operational variables. Preliminary leaching results show that the majority of gold is found in the smaller size classes (-150 microns) and the difference in grade between -150+75microns and -75+25microns is small, suggesting that a size of -150 microns is an adequate cut-off for milling, rather than the -75microns currently employed.

11.50 **Real-time grind control enabled by diffuse reflective spectroscopy.....201**
C. Steyn, W. Breytenbach (Anglo American Platinum, South Africa) and K. Keet (Blue Cube Systems, (Pty) Ltd, South Africa)

Grind together with feed flow specifications and changes to ore contributes to the performance of flotation. The grind is a function of the complex comminution process which typically includes a tumbling mill and classification unit in closed circuit. Model predictive control has been widely implemented on mineral concentrators but the availability of reliable grind sensors are limited. This study investigates the use of diffuse reflective spectroscopy to distinguish between size fractions % -75 µm, % 75 – 150 µm and % +150 µm in real-time. If successful, the technology can be used in closed loop control around comminution circuits and would in turn contribute to the efficient recovery of minerals on beneficiary operations.

12.10 **Multi-component modelling of a clinker grinding circuit.....216**
D. Altun, H. Benzer and N.K Aydoğan (Hacettepe University, Turkey)

Portland composite cements containing limestone have many benefits economically, technically and environmentally. Increasing limestone content of the cement leads to reduction in energy consumption and green house gas emissions. In addition to benefits, its effects on equipment-circuit performance and cement quality should be take into consideration.

Based on this, aim of this study is to compare effects of limestone with different chemical content and amount (7.5-11%) on cement grinding circuit performance. With this aim, three sampling studies were carried out at the cement grinding circuit. Samples collected from around the circuit were screened by alpine and separated into definite size fractions. For each size fraction, limestone and gypsum content was determined. Thus size distributions of clinker, limestone and gypsum was calculated and used in mass balance studies. As a result of the multi component mass balance studies, behaviour of each component such as clinker, limestone and gypsum were investigated separately. Breakage rates of each component were calculated by modelling of the circuit. Cement strength for each sampling condition was measured and cement quality was associated with limestone addition to the circuit.

12.30 **Prediction of solids flow and energy transfer in vertical shaft impact crushers using DEM.....N/A**
E.R. da Cunha, R.M. de Carvalho, L.M. Tavares (Universidade Federal do Rio de Janeiro, Brazil)

In spite of its relative operational simplicity and the earlier attempts already made to model its performance, the Vertical Shaft Impact crusher (VSI) is still lacking a comprehensive mathematical description that allows predicting the performance of this machine accurately. One of the reasons for that is the limited knowledge of particle interaction and solids flow within the machine. The paper deals with the application of the Discrete Element Method (DEM) in the prediction of solids flow within pilot and full-scale machines for a range of operating conditions, including solids feed rate and rotor speed. A large amount of data has been generated in these simulations, which has been used to calculate the residence time distribution of particles in the machine, as well as the collision energy spectra. These data, along with the mechanistic model framework of particle breakage developed at the authors' laboratory, will form the basis of fully-predictive crushing models of these machines in the future.

12.50 Lunch

14.00 *Technical Session 4*
Chairmen: E. Hulthén (Chalmers University of Technology, Sweden) and P. Cleary (CSIRO, Australia)

14.00 **Recent installations and developments of Loesche Vertical - Roller - Mills in the ore industry.....230**
C. Gerold (Loesche GmbH, Germany)

The paper is giving an overview about successful operating Loesche Vertical – Roller – Mills (VRM) installations and summarises the main benefits of the dry compressive Loesche grinding technologies in Air-swept and Overflow Mode. Some of these benefits are optimised energy efficiency of the grinding - classifying - circuits, increased mineral recoveries and decreased OPEX costs, at a parallel simplification of the process route. Within this paper the process values of the Loesche VRM are compared to existing or planned conventional grinding – classifying circuits. Further remarkable advantages discovered in pilot trials and examples for new more efficient process route alternatives are given. The paper reports about production and pilot trial experiences obtained by crushing and grinding Iron Ore, Iron Ore Concentrates, Zinc Ore, Copper Shale, Titanium Slag, Tin Slag, Copper Slag, Steel and Stainless Steel Slags and Copper Matte with Loesche VRM.

14.20 **The crushing and air classification processes in the production of manufactured sand for concrete.....252**
R. Johansson and M. Evertsson (Chalmers University of Technology, Sweden)

In several regions the supply of natural sand is scarce and the concrete industry investigates manufactured sand as a replacement. Producing manufactured sand requires an understanding of the influence from the manufacturing process on the produced sand. This paper presents how to employ existing crushing and classification techniques to produce good quality manufactured sand.

Obtaining a good particle shape is possible using energy based crushing, as found in vertical shaft impact crushers (VSI). The particle shape improves as the particle undergoes both size reduction and shaping attrition. A good particle shape for the whole particle size range can be achieved with a high VSI rotor velocity. This will, however, increase the amount of fines, i.e. particles below 63 µm, which is undesirable for the concrete production. Employing gravitational or centrifugal air classifiers can reduce the amount of fines from 15-25% to levels acceptable for the concrete industry.

14.40 **A model that simulates pulverised fuel production in an air-swept tube mill.....263**
M.M. Bwalya and M.H. Moys (University of the Witwatersrand, South Africa)

The grinding process of an Air-swept tube mill can be modelled adequately using the selection and breakage functions. However to model Pulverised Fuel (PF) production, all the other sub-processes that include; release of the ground product from the ball charge, internal air-classification within the mill and classification of an installed external classifier must be considered. Inefficiency in any one of these process steps can negate the overall mill capacity with little compensation from the other processes.

Using industrial data from Kendal power station and data from a scaled down pilot mill at the University of Witwatersrand, a system of sub-process models have been defined and a simulator developed. We were able to impose the controls in practice on the simulator and were able to predict mill performance over the entire liner life. The model details and some of the results of industrial modelling are discussed.

15.00 **Design exercise of an HPGR.....274**
H. Dundar, H. Benzer and N. Aydoğan (Hacettepe University, Turkey)

It is well known that the HPGRs can only be operated efficiently under choke feeding conditions in which a material bed is built up between the rollers to ensure inter-particle breakage. Increasing the amount of fines in the feed promotes the formation of a uniform bed within the HPGR which leads to high compression efficiencies in the device. A well structured test program was designed to assess the effect of fine recycle on the overall performance of the HPGR. The performance was analysed in terms of energy consumed to produce designated size classes in the product stream. The experiments were carried out using a 1m roll diameter Koppern HPGR based at Mintek in South Africa. The ore used for this work is a low grade Zinc ore. The results appear to indicate that the product size distribution vary with different proportions of fines in the feed. This paper discusses the results from the tests performed to assess the influence of the fines proportion in the feed on the performance of the HPGR. Other variables included in the testwork were different top sizes and pressure settings

15.20 Coffee

15.50 **The effect of feed moisture on the comminution efficiency of HPGR circuits.....281**
D. Saramak (AGH University of Science & Technology, Poland) and R.A. Kleiv (Norwegian University of Science & Technology, Norway)

The comminution efficiency of high-pressure-grinding-rolls (HPGR) is a well described function of a number of feed parameters including grindability, abrasion index, granulometric composition, top size and particle size distribution. Far less studied is the effect of feed moisture. This paper investigates both the overall and the specific communition efficiency of a circuit consisting of a pilot HPGR unit followed by a batch ball mill as a function of the moisture level in the HPGR feed. Forsterite olivine sand (-7 mm) supplied by Sibelco Nordic was used as feed material. The results showed that relationship between moisture and crushing efficiency both for HPGR and the circuit can be well described by means of parabolic function. Dry material, as well as the one with the highest moisture content showed lowest particle size reduction ratios regardless the operating pressure value. The suitable comminution models were determined for the press and circuit.

16.10 **Benefits of the HPGR replacing conventional grinding in mineral applications.....293**
S. Oenol and F.P. Van der Meer (Humboldt Wedag GmbH, Germany)

High Pressure Grinding Rolls (HPGR) has become standard grinding equipment for minerals industry in many comminution applications as a state of the art energy efficient grinding technology. It is considered as a proven technology for almost every grinding circuits either instead of conventional grinding or prior to the conventional grinding to provide better energy efficiency.

This paper summarizes the experiences of HPGR grinding in various mineral processing operations with its operating limits and demonstrates a case study to optimize an existing grinding process by installing HPGR as a replacement of conventional grinding in a mineral application.

Financial benefits of the HPGR with its energy efficient technology and state of the art stud lining technology are also discussed by comparing CAPEX and OPEX of HPGR and conventional grinding in a coarse grinding process.

16.30 **HPGR technologies in the processing plants of Russia and Kazakhstan.....306**
A. Senchenko, Institute TOMS, Russia) and A. Romanchenko (TOMS-Engineering, Russia)

High Pressure Grinding Rolls – is very prospective equipment that is spreading all over the world (operating plants, projects). There are different circuits and technological solutions that are not always optimal for different ores or equipment operating conditions.

The paper considers examples of different TOMS projects, including the information about operating plants on the territory of Russia and Kazakhstan (Au and Cu ores, plants' throughput from 1 to 8 mln. tpa). Many circuits with HPGR are considered. Positive and negative experience of HPGR usage is considered, the influence of different factors on the process was analyzed. The examples of HGPR circuits design and optimization, their advantages and disadvantages as well as the successful implementation of technologies on the HGPR basis are presented in the paper.

Thursday 19th April

08.20 *Technical Session 5*
Chairmen: C. Philippe (Magotteaux International SA, Belgium) and S. Palaniandy (JKMRC, Australia)

08.20 **IsaMill- 1:1 direct scaleup from ultrafine to coarse grinding.....320**
M. Larson, G. Anderson, K. Barns and V. Villadolid (Xstrata Technology, Australia)

The IsaMill has been used commercially in concentrator plants for over 15 years. Improvements in ceramic grinding media, mill design and wear components have advanced the IsaMill to the point where it can readily accept F_{80}'s of +300 microns. One thing that has not changed since the early days of development is the robust 1:1 scaleup of the mill from the laboratory to the mine site. This paper examines Xstrata Technology's efforts to both improve the grinding capability of the IsaMill and the work that has gone into ensuring the accuracy and precision of independent laboratories across the world that perform IsaMill signature plot scaleup work. Common issues encountered in design testwork are discussed in an effort to promote proper scaleup among all suppliers.

08.40 **Characterising grinding media motion inside an M4 IsaMill™ using PEPT.....332**
A.P. van der Westhuizen, I. Govender, A.N. Mainza (University of Cape Town, South Africa), H. de Waal (Xstrata Technology, South Africa) and K. Barns (Xstrata Technology, Australia)

Finer grinding is increasingly needed in the minerals industry in order to liberate finely disseminated mineral species and in the minerals industry, stirred milling is continually gaining acceptance as the most energy efficient means of achieving such a fine grind. The IsaMill™ is a high intensity stirred mill with a horizontal configuration and internal classification. This work describes the application of Positron Emission Particle Tracking (PEPT) to trace the motion of a grinding media bead in a M4 IsaMill™ for the very first time. The PEPT system has the advantage of being able to obtain detailed charge motion measurements in opaque and aggressive environments such as those encountered in grinding processes. In this paper, the interaction of the operating conditions, mill speed and feed rate is investigated on in-situ grinding media features such as packing density, velocity, shear, and acceleration through the use of the PEPT technology.

09.00 **Effect of operating parameters on dry stirred milling efficiency.....347**
O. Altun, H. Benzer (Hacettepe University, Turkey) and U. Enderle (NETZSCH-Feinmahltechnik GmbH, Germany)

High intensity stirred milling is an industry accepted method to efficiently grind fine and coarse particles. Later in 1990's horizontal stirred mills were developed in order to achieve sufficient liberation. Development of IsaMill technology was driven by the metallurgical requirements of

Lead/Zinc deposits at Mount Isa in Queensland and McArthur River in the Northern Territory, both of which were controlled by Mount Isa Mines Limited. IsaMill developed for fine milliing is now being included in coarser applications also.

Successful operation of IsaMill in wet applications encouraged the studies in dry applications. Dry fine grinding also has wide range of operation which requires energy efficiency.

In this study the idea is to use dry horizontal stirred mill in order to evaluate the efficiency and benefits of the operation. Therefore a prototype of 42lt mill was developed by NETZSCH--Feinmahltechnik Gmbh and grinding tests were performed by Hacettepe University Comminution Group. Cement industry was chosen as a partner where dry fine grinding is required in order to improve cement quality. In this study the first aim was to conduct several tests and to observe if any mechanical problem was encountered. As a result of the studies effect of operating parameters such as ball loading, ball size, stirrer speed, feed rate etc. on grinding in terms of size reduction and energy consumption were investigated. The results indicated that the operational parameters have big impact on the performance of the equipment therefore each application has to be optimized for the specified operational parameters.

09.20 **Grinding to nano-sizes: effect of media size and slurry viscosity.....371**
M.H. Moys (University of the Witwatersrand, South Africa) and Pradip (Tata Research Development and Design Centre, India)

The growing trend towards ultrafine milling makes it worthwhile to study the effect of key variables on this process. The concept of the "grinding zone" is defined and analysed. It is found that (volume of grinding zone)/(volume of voids between media) is proportional to $[(\text{particle size})/(\text{media size})]^2$. The interaction between media travelling towards each other is analysed and the pressure developed between media is shown to be very high. The pressure acts on a small area of the media surface, so only affects media behaviour significantly when slurry viscosity is high. The analysis provides a basis for the development of a DEM contact model for interaction between media in a viscous slurry.

09.40 **Prediction of energy effective grinding conditions.....384**
S. Breitung-Faes (Institute for Particle Technology, Germany)

Grinding processes in general are extremely energy intensive. To optimize the energy consumption the choice of the process parameters are important. The decision on the process parameters often depends on experiences or a certain number of experiments before starting a process.

Here a model will be shown which enables the prediction of optimal process parameters for ceramic materials in wet stirred media milling. The model was build up on the knowledge regarding the model of stress energy. The optimal stress intensity (optimal stress energy related to single particle mass) is correlated with the compression strength, due to the assumption that this type of stress is dominant in stirred media mills. This term describing the strength of the particles is correlated with a term describing the size, whereas the grinding limit has to be taken into account. This model enables the prediction of grinding media size and stirrer tip speed for certain desired particle finesse, if material parameters like Young´s moduli and density of product and grinding media as well as the compressive strength are known. Beside that multi-step processes can be designed, e.g. if the optimal parameters for the end product are not suitable for the feed material.

10.00 **Energy efficient drying, grinding and classification of minerals and ceramics below 1 µm.....400**
U. Enderle (NETZSCH-Feinmahltechnik GmbH, Germany)

The use of superheated steam in jet mills can minimize the energy requirement dramatically by combining the drying, grinding and classification in one process step.

Especially for products with particle sizing $d\ 50 < 1\ \mu m$ the required energy consumption is reduced, the classification is improved and a separate spray drying process before grinding can be eliminated.
Based on the thermodynamics of superheated steam and its physical properties the benefits for grinding and classification are explained. The limitations where the excessive energy can be used for drying wet or dispersed products are shown.

Test results gained by the new process for products e.g. talc, graphite and ceramic pigments prove the advantage of the new process.

10.20 Coffee

11.00 **Validation of product size distributions predicted using DEM for a cone crusher.....N/A**
P.W. Cleary, G. Delaney (CSIRO Mathematics, Informatics and Statistics) and R.D. Morrison (JKMRC, Australia)

Predictions of particle flow and compression breakage of non-round rock passing through a laboratory scale cone crusher are compared against experimental data. Particles can fracture due to either single high compression events or due to accumulation of damage from sequences of lower intensity events. Damage is generated only when particles are compressed above their elastic threshold. This DEM model is able to predict the production of both coarser progeny which are resolved in the DEM model and finer progeny which are not. This allows the prediction of product down to small sizes, limited only by the fineness of the fragments measured in the breakage characterisation (typically JKDWT or JKRBT). The predicted product size distribution and throughput are compared to experiment for a range of conditions. Finally, predictions of power draw and liner wear are discussed.

11.20 **Simulating pressure distribution in HPGR using the discrete element method.....410**
J. Quist and M. Evertsson (Chalmers University of Technology, Sweden)

It has previously been shown that the compressive breakage principle utilized in a HPGR is a highly energy efficient way of reducing the size of rock material. However, there are a number of operational issues known related to the HPGRs. Due to the high forces and local pressures acting upon the roller surface the wear rate is commonly severe contributing to a substantial part of the operational cost.

In this paper the rock breakage and roller pressure distribution are investigated using the discrete element method (DEM). Rock breakage is modeled using the bonded particle model (BPM) approach. The BPM model has been calibrated using single rock particle compression tests. The complex free floating dynamics of the HPGR operation have been modeled by coupling DEM with multibody dynamics analysis software. Results shows that DEM can be used for modeling and simulating HPGR machines giving novel information regarding wear, particle breakage and flow characteristics.

11.40 **Tactical mill management using next generation DEM tools.....424**
G. Naidoo (Optsys Engineering, South Africa)

DEM and related simulation techniques have shown real promise over the last few decades. Invariably computing power has lagged the innovative thinking of comminution practitioners – until now. Recent advances in information technology not only enable simulation of realistic comminution behavior, but also have the potential of putting DEM tools within reach of a much wider group of comminution stakeholders irrespective of computer literacy levels. Next generation DEM promises to bridge the gap between strategic thinkers and practical operators, providing a common platform where comminution management tactics can be agreed upon.

This paper serves to demonstrate successful DEM modeling of coupled liquid-solid mill simulations, allowing easy manipulation of key variables like mill speed, lifter design, liquid viscosity, optimum size distribution of media and mill filling. Current technology enables realistic liquid-solid models providing quick answers that can be practically applied in managing the mill operation. One of the most important uses of these multi-phase models is to facilitate training and buy-in from operations staff into tactical changes suggested by the optimization team as well as incorporating practical know-how from the operations team into the models.

This paper concludes by sketching out the future of DEM tools in simulating a continuous minerals processing plant operation involving multi-phase materials including chemical interactions.

12.00 **Simulation of the breakage of bonded agglomerates in a ball mill.....431**
M.J. Metzger and B.J. Glasser (The State University of New Jersey, USA)

Size reduction is an essential operation across many industries. Despite its prevalence, the efficiency of the conversion of applied force to the creation of new surfaces is extremely poor, none worse than the commonly encountered ball mill. However, tuning of operational parameters may be a means to increase the low efficiency levels, if the proper connection between operating conditions and breakage conditions can be determined. Described here is the implementation of the Bonded Particle Model (BPM) within the Discrete Element Method (DEM) framework to analyze the breakage of bonded agglomerates within a batch ball mill. It is found that agglomerate strength and grinding media diameter affect breakage significantly; whereas grinding media fill level has a minor affect. The majority of breakage occurs near the mill shell, rather than at the point of impact between the media and material and the extent of material breakage has a significant influence on the material flow within the mill.

12.20 **Influence of operating and design variables in batch milling using the mechanistic model of the ball mill** /
R.M. de Carvalho, L.M. Tavares (Universidade Federal do Rio de Janeiro, Brazil)

Batch grinding has been a very good tool to understand the effect of design and operating variables in ball milling, as well as in providing data in a couple of methods used for scale-up of these mills. Recently, a mechanistic mathematical model of the ball mill has been proposed, and the present paper describes its application in the simulation of a batch mill operating over a range of operating conditions. Breakage rates have been estimated using this model and these are compared, qualitatively, with those estimated using Austin-Klimpel-Luckie´s and Herbst-Fuerstenau´s methods of scaling-up of ball mills.

12.40 **Effect of slurry density on load dynamic and milling performances in an iron ore ball mill - on-line estimation of in-mill slurry density.....442**
B. de Haas, A. Van den Bosch (Magotteaux, Belgium) and A. Köttgen (University of Liège, Belgium)

In ball milling, the transmission of grinding energy from the steel balls to the particles in the slurry is closely linked to the way the media and the slurry are mixed. One of the key parameters that influence this mixing is related to the pulp rheological properties, and more precisely its viscosity. As the slurry viscosity is difficult to measure on regular basis in concentrator operations, the pulp density is often assessed instead as a convenient substitute.

For the current work, extensive surveys have been performed on an industrial overflow ball mill, processing iron ore. The slurry density was set to different values by adapting the water addition flow at the mill inlet. The mill is equipped with a Sensomag which provides information about the ball load and pulp volume, values and positions. For each density tested, mill discharge slurry samples were taken and assessed for density and Blaine. The load position and mill absorbed power were recorded by the Sensomag. The ball level was kept constant throughout the surveys with the help of a Magoload.

The main outcomes of the work that has been performed are: the highlight of an optimal pulp density leading to optimal mill performances, the quantification of the slurry density effect on the mill load position, and the elaboration and validation of a density model able to estimate the in-mill density while the mill is operation.

Most of the results presented in the article are corresponding to what has been found previously in platinum ore milling.

13.00 Lunch

14.00 *Technical Session 6*
Chairmen: D. Way (JKTech, Australia) and G. Dean (Keramos, Australia)

14.00 **Do's and don'ts of measuring ceramic beads wear in the lab and in the industry.....451**
B. Clermont and C. Philippe (Magotteaux International SA, Belgium)

Fine grinding using stirred mills and ceramic beads is quite new to the mining industry. There isn't much shared knowledge available to help metallurgists decide which bead is best for their application.

Magotteaux has conducted extensive beads wear test in their M20 IsaMill®lab using ores from various mine sites

- The paper is aimed at sharing the acquired knowledge for the benefit of the industry as a whole.
- Best practice for lab scale beads wear trials will be discussed.
- Do's and don'ts of lab scale testing will be explained through practical examples.
- The paper will show how adequate lab-scale testing scales-up to industrial results.
- Hints on how to measure beads wear in the industry on a daily basis will be given.
- The various ways of conducting a wear test to benchmark different beads at industrial scale will be explained and compared.

14.20 **Fine grind attritional mills: can they or should they go coarser?.....470**
D. Capstick and B. Currie (FLSmidth Knelson, Canada)

Since the introduction of fine grind attritional mills a number of years ago they have predominately been used on ultra fine and fine grind milling activities. The technology has been successfully applied extensively on regrind circuits, tailings and dump retreatment operations.

Recently more interest has been shown on moving this technology further up the milling circuit to operate as a tertiary and secondary milling application downstream from the traditional ball mills. The move towards manufacturing much larger stirred mill has enabled the technology to be considered for run of mine processing. Is this a threat to traditional tumbling ball mills? Or can it been seen as complimentary?

This paper investigates the experience of using the Deswik mills in coarse feed applications The costs benefits in terms of OPEX, and the implications of using what was thought to be a ultra and fine grind technology in a different milling environment.

14.40 **Introducing a novel new ultrafine grinding mill with an evaluation of its grinding efficiency compared to a horizontal and vertical mill.....N/A**
M. Varley, R. Pullin, A. Griffiths (Cardiff University, UK), D. Young, M. Battersby, S. Flatman and R. Imhof (Maelgwyn Mineral Services Ltd, UK)

Improved efficiency in ultrafine grinding is becoming increasingly important as global energy prices rise and the commercial requirement to liberate minerals at even finer sizes becomes more common. This paper introduces a new type of ultrafine grinding mill that incorporates a twin drive mechanism that offers potential savings and compares the effectiveness of its primary grinding mechanism to two types of current ultrafine grinding mills – a single drive horizontal mill and a vertical mill.

The single drive horizontal mill relies on high shear near the surface of the impeller disks to obtain particle breakage whilst the vertical mill relies on a combination of the rotational shear and the static head of the media load. The new twin drive mill creates a fixed bed in which the media are subjected to high shear and compressive forces to abrade feed material whilst reclaiming and recycling excess energy from the media mass.

Each mill is optimised over a range of speeds, media loads and slurry densities in a batch grinding process and comparisons are made on time and specific energy requirements to achieve a reduction from d90 - 70µm to d90 - 5µm of fly ash

15.00 **Selecting ceramic media: the theory.....477**
H. Kotzé (Consensi Consulting, South Africa)

The selection of inert grinding media for use in strirred mills is influenced by several parameters. In the mining industry where large volumes of grinding media is required per mill, media wear vs. cost is an important optimisation consideration. Quantification of media plant-wear is however often problematic. Media wear can be directly quantified via small scale laboratory mill tests, or potentially via measurement of its physical and mechanical properties: size, density, sphericity, hardness, toughness, etc. While some of these parameters are easily quantifiable, hardness and toughness as indicators of media wear are not as straight forward. This paper explains the importance of hardness and toughness of grinding media in the stirred mill environment and the considerations that should be born in mind when using these measurements as quality parameters. These considerations are given with the against the various manufacturing methods of ceramic grinding media as background and the influence thereof on media quality.

15.20 **Detecting mill unbalance and creating an optimum milling environment.....491**
H. Kotzé (Consensi Consulting, South Africa)

A balanced stirred mill is characterised by a relatively even distribution of grinding media throughout the mill chamber. Accumulation of media in prediposed volumes of the grinding chamber leads to amongst others increased power consumption and higher media and mill wear rates. This accumulation of media is referred to as “hydraulic packing” or “media packing” in the literature. Media packing is a known phenomena in smaller stirred mills such as is used in the pigments industry. Transfer and expansion of knowledge on this topic are required for the larger stirred mills typically used in the mining industry during the last decade. This paper discusses the influences of milling parameters of packing (grinding media properties, slurry flowrate and viscosity, and mill operating parameters). Tell

tales of the presence of media packing are discussed. Finally methods to re-balance large scale mills are proposed.

15.40 **Viscosity effects in stirred media milling.....N/A**
A. Kwade, C. Schröder and S. Breitung-Faes (Institute for Particle Technology, TU Braunschweig, Germany)

The viscosity of the product suspension affects in two ways the grinding efficiency and the operation behaviour of stirred media mills: On particle scale the collision of the grinding media is damped by the displacement of the suspension between two colliding grinding media: The higher the viscosity of the suspension is, the lower is the collision velocity. A model equation was developed to describe this effect and to calculate the decrease in active stress energy by using the Stokes number of the grinding media. Based on the model the viscosity can be determined at which the stress intensity gets zero, i.e. just no collision of the grinding media takes place. On the other hand the movement and axial distribution of the grinding media depend on the suspension viscosity. The grinding media are compressed at the mill exit resulting in a higher power consumption and a higher pressure drop. The effect of different operating parameters like tip speed on the axial grinding media distribution can be described based on well known equations either for the pressure drop or for the grinding media inertia.

16.00 Coffee

Friday 20th April

09.00 *Technical Session 7*
Chairmen: J.T. Kalala (Mintek, South Africa) and M. Narasimhaa (Indian Institute of Technology, India)

09.00 **Rock shapes and incremental damage.....N/A**
R. Chandramohan (Ausenco, Australia), M.S. Powell and P. Holtham (JKMRC, Australia)

Comminution, the science of size reduction is an integral part of mineral processing. It has been investigated and shown using numerical modelling that breakage modes in mills can be classified into distinct regions. It was shown that abrasion mode accounts for majority of the comminution energy utilisation; one-hit and incremental damage accounts for substantially less comminution energy utilisation and is pertinent for the comminution process.

The work presented in this paper investigates the rock shape effect in AG / SAG milling. The work investigates the effect of incremental damage on rock strength in an experimental lab-scale mill. The work shows that rock shapes control the degree of breakage and hence the degree of accumulated damage. Controlled high speed video filming of rock breakage is used to develop an understanding the rock shape effect. The insights gained from this work provide an understanding of the incremental damage effect on rock shapes.

09.20 **Designing liners for performance not life.....501**
P. Toor and J. Franke (Scanalyse Pty Ltd, Australia)

Scanalyse in collaboration with JKMRC conducted an extensive study of the effect of liner wear on mill performance of a 32 foot SAG mill in Australia. The methodology of determining the optimum liner shape was previously presented at Metplant 2011, and expanded on at the SAG12 conference in Vancouver. The results presented indicated that liners with a reduced mass and shorter life outperform their longer life counter parts in all key production parameters of throughput, energy consumption and product size.

This paper quantifies the benefit of having shorter liner life cycles for improved performance by calculating the increase in throughput and reduction in power based on historical data for a number of operational mills and predicting the benefit on flotation by producing a finer product size for the 32 foot mill case. It also presents the total overall gain by accounting for the increase in required reline effort. This provides a holistic view of the net achievements when designing liners for performance and not life.

09.40 **Modeling ball impact on the wet mill liners and its application in predicting mill magnetic liner performance.....515**
M. Wu and V. Wang (AMEC Americas Ltd., Canada)

Numerous studies have been conducted in the past and models developed to simulate ball motions in horizontal mills. Equations are published to calculate falling velocity of the grinding media upon impacting the mill shell (liner). These equations are suitable for dry mill applications.

To simulate the impact of falling balls on the liners in the wet mills, the authors have developed models to determine the ball impact location and velocity as the ball contacts the mill liner. Drag as well as buoyancy forces are considered the instant the ball submerges in the pulp inside the mill.

The models are applied to calculate the falling ball impacts on the mill magnetic liners. Various scenarios are simulated and results are used to predict the performance of magnetic mill liners in various ball mill applications.

10.00 **Prediction of plant ball mill media wear rates from laboratory ball mill test data.....530**
J.D. Gates (University of Queensland, Australia), A. Giblett and R. Dunne (Newmont Mining Corporation, USA)

The Levin approach to determining grindability for fine materials has been applied to the prediction of plant ball mill media wear rates from laboratory ball mill test data. A laboratory mill similar to that used for the standard Bond ball mill work index test was used. The mill was calibrated using a well-characterized ore from the Newmont Tanami Operations in Australia, determining the test parameters required to match the plant product P_{80} and determining the grinding energy input to achieve this grinding. The measured media wear rate, when quantified as weight loss per grinding energy (kg/kWh), was within 10% of the reported plant wear rate. Experiments were then conducted to assess the method's sensitivity to deviation from ideal test parameters. It was found that variations in P_{80} due to variations in either test duration or feed volume resulted in only modest alterations in calculated wear rate, less than the statistical scatter, and it was judged that a simple average of data within a specified P_{80} range was more useful than an equation to correct for P_{80}. Within reasonable limits the sensitivity to feed particle size (F_{80}) was also found to be modest, but the small mill size places limitations on the feed particle sizes that can be accommodated. Alternative methods for determining the energy input for a given test were explored and their relative merits compared. The original method calculated the grinding energy using the Bond equation, previously measured work index and the F_{80} & P_{80} for each individual test, while the Levin method uses a fixed mill power calibration constant. Finally, wear rates were measured for two additional ball mill feed samples provided by Newmont from their KCGM and Jundee operations. Using the Levin approach the wear rates from both ores were measured to be within 20% of average plant wear rates.

10.20 Coffee

11.00 **The optimization of the grinding media and solid contents in primary ball mill circuit in Sungun Copper concentrator plant.....553**
B. Ebadnejad, G. Karimi (School of Mining & Petroleum, Iran) and A. Bagherian (NICICO, Iran)

Most investigators agree that grinding efficiency in ball mill is very low. Improved grinding efficiency requires a change from energy per ton basis to an efficient particle breakage basis.

Grinding efficiency improvement is investigated by making key changes to milling system as follows: Correcting make-up media size, operating the mill in appropriate mode and controlling milling circuit in modified mode.

Make-up media based on particle breakage optimization was investigated in a series of tests using different arrangement of grinding media size. Results showed that at constant energy, impact velocity to initiate breakage could be minimized.

Solid contents are considered to be in bilateral relation with grinding media size to improve comminution efficiency. Experiments carried out at solid contents between 60 to 80%. Calculations for new surface area generated versus breakage energy illustrated that the lowest energy required for breakage created the most new surface area per unit of input energy.

11.20 **Predicting slurry flow within and discharge from a 3D pilot SAG mill using a coupled DEM-SPH model.....N/A**

P.W. Cleary (CSIRO Mathematics, Informatics and Statistics, Australia) and R.D. Morrison (JKMRC, Australia)

Slurry flow, including flow through the charge, through the discharge grates, along the pulp lifters and its discharge from the mill is an important contributor to the efficiency of the grinding process within a SAG mill. Poor transport of finer ground material can adversely affect grinding leading to excess energy consumption and over-grinding of fine material. A coupled DEM (discrete element method) and SPH (smoothed particle hydrodynamics) method is used to predict fluid flow within and from the mill. DEM simulates the motion of the coarser particulates while SPH simulates the slurry (water and finer particulates). This is demonstrated in three dimensions using an industry standard 1.8 m diameter by 0.6 m long AG/SAG pilot mill. This provides detailed information on the internal flow of charge (particulates and slurry) within a SAG mill, including the prediction of dry regions and of slurry pooling. Full 3D analysis also allows the pulp flow patterns into and out of the mill via pulp lifter chamber to be investigated. In particular, we are able to quantify the degree of short circuiting of slurry from the pulp chamber back into the grinding chamber and predict the slurry discharge rates from the mill. The pumping action of the end wall lifters on the discharge end of the mill is also explored.

11.40 **Using Positron Emission Particle Tracking (PEPT) to investigate grinding regions in a laboratory scale tumbling mill.....N/A**

A.J. Morrison, I Govender, A.N. Mainza (University of Cape Town, South Africa) and X. Fan (University of Birmingham, UK)

A detailed experimental study of time-averaged charge kinematics (velocity, acceleration, shear rates), distributions (mass, porosity, density) and geometry (toe, shoulder, centre of circulation, charge circulation) was conducted in a laboratory tumbling mill using Positron emission particle tracking (PEPT). At the heart of this study are robust numerical schemes – key ingredients for deriving quantitative insights into charge flow and dynamics from PEPT data. In this paper we present analyses for a wide range of mill loads, speeds, lifter profiles and mill diameters.

12.00 **Comparing methods of determining power draw in tumbling mills using the discrete element method.....N/A**

L.S. Bbosa, I. Govender, A.N. Mainza (University of Cape Town, South Africa) and M.S. Powell (JKMRC, Australia)

Experiments using a laboratory scale tumbling mill with glass beads as charge are conducted over several speeds in the cascading and cataracting regime. The mill is fitted with lifter bars and run dry in batch mode, with a torque transducer mounted along the shaft to measure the power drawn. Simulations of these experiments are carried out using the Discrete Element Method (DEM). By this method, particle velocities and interaction forces are calculated using Newton's laws and the Hertz-Mindlin contact model respectively, and are used to calculate Power Draw. Traditional approaches of determining mill power (Mean centre of mass, Force balance, Energy balance) are computed and compared to measured power.

12.20 **An introduction to the Coalition for Eco-Efficient Comminution** /

M.S. Powell (JKMRC, Australia)

Comminution is the largest consumer of energy on most hard rock mine sites, with a correspondingly significant opportunity to improve process efficiency. Although a lot of research has been done in the field of eco-efficient comminution, much of the research output does not exist in a form which can be easily used by those wishing to design or operate eco-efficient comminution circuits. CEEC (the Coalition for Eco-Efficient Comminution) was set up in 2011 to remedy this situation. CEEC is a not-for-profit company, supported by a number of mining industry organisations, whose mission is to facilitate technology transfer in this area using a website, web discussion forums, workshops and other mechanisms. This presentation summarises progress so far and CEEC's plans for the future.

12.30 Lunch

14.00 *Technical Session 8*
Chairmen: J.D. Gates (University of Queensland, Australia

14.00 **Experimental and simulated instrumented ball in a tumbling mill—a comparison.....562**
S. Martins, W. Li, P. Radziszewski (McGill University, Canada), B. Picard, A. Faucher, and S. Makni (COREM, Canada)

Tumbling mills play an essential role in modern mineral processing. Because of the nature of the mill, the internal forces make instrumentation of the mill interior difficult. One solution to this problem is the use of an instrumented ball. An instrumented ball, equipped with an accelerometer, rotation rate sensors and a temperature sensor has been built. The instrumented ball and a camera system are used to measure the state of the charge within a laboratory mill. In parallel, a discrete element model (DEM) of the laboratory mill is developed. Using the distributions and moments of the energy terms of the charge, the simulation and experimental results are analyzed and compared. The moments are used to tune the DEM, such that the simulation results are in agreement with the experimental results. The comparison also identifies which aspects require further improvement.

14.20 **A GPGPU implementation of the DEM method applied to tumbling mills.....N/A**
M. Hromnik and I. Govender (University of Cape Town, South Africa)

A discrete element method (DEM) computer code in the Nvidia GPU programming language CUDA (and C++) was developed for the intrinsically parallel architecture of a graphics processing unit (GPU) to simulate the dynamic particulate environment inside a pilot scale tumbling mill filled with mono-sized spherical particles. A Hertz-Mindlin contact model was implemented together with a GPU collision detection algorithm. The use of general purpose GPU computing was shown to be very suitable to the problem, providing considerably improved performance and control of the physics and mechanism over traditional CPU based DEM packages. Confidence in the computational results was obtained through standard elementary tests as well as comparison to data from the Positron Emission Particle Tracking (PEPT) experiments.

14.40 **Incorporating the influence of the lifter profile in tumbling mill models using data from the PEPT system.....N/A**
H. Brodner, A. Mainza, I. Govender, A.J. Morrison (University of Cape Town, South Africa) and M.S. Powell (JKMRC, Australia)

Energy optimization to date has been implemented with the help of power models that predict the mills performance with changes to operating conditions. The Morrell Power Model (Morrell (1993)) has set a benchmark with its accuracy and applicability. The Morrell Power Model introduced the concept of velocity profiles and charge shape, but completely disregards liner design. Liner design can significantly alter velocity profiles and charge shape which clearly affects mill performances. The (implicit) integration of lifter height into a continuum based model of the velocity field was investigated within the en-masse region of a tumbling mill. Positron emission particle tracking (PEPT) is used to measure and verify the model predictions across a range of lifter heights, mill speeds and load fractions. Additionally the charge toe and shoulder are accurately described by the PEPT data, which assists in determining impact areas and charge behaviour.

15.00 **Implementation of optimized compressive crushing in full scale experiments.....575**
E. Lee and M. Evertsson (Chalmers University of Technology, Sweden)

Commonly used at the coarser end of the comminution process, cone crushers often operate as the final crushing stage in the aggregrate industry, or as the supplier of feed material for HPGRs or ball mills in the mining industry. As such, the performance of the cone crushers inevitably affects the performance and efficiency of the overall process. The aim of this study is therefore to examine the effects of implementing optimized compressive crushing when compared to today’s cone crushers.

Two different prototypes are manufactured based on the conceptual designs obtained from theoretical optimizations with respect to compressive crushing. Tested in full scale experiments, the results from the prototypes (designed for aggregate production and mining operation respectively) are then compared to the measured data from standard crusher designs. This analysis suggests that the performance of cone crushers can be improved in terms of product yield as well as reduction ratio.

15.20 **Formulation of grinding media models and their implications for breakage energy assumptions in tumbling mills.....N/A**
D.V.V. Kallon, I. Govender, A.N. Mainza and A.J. Morrison (University of Cape Town, South Africa)

The most common approach to quantifying power drawn by the media in grinding mills is to compute the power from a torque arm approach. The values so obtained are compared with the motor or mill shell power as recorded by the distributed controls systems readings. However, the disparity between experiment and theory remains large particularly at low mill speeds [Bbosa et al, 2011]. This paper reports the development of a number of grinding media motion models using positron-emission-particle-tracking (PEPT) data. The experimental approach is highly suited to allow us to effectively examine the assumption that the grinding media in these mills circulate at a constant rate of unity. A notable outcome has been the development of a model linking the circulation rate of charge particles with physical mill parameters (load fraction, shoulder angle and friction), giving near linear relationship in each case. This model allows for characterization of the shape of the charge body into distinct flow regimes and hence the transitions between these regimes can now be mapped to more physical geometric interpretations [Kallon et al, 2011]. Building on this, the distributions of energy in the grinding media has been modelled leading to an analysis of breakage potential in tumbling mills.

15.40 **Conference summary**
M.S. Powell (JKMRC, Australia) and A.Mainza (University of Cape Town, South Africa)

15.55 **Closing Remarks and Invitation to Comminution '14**
A.J. Wills (MEI, UK)

Poster Presentations

Efficiency of stabilizers of grinding in cement clinker processing.....589
T. Sverak (Brno University of Technology, Czech Republic) and C. Baker (Kuwait University, Kuwait)

The grinding processes with the adding of stabilizers of grinding are very common in the productions of very fine ground particulate materials and such the additives doping is an absolutely essential process step in the production of ultra-fine and nano-fine ground particulate solids. In all these processes the additives work as the inhibitors and blockers of the re-agglomeration tendency of fine particles. The additives are well known in both the dry grinding and the wet grinding processes as well under the name as "grinding aids", "activators of grinding", "milling adds", "stabilization additives of grinding"... The additives which are defined as the terms above are used in the cement production area as the add materials which help to decrease the enormous energy consumption of the cement production in the processes of raw material grinding and the cement clinker grinding as well.

The doping of cement materials grinding processes unwinds of the choice of the three basic sort of function:

- the electro-conductive additives;
- the long molecular chemicals with electrical charge on the one end of molecules and the active groups on the other end which are able to bind on the strongest surface groups of the ground stock;
- the reactive chemicals which quickly passivate surface groups of the ground stock.

This paper shows the essential features of the stabilizers of grinding additives which are used in the cement clinker grinding processes usually: none additives (1), trietanolamine (2), fat acids mixture (3), PE glycol (4), fatty acids salts (5), titanate and phoshite base (6), water (7), butyl acrylate (8) and acetates, which were tested in the laboratory ring mill device.

Initial investigations of the Deswik vertical stirred mill using DEM simulations.....600
P. Radziszewski, P. Hosseini and S. Martins (McGill University, Canada)

The Knelson-Deswik (KD) mills are vertical mills which are designed for fine grinding applications across a wide range of operating conditions. The mills were originally developed in the mid-1990s to provide an economic means for producing fine pigments for the South African manufacturing industry. The technology has progressed from humble beginnings within a family-owned milling business to a robust milling system that is manufactured and marketed by a global equipment manufacturer. The KD

mill's power intensity has been illustrated as tending to "bridge the gap" between lower power and speed vertical mills and higher power and speed horizontally stirred mills.

In this presentation, the initial results of an investigation into understanding better the charge dynamics of the KD mill will be presented along with a description of the milling technology, the DEM modelling methodology used and the limitations to the current study.

Challenges and difficulties of comminution processes in the KGHM PM S.A. Division of.....610 Concentrators

A. Konieczny and B. Bazan (KGHM PM S.A., Poland)

The KGHM Polska Miedź S.A. as a organization based on stability, responsibility and high ability to adept. KGHM is the 9th producer of copper and the 3rd producer of silver on the World. The electrolytic copper of KGHM is registered by the London Metal Exchange (LME) as Grade A.

The year 2010 saw results in the production of electrolytic copper – 547 100 mt – and of metallic silver – 1 161 mt.

The Division of Concentrators is comprised of three plants. All of the enrichment facilities use the same basic methods and processes of ore comminution. However, due to the varying quality of the ore which is processed, each of the facilities applies these methods in fundamentally different ways. These methods are comprised of sifting and crushing, milling and classifying which preceding flotations processes.

The methods and technology used by the Division of Concentrators facilities provide for the efficient recovery of copper, silver and other minerals from the extracted rock – generally considered as hard to enrich. This efficiency is shown by the high level of recovery of these metals (up to 90%) and the high Cu content in concentrate (up to 30%).

The Division of Concentrators as a part of modern and innovative company determined the own mission as a maximise metal recovery and to produce concentrate with the quality parameters required by the smelters, at the lowest possible cost.

This paper describes the present technology of comminution supported the Division of Concentrators activity, investigates the main bottlenecks of this process to determine the possible ways of evolution it. The paper will discuss an self-analysis of defiances and problems occures during implementation the development process in Division of Concentrators.

Modelling abrasion of rocks in discrete element method.....N/A

A. Potapov, L. Nordell (Comminution Technology, Australia) and R. Chandramohan (Ausenco, Australia)

Discrete Element Methods (DEM) is widely becoming used to understand the flow of granular materials in complex systems. DEM provides an in-depth understanding of energy transfer and distribution of rocks and media in an AG / SAG type environment. Rocky DEM simulates impact breakage of rocks using a simplified population balance model. This capability has been demonstrated and tested rigorously for the last ten years. With recent advancement in speed and multi-core capability, Rocky DEM code and its potential in modelling full breakage environment of mills.

Recently, Rocky DEM code has implemented the dynamics of rock abrasion and wear of liner surfaces. The work presented in this paper shows the development of the rock abrasion and liner wear model in the Rocky DEM code. The code is validated with controlled experimental data. The results show promising results between experimental and numerical data.